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*ТЕХНИЧЕСКИЕ НАУКИ /
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ИНФОРМАТИКА, ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА И УПРАВЛЕНИЕ / INFORMATICS, COMPUTER ENGINEERING AND MANAGEMENT

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Ирина Сергеевна Клименко
[Irina S. Klimenko]

Метод анализа иерархий в моделировании стратегии формирования инновационного потенциала

The method of hierarchy analysis in modeling the strategy of formation of innovative potential

Северо-Кавказский федеральный университет, Пятигорский институт (филиал) г. Пятигорск, Россия, iskl@bk.ru / North-Caucasus Federal University, Pyatigorsk Institute (branch), Pyatigorsk, Russia, iskl@bk.ru

Аннотация. *В статье разработана математическая модель управления инновационным потенциалом. Выполнен анализ факторов, влияющих на инновационный климат, предпринята попытка обосновать целесообразность применения методов математического моделирования к процессам управления инновационным климатом. Автором рассмотрены основные этапы стратегического планирования; основное содержание исследования посвящено интеграции методов моделирования в практику управления инновационной деятельностью. В результате исследования автор приходит к выводу о необходимости комплексного использования методов формального и неформального моделирования в системе формирования и развития инновационного потенциала хозяйствующих субъектов.*

Ключевые слова: инновационная деятельность, инновационный потенциал, самоопределение, иерархия действующих факторов, модели и алгоритмы управления

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Abstract. *The article develops a mathematical model of innovation potential management. The analysis of the factors influencing the innovation climate is carried out, an attempt is made to justify the expediency of applying mathematical modeling methods to the processes of managing the innovation climate. The author considers the main stages of strategic planning; the main content of the study is devoted to the integration of modeling methods into the practice of innovation management. Because of the research, the author comes to the conclusion about the need for the integrated use of formal and informal modeling methods in the system of formation and development of the innovative potential of economic entities.*

Keywords: innovative activity, innovative potential, self-determination, hierarchy of acting factors, management models and algorithms

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Introduction. Studying the problems of managing the innovation climate, which influences the efficiency of the functioning of business entities, requires the use of methods that meet the challenges of a modern high-tech society.

Today, the fact that in the conditions for the development of intelligent information systems require a scientifically based approach to diagnostics, planning of innovative activities, and forecasting of expected results in the context of their competitiveness. The relevance of the study is due to the influence that innovation activity (IA) has on the economic processes of the region and the country as a whole. Agreeing with the positioning of ID as a tool that ensures economic development and social progress without damaging the natural environment [1], we accept a priori that this type of activity, like any other, requires management. An analysis of scientific publications on the problems of ID management revealed a certain pattern: research in the field of strategic planning of ID is mainly concerned with economic specialists [2-5], while mathematical models, in the author's opinion, make it possible to increase the validity of strategic and operational planning, which is confirmed by the results own research and the attention of domestic scientists to the identified problem [6-8]. This was the main motivation for conducting a comprehensive interdisciplinary study of the opportunities that mathematical modeling provides for practitioners of managing complex systems [9, 10].

Materials and research methods. Innovative activity, as one of the key factors ensuring the compliance of an enterprise/organization with the modern level of development of technology and technology, is a complex dynamic process, which must be managed on a systematic basis. Systematicity in management presupposes the correct determination of the stages of management, its goals, both global and local, stage-by-stage.

The classical management scheme includes planning, as the stage of defining goals, organization, as the stage of co-organization of resources and distribution in accordance with the goals and objectives; accounting and analysis, in essence, monitoring processes to identify the degree of compliance between the planned and actual states of the control object; formation of control actions. To move from a generalized, abstract-descriptive model to a concrete one, "tied" to the control object, it is advisable to supplement the outline sketch of the control system with procedures such as assessing the degree of risk and implementing feedback. Table 1 presents the sequence of management stages, which is proposed to be considered as version 1.0 of the management model with a corresponding graphical interpretation (Figure 1).

Table 1 – Innovation management model: sequence of stages

Contents of work at the stage	Result
Goal setting	Formulating the goal in terms that allow a quantitative assessment of the result: improving the innovation climate; increasing innovative potential.
Problematization	Description of the problem field: unpreparedness for ID of the team and leader; lack of human capital; low competitiveness
Self-determination in goals, position, situation	Quantitative indicators characterizing: the actual state of personnel and its relationship to ID; ID level; scientific and financial potential; innovative activity of the team and the manager.
Formation of a field of alternatives	A finite number of alternatives.
Formation of a system of criteria for selecting alternatives	A system of quantitative indicators/indicators that allow you to search, select and select the optimal alternative.
Selecting or constructing a mathematical model	Determination of the hierarchy of goals and objectives; ranking criteria/determining the "weight" of each criterion
Approbation of the model	Finding a solution using the experiment planning technique.
Checking the model for adequacy	Analysis of the structure of the resulting optimal solution, determining the degree of compliance between goals and results.
Adjustment of the model if necessary	*Changing the objective function, boundary conditions, solution method.*
Finding a solution	Analytical, graphical, numerical methods.
Comparative variant analysis of the solutions obtained	Selecting a strategy and developing an implementation plan.

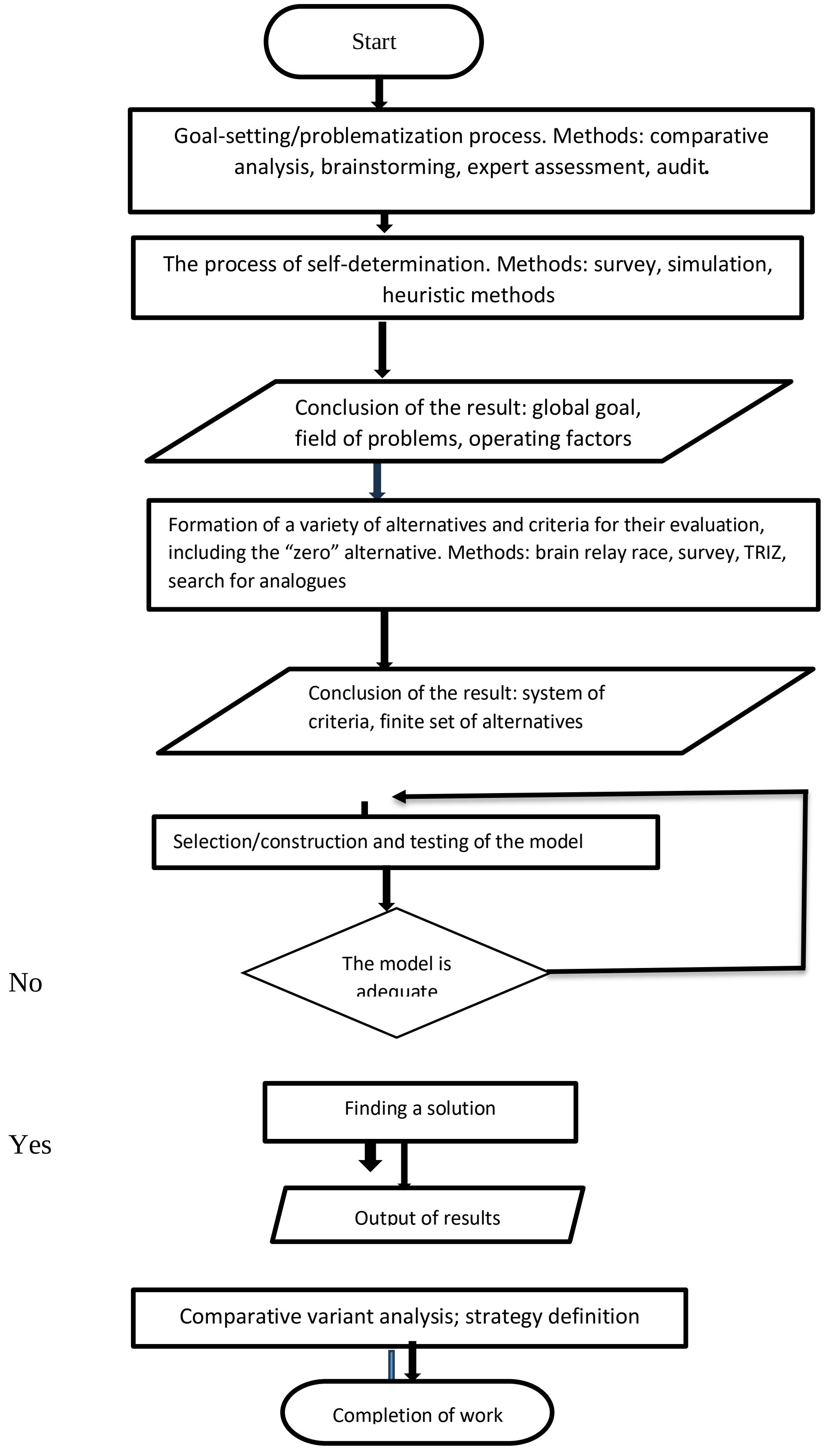

Figure 1 – Graphical interpretation of the optimal strategy search model

The proposed model allows us to identify at least four levels of solving the problem of determining the strategy for the formation of innovative potential: static, dynamic, cybernetic, synergetic.

The static and dynamic level is the level of solving local problems of operational planning and management; the cybernetic level is the level of management of complex systems at which problems of managing systems with behavior are solved and optimization methods are used.

In the context of this study, it is proposed to consider the synergetic level of strategic planning: an open nonlinear system of strategic planning, being in the process of self-organization, with the goal of improving the innovation climate, passes a bifurcation point, which leads to qualitative changes in the behavior of the system. The openness of the system is confirmed by the presence of processes of exchange of information, material, labor, etc. resources with the external environment, the nonlinearity of the system is due to stochastic processes occurring under the influence of disturbing influences, the bifurcation point is the moment of transition from intuitive decision-making methods to scientifically based algorithms, in which are based on formal and informal modeling methods; in this case, the Hierarchy Analysis Method (HAI).

Next, we will show the application of AHP to the search on a given finite set for an alternative that is optimal according to some criterion. The idea of the method is that the system of assessments presented at a qualitative, descriptive level is transformed into a system of quantitative indicators, which, of course, affects the validity of the choice. The method is iterative.

Step 1. Definition of hierarchy. When projecting the MAI onto the problem of choosing the optimal strategy for the formation of innovative potential, the following hierarchy is proposed:

– upper level - global goal - increasing innovative potential;

– alternatives: A1-improving innovation management; A2-selection of priority areas of ID; A3 - improving the innovation climate; A4 - increasing the innovative activity of personnel; A5 - development of a system for stimulating innovative activity;

– criteria for evaluating alternatives: K1 - systematicity (consistency) in the implementation of the alternative; K2-inherence _ correspondence of the alternative to the environment; K3-acceptability for participants in the innovation process; K4 - issue price; K5 – degree of risk.

Step 2. Construction of a matrix of pairwise comparisons of criteria. Matrix K 5X5 (Table 2) reflects the ratio of criterion ***i to criterion j;*** the assessment was made on a scale from 1 to 9. If the criteria are equivalent, the ratio is 1; a score in the range 2–4 shows that the priority of criterion ***i*** not significantly higher than the criterion ***j*** score in the range of 5-6, which criterion ***i*** preferable to criterion ***j;*** a score of 7-8 indicates significant priority of the criterion ***i ,*** score 9 - indicator of unconditional primacy of the criterion ***i .*** The matrix is filled in according to the principle of mutual complementation: for $k_{ij} = m$ $k_{ji} = 1/m$.

Table 2 – Matrix of binary relation criteria

	K1 - systematic	**K2 -inherence**	**K3 - acceptability**	**K4 - price**	**K5 - degree of risk**
K1	1	2	5	1/8	4
K2	1/2	1	1/3	7	9
K3	1/5	3	1	1/6	1/8
K4	8	1/7	6	1	1/2
K5	1/4	1/9	8	2	1
Sum	9.95	6.25	20.33	10.28	14.5

Step 3. Normalization. Matrix normalization rule:

– the sum of the elements of each matrix column is determined

$$Sj = to_{1j} + to_{2j} + \ldots + to_{nj}$$

– divide each element of matrix K by the sum of the elements of the corresponding column

K ij norms= K ij/ Sj

– We determine the average value of the criterion, which characterizes its weight.

The results of normalization are presented in Table 3; criteria K2 - inherence and K4 - price of the issue, according to experts, are priorities in the system for choosing the optimal strategy for improving the innovation climate.

Table 3 – Calculated values of criteria weights

	K1	K2	K3	K4	K5	Average	Weight
K1	0.1005	0.3200	0.2459	0.0121	0.2735	0.1904	19.04%
K2	0.0503	0.1600	0.0162	0.6802	0.6154	0.3044	30.44%
K3	0.0201	0.4800	0.0492	0.0161	0.0085	0.1148	11.48%
K4	0.8040	0.0224	0.2951	0.0972	0.0342	0.2506	25.06%
K5	0.0251	0.0176	0.3935	0.1943	0.0684	0.1398	13.98%

Step 4. Pairwise comparison of alternatives for each of the given criteria.

Tables 4–13 present the results of pairwise comparison of alternatives and determination of the weights of alternatives according to criteria K1 – K5.

Table 4 – Binary relation of alternatives according to criterion K1 - systematicity

K1 - systematic	A1	A2	A3	A4	A5
A1	1	3	2	6	0.25
A2	0.33	1	0.25	0.14	8
A3	0.5	4	1	6	0.2
A4	0.16	7	0.16	1	4
A5	4	0.125	5	0.25	1
Sum	5.99	15.125	8.41	13.39	13.45

Table 5 – Calculated weights of alternatives according to criterion K1 - consistency

K1 - systematic	A1	A2	A3	A4	A5	Average	Weight
A1	0.1669	0.1983	0.2378	0.4481	0.0186	0.2140	**21.40%**
A2	0.0551	0.0661	0.0297	0.0105	0.5948	0.1512	15.12%
A3	0.0835	0.2645	0.1189	0.4481	0.0149	0.1860	18.60%
A4	0.0267	0.4628	0.0190	0.0747	0.2974	0.1761	17.61%
A5	0.6678	0.0083	0.5945	0.0187	0.0743	0.2727	**27.27%**

Conclusion: experts have not identified any fundamentally significant alternatives; alternatives A1 - improvement of the innovation management system and A5 - development of a system for stimulating innovative activity can be considered preferable.

Table 6 – Binary relation of alternatives according to criterion K2 - inherence

K2-inherence	A1	A2	A3	A4	A5
A1	1	0.125	3	0.25	5
A2	8	1	2	6	7
A3	0.33	0.5	1	2	0.125
A4	4	0.16	0.5	1	0.33
A5	0.2	0.14	8	3	1
Sum	13.53	1.925	14.5	12.25	13,455

Table 7 – Calculated values of the weight of alternatives according to the criterion K2 - inherence

K2-inherence	A1	A2	A3	A4	A5	Average	Weight

A1	0.0739	0.0649	0.2069	0.0204	0.3716	0.1476	14.76%
A2	0.5913	0.5195	0.1379	0.4898	0.5203	0.4517	**45.17%**
A3	0.0244	0.2597	0.0690	0.1633	0.0093	0.1051	10.51%
A4	0.2956	0.0831	0.0345	0.0816	0.0245	0.1039	10.39%
A5	0.0148	0.0727	0.5517	0.2449	0.0743	0.1917	**19.17%**

Conclusion: the most preferred (weighty) alternatives according to criterion K2 - inherence: A2 - selection of priority areas, A5 - development of a system for stimulating innovative activity, the weights of which ensured their placement at the upper levels of the hierarchy.

Table 8 – Binary relation of alternatives according to criterion K3 - acceptability

K3 - acceptability	A1	A2	A3	A4	A5
A1	1	0.5	0.33	0.125	1
A2	2	1	4	3	0.166
A3	3	0.25	1	5	7
A4	8	0.33	0.2	1	3
A5	1	6	0.14	0.33	1
Sum	15	8.08	5.67	9.455	12,166

Table 9 – Calculated values of the weight of alternatives according to criterion K3 - acceptability

K3 - acceptability	A1	A2	A3	A4	A5	Average	Weight
A1	0.0667	0.0619	0.0582	0.0132	0.0822	0.0564	5.64%
A2	0.1333	0.1238	0.7055	0.3173	0.0136	0.2587	**25.87%**
A3	0.2000	0.0309	0.1764	0.5288	0.5754	0.3023	**30.23%**
A4	0.5333	0.0408	0.0353	0.1058	0.2466	0.1924	19.24%
A5	0.0667	0.7426	0.0247	0.0349	0.0822	0.1902	19.02%

Conclusion: a pairwise comparison of alternatives according to the criterion K3 - acceptability showed that the hierarchy of alternatives in this case has the form A3 - the top level, then descending A2, A4, A5, A1. That is, the innovation climate is assessed as the most significant factor that must be taken into account when determining the strategy for the formation of innovative potential.

Table 10 – Binary ratio of alternatives according to criterion K4 - issue price

K4	A1	A2	A3	A4	A5
A1	1	2	0.25	0.33	6
A2	0.5	1	0.14	5	0.25
A3	4	7	1	1	2
A4	3	0.2	1	1	1
A5	0.166	4	0.5	1	1
Sum	8,666	14.2	2.89	8.33	10.25

Table 11 – Calculated values of the weight of alternatives according to criterion K4 - issue price

K4 - issue price	A1	A2	A3	A4	A5	Average	Weight
A1	0.1155	0.1408	0.0865	0.0396	0.5854	0.1936	**19.36%**
A2	0.0577	0.0704	0.0484	0.6002	0.0244	0.1602	16.02%
A3	0.4619	0.4930	0.3460	0.1200	0.1951	0.3232	**32.32%**
A4	0.3464	0.0141	0.3460	0.1200	0.0976	0.1848	18.48%
A5	0.0192	0.2817	0.1730	0.1200	0.0976	0.1383	13.83%

Conclusion: A3 and A1 are alternatives of the top level of the hierarchy, at the same time, it should be noted that the absolute values of the weights do not have fundamental differences; in fact, none of the alternatives gained weight above 50%. This almost uniform distribution of weights indicates the need for additional assessment expertise.

Table 12 – Binary ratio of alternatives according to criterion K5 - degree of risk.

K5-degree of risk	A1	A2	A3	A4	A5
A1	1	2	3	0.166	0.25
A2	0.5	1	0.14	5	8
A3	0.33	7	1	1	2
A4	6	0.2	1	1	3
A5	4	0.125	0.5	0.33	1
Sum	11.83	10.325	5.64	7,496	14.25

Table 13 – Calculated values of the weight of alternatives according to criterion K5 - degree of risk

K5-degree of risk	A1	A2	A3	A4	A5	Average	Weight
A1	**0.0845**	**0.1937**	**0.5319**	**0.0221**	**0.0175**	**0.1700**	**17.00%**
A2	0.0423	0.0969	0.0248	0.6670	0.5614	0.2785	**27.85%**
A3	0.0279	0.6780	0.1773	0.1334	0.1404	0.2314	**23.14%**
A4	0.5072	0.0194	0.1773	0.1334	0.2105	0.2096	20.96%
A5	0.3381	0.0121	0.0887	0.0440	0.0702	0.1106	11.06%

Conclusion: the upper levels of the hierarchy when compared according to the K5 criterion - degree of risk - are occupied by alternatives A2, A3.

The ranking of alternatives by hierarchy levels, presented in summary table 14, shows the ambiguity of the results obtained, which may serve as a prerequisite for revising the system of criteria, as well as the use of alternative research methods, such as the method of active sociological testing, game theory methods, which do not require special mathematical training from the decision maker [eleven].

Table 14 – Summary table

	K1	K2	K3	K4	K5	Average Rank
A1	1	3	5	2	4	3.00
A2	5	1	2	4	1	2.60
A3	3	5	1	1	2	**2.40**
A4	4	4	3	3	3	3.40
A5	2	2	4	5	5	3.60

Conclusion: the hierarchy of alternatives based on the average rank value is built as follows: at the top level, alternative A3 is improving the innovation climate; further A2 - selection of priority areas; A1 - improvement of innovation management; A4 - increasing the innovative activity of personnel; A5 - development of a system for stimulating innovative activity.

Conditions for the applicability of the hierarchy analysis method:

– It is advisable to formulate the problem, procedures for developing alternatives and determining criteria at the description level using the method of expert assessments with the involvement of all participants in the organization and implementation of the innovation process as representatives;

– to process the results of expert assessment and construct mathematical models, it is necessary to involve specialists of the relevant profile (operations research, simulation modeling, mathematical programming, etc.);

– Regardless of the dimension of the resulting model, use software products with an intuitive interface.

Conclusion. The algorithm for searching for the optimal alternative using the hierarchy analysis method is characterized by invariance with respect to the subject area and unlimited possibilities for determining a variety of alternatives. At the same time, fairness requires noting some difficulties that decision makers may encounter in the process of using the methodology proposed by the author. The solution to the problem lies on the surface: the use of various software tools and the involvement of specialists will help to appreciate the method of hierarchy analysis. The presented material is only part of a study devoted to the integration of methodologies that provide scientific justification for decisions made.

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ИНФОРМАЦИЯ ОБ АВТОРЕ

Ирина Сергеевна Клименко – доктор технических наук, доцент, ведущий научный сотрудник, отдел организации проектно-грантовой деятельности, Пятигорский институт (филиал), Северо-Кавказский федеральный университет, iskl@bk.ru

INFORMATION ABOUT THE AUTHOR

Irina S. Klimenko – Dr. Sci. (Techn.), Associate Professor, Leading Researcher, Department of Organization of Project and Grant Activities, Pyatigorsk Institute (branch), North-Caucasus Federal University, iskl@bk.ru

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