Наука и инновации в информационном обществе

DEVELOPMENT OF A MODEL FOR DETERMINING THE LEVEL OF EFFICIENCY OF THE ACTIVITY OF INNOVATIVE ENTERPRISES

Статья рекомендована к публикации членом редакционного совета А.Н. Райковым 25.12.2022.

Aliyev, Alovsat Garaja

Doctor of economic sciences
Institute of Information Technology of Azerbaijan National Academy of Sciences, head of department
Baku, Azerbaijan
alovsat_qaraca@mail.ru

Shahverdiyeva, Roza Ordukhan

PhD in technical sciences
Institute of Information Technology of Azerbaijan National Academy of Sciences
Baku, Azerbaijan
shahverdiyevar@gmail.com

Abstract

The article is devoted to the development of a model for determining the level of efficiency of the activity of innovative enterprises. The importance of digitalization and expanding the application of innovations is justified. The urgency of the application of the Internet of Things, 5G, robotics, Big Data, cloud, and artificial intelligence technologies were noted. The special role of high technologies and innovative enterprises in the development of the digital and innovative economy has been shown. Prospects for the application of Industry 4.0 technologies in the activities of technopark structures aimed at the realization of knowledge-based, innovative product manufacturing were studied. Relevant work in this area has been studied, problems of effective management of the activity of innovative enterprises have been identified and solutions have been commented on.

The functions of the management system of innovative enterprises were noted and a model of operation of modern innovative science and technoparks was proposed. A comprehensive evaluation method has been developed for indicators, criteria and efficiency of evaluating the performance of innovative enterprises. A comprehensive analysis of the system of indicators on the analysis of the activities of innovative enterprises was conducted. A system of composite indices for evaluating the performance of innovative enterprises has been proposed, and its architecture has been developed in a multi-level manner. The method of calculating the composite index is presented, and its dependence on other subindices is shown.

It was noted that each of the 10 important indices that make up the composite index consists of sub-indices of different levels. These functional dependencies are expressed in the form of multivariate regression equations. A method of comparative assessment of the complex performance of innovative enterprises has been developed. The relationships between the values of the composite index and the indices that affect it are mathematically modeled and the results are presented schematically. Estimates of statistical parameters of the composite index assessment model of innovative enterprises are given. The results of expert assessments of weight coefficients of composite indices on a comparative assessment of the activity of innovative enterprises are shown.

The final score was calculated for each index of the weight coefficients given by the experts to the indices selected to form the composite index. The results of expert assessments of the proposed indices and their weight ratios, which have a significant impact on the composite index and are proposed for the comparative assessment of the activities of innovative enterprises, were calculated. Relevant recommendations for the application of the models are given.

https://doi.org/10.52605/16059921_2023_04_59

Keywords
digital and innovative economy, innovation infrastructure, high technology, science-intensive and innovative products, innovative enterprises, technopark, composite index, weight coefficient, expert assessments, Industry 4.0 platform.

Introduction

Against the background of the application of high technologies in all areas, the leading countries of the world are entering a new development environment and implementing many projects to increase the level of digitalization. The application of rapid developing Internet of Things (IoT), 5G, robotics, Big Data, cloud, artificial intelligence technologies in the world makes it necessary to develop the high-tech sector. One of the main directions of economic development is the application of "Industry, Innovation and Infrastructure", one of the UN 2030 Sustainable Development Goals [1], the elements of the Industrial 4.0 platform in the activities of innovation structures. The spheres of production of ICT and other high-tech products are already major trends in the world economy. This requires addressing the issues of effective management of the activity of innovative enterprises, where high technologies are formed and produced. In order to digitize the economy (https://president.az/articles/51299), the ICT infrastructure must be improved, and the potential of the ICT industry must be increased. At present, the main condition is to achieve sustainable development of the economy. Innovative enterprises, high-tech parks and science-industrial technoparks are the main driving force for the transition to a digital and innovative economy. Improving regulatory mechanisms and creating a healthy competitive environment in the development of information technology is very important for their effective operation. The solution of the mentioned problems is one of the main goals [2]. In this regard, the development of innovative enterprises, science and innovation technoparks, science and education centers is one of the priority directions. Further expansion of high-tech industries is one of the important issues to ensure sustainable economic development. In order to create modern complexes in this area, it is necessary to form an innovative product-service production with high export potential.

The development of innovative enterprises, high-tech technopark structures, determining the prospects for the application of the components of the Industrial 4.0 revolution in the activities of innovative enterprises is one of the key issues ahead. Therefore, there is a great need for a comprehensive analytical analysis of the problems of determining the efficiency of technopark structures and raising its level on the Industrial 4.0 platform. Modern scientific research conducted at the international level directly confirms the relevance of these areas. The presented article is devoted to the problems of determining the level of efficiency of innovative enterprises.

The purpose of the study

The purpose of the research conducted in the article is to show the importance of developing a model of composite index formation and determining evaluation indicators and criteria in determining the level of efficiency of innovative enterprises. It is the development of the theoretical basis of an improved form of the method of multi-criteria expert assessments in this process. It is also giving recommendations on the perspective directions of improvement of the main indices on the composite index of the activity of innovative enterprises, methods of expert assessment of subindices in the complex assessment of the efficiency of innovative enterprises. It aims to show that the application of the results of multi-criteria expert assessments in decision-making processes allows to obtain important results.

Research methods used

System analysis, correlation and regression analysis, mathematical and econometric modeling methods, expert assessment method, qualimetry, measurement theory, algorithmization and ICT tools were applied in the processes of developing the model for determining the level of efficiency of the composite index of the activity of innovative enterprises.

1 Problem statement and research situation

In modern times, the economy as a whole is transforming on the basis of innovative technologies. Ensuring its innovation-based progress, modernization on the basis of technological innovation, the formation of high-tech sectors, the development of new areas such as artificial intelligence and robotics, bio, nano, information and communication, space, etc. is one of the main ways to achieve faster development of the real economic sector (https://president.az/articles/22382). One of the main goals in building an innovation-oriented, knowledge-based economy is to bring high-quality and competitive information technology products to international and local markets, to create high-tech parks and to evaluate their activities. The process of determining the level of efficiency of the complex activities of innovative enterprises in the conditions of digitalization should be carried out on the basis of modern ICT achievements and proposals and recommendations should be developed in perspective areas. In such complex problems, new management principles and models should be developed and implemented, taking into account the recommendations of international organizations, as well as the prospects for the application of new technological components of the Industrial 4.0 Revolution [3]. To do this, a system of indicators and indices characterizing the innovative enterprises must be developed and improved.

2. Research of relevant related works

Regarding the state of development of the problem, it should be noted that there are many researches on the general activity of innovative enterprises, technoparks [4-15]. Some researchers have done some work of a specific nature.

Thus, Aliyev [4] examines the application of mathematical methods and models in product-service production processes in scientifically innovative technoparks. The importance of the application of economic-mathematical models and methods in the activities of innovative structures is substantiated in the work. A system of indicators and criteria has been developed to assess the effective management of the activity of technoparks. An information model based on their system of indicators has been proposed. A mathematical model of the general management of technoparks has been proposed. An econometric model has been developed for the effective operation of innovative product and service production. A system of indicators and composite indices for a comparative assessment of the performance of technoparks was proposed and the results of the experimental application of the models were given.

Estrella [5] considered the application of the fuzzy linguistic TOPSIS model in the selection of firms in the University technology parks in a heterogeneous context. It analyzes the activity features of technoparks as innovation centers aimed at strengthening cooperation between universities and enterprises. It was noted that in the technoparks, enterprises and resident companies operate in an effort to achieve the best results. However, despite the large number of firms in the technoparks, a number of firms that have achieved more effective results are selected there. Therefore, the process of analyzing complex decisions involving a number of conflicting criteria evaluated under uncertain conditions has been performed. To manage such complexity, the article proposes a fuzzy TOPSIS multi-criteria decision-making method using fuzzy modeling and fuzzy linguistic term sets. The proposed method will lead to significant results in the selection process, facilitating the discovery of information by experts in order to obtain reliable information. FLINTSTONES software was used to support the model selection process and was applied to a real case study of the Istanbul Technical University Technopark. Sensitivity analyzes were also performed to test the validity of decisions given as experiments.

Nan [6] developed a fuzzy complex evaluation model to assess the competitiveness of high-tech parks as a result of the use of fuzzy data. In this article, the authors explore multi-criteria decision-making problems to assess the competitiveness of triangular fuzzy information high-tech parks. Using the proposed operators, they proposed a multi-criteria decision-making program with triangular fuzzy environments. As a result, a practical example is given to assess the competitiveness of high-tech parks with triangular fuzzy data to prove the effectiveness of the approach.

Aliyev [7] developed a system of composite indices for a comparative assessment of the performance of innovative technoparks. The article examines the scientific and methodological bases of improving the system of composite indices. The stages of formation, content characteristics and structure of the composite index system are studied. The stages of formation of indicators on which the main indices and sub-indices of technoparks depend are developed in the research work.

Zapolskyte [8] discussed the assessment of sustainable mobility with the application of multi-criteria decision-making methods in science and technology parks. The work shows the urgency of ensuring the necessary access to transport infrastructure and services in science and technology parks. An attempt was made to assess the level of development of infrastructure and transport services that create conditions for sustainable mobility of employees of the science and technology park. Recommendations are made for the planning and sustainable development of science and technology parks and similar institutions in terms of sustainable urban mobility. To achieve the set goal, the authors used scientific empirical and theoretical research, as well as multi-criteria decision-making methods. The results showed a more continuous staff mobility between science and technology parks and the city center. For this reason, it was suggested that science and technology parks be located close to the city center. The article also proposes the main criteria for assessing the effective development of science and technology parks.

Aliyev [9] examines some methodological problems of increasing the efficiency of operation and management of innovative enterprises. The issues of management of activity and development processes of modern innovative enterprises are considered here. The work shows the need to create modern innovative enterprises, determines their management features and indicators, as well as management models of modern innovative enterprises. The article proposes its exemplary organizational structure as a result of the study of organizational management structure models of innovation structures of different profiles.

Structures of the management system based on the intellectual features of management are proposed. The article develops an architectural-technological structural model of a network of modern innovative enterprises of various profiles. The main directions of management of innovative enterprises of the future have been identified and an appropriate conceptual model of management has been proposed based on the recommendations of international organizations. A conceptual model of the intelligent management system of complex activities of innovative enterprises has been proposed.

Appropriate approaches and models have been proposed to improve product/service production in innovative enterprises. Infrastructural problems and institutional mechanisms to increase the efficiency of perspective activities of regional innovative enterprises, taking into account the recommendations of international organizations, were commented. Prospects for the application of the Industrial 4.0 platform to increase the efficiency of management of the activity of innovative enterprises are shown. The study provides an opportunity to apply the proposed approaches and models to improve the management processes of innovative enterprises in other relevant innovation structures. Analysis of the scientific literature shows that despite the large number of scientific and experimental research in this area, there is still no established methodology and theory. Therefore, there is a serious need to develop appropriate recommendations to address the problem based on the analysis of the existing scientific research in a similar field and regional-sectoral features of the issue.

3. Problems of effective management of the activity of innovative enterprises

When developing the model for determining the efficiency level of the activity of innovative enterprises, analyzing the functions of its management system, as well as when determining the indicators of the formation of composite indices and the evaluation of the activity of innovative enterprises in that field, we should not forget the existing important international standards. Thus taking into account standards such as ISO/TR 56004:2019 "Innovation Management Assessment - Guidance", ISO 56000:2020 «Innovation management - Fundamentals and vocabulary», Oslo Manual, etc. will further improve the content quality of the considered issues (https://cdn.standards.iteh.ai/samples/72047/873cfdea4a8a4acd9c0fee1c4d487665/SIST -TP-CEN-ISO-TR-56004-2020.pdf). In those documents, 1) the reasons for conducting an innovation management assessment, 2) choosing an innovation management assessment approach, 3) understanding different approaches to the innovation management assessment, 4) activity criteria for innovation management, 5) options for implementing an innovation management assessment, 6) type and quality of innovation management assessment results, 7) formats of innovation management assessment outputs, 8) preparation of innovation management assessment process, 9) strategic goal and scope of innovation management assessment, 10) suitable design of innovation management assessment for the organization design, 11) expected results of innovation management assessment, 12) activity indicator for innovation management evaluation performance indicators, etc. such issues were described and relevant analyzes were carried out.

These confirm that managing innovation in a systematic way creates value and secures the future of the organization. As a result, organizations are looking for guidance to continuously improve their innovation management capabilities and performance. A prerequisite is the transparency of the organization's current innovation management activities. Here, regular and effective evaluation of innovation management is essential to achieve the necessary transparency. Despite all this, the guidelines and instructions of the mentioned standards are not able to fully satisfy the full requirements of modern innovative enterprises. Therefore, there is a need to conduct the necessary research in the relevant field and develop appropriate solution mechanisms.

In addition, in the process of developing the model for determining the efficiency level of the activity of innovative enterprises, and the architectural-technological structure model of its information support, it is necessary to take into account the strategy of the enterprise's architecture as a basis. Thus, the architecture of the enterprise is a well-defined approach, and method for the analysis, design, planning, and implementation of the enterprise, always using a unified approach for the successful development and implementation of the relevant strategy. Enterprise architecture applies architecture principles and practices to manage organizations through the technological changes needed to implement their business process and information strategies. These practices help identify, motivate, and achieve change using various aspects of the enterprise, understand the strategic intent of the business, and then drive better business performance in everything from business processes to supporting technology, partner relationships, and infrastructure. Enterprise architecture is based on the principles governing the organization of the system, the relationships of its components with each other and with the environment, and their design and evolution (https://www.archimetric.com/what-is-togaf/).

Enterprise architecture is presented as a conceptual framework document by The Open Group as a methodology used by the world's leading organizations. That methodology, called The Open Group Architecture Framework (TOGAF), is an enterprise architecture methodology and framework used by the world's leading organizations to improve business efficiency. It is an enterprise architecture standard that provides consistent standards, methods, and communication among enterprise architecture professionals so that enterprise architecture work can be done better.

The Open Group Architecture Framework is a collection of methods and tools used to 1) build an iterative process model supported by best practices, 2) create a reusable set of existing architectural assets, and 3) plan, develop, implement, and maintain an enterprise architecture.

The Open Group Architecture Framework, first published in 1995, is based on the US Department of Defense Information Management Technical Architecture Framework. Since then, the Open Group Architecture Forum has regularly developed successive versions of the Open Group Architecture Framework (https://www.archimetric.com/what-is-togaf/).

The Open Group Architecture structure is based on four interrelated levels called architectural domains:

1. Business architecture defines the organization's business strategy, management, organization, and main business processes.
2. Information architecture describes the structure of an organization's logical and physical information assets and associated information management resources.
3. The architecture of applications provides frameworks of services to be presented as business functions for individual systems to be applied, the interaction between application systems, and the integration of their relationships with the organization's main business processes.
4. The technical or technology architecture describes the hardware, software, and network infrastructure needed to support the deployment of key, mission-critical applications.

As of 2016, the Open Group Architecture Framework is reported to be used by 80% of Global 50 companies and 60% of Fortune 500 companies.

The Structure of the Open Group Architecture Framework (https://www.archimetric.com/what-is-togaf/) includes: 1) Architecture development method, 2) Architecture development method guidelines and techniques, 3) Architecture content structure, 4) Enterprise continuity and tools, 5) Open Group Architecture Framework reference models, 6) Architecture capacity structure.

The Open Group Architecture Framework has the following advantages (https://www.archimetric.com/what-is-togaf/): 1)It provides a comprehensive checklist of architectural deliverables. 2) Promotes better integration of work products if adopted within the enterprise. 3) It provides a detailed open standard for how architectures should be described.

The Open Group Architecture Framework has been the most widely used structural model for enterprise architecture as of 2020. Although it is applied in most cases as the main approach to designing, planning, and managing the information technology architecture of the enterprise, in some cases it cannot fully meet modern technological needs. In particular, the Industry 4.0 platform components and the integration of enterprises into the European Single Digital Market are not fully compatible with the platforms.

The management mission of the innovative enterprises is to create conditions for the formation of an integrated "science-education-business" trio in order to accelerate the development and application of scientific, technical and technological achievements in the production of high quality innovative products and services relevant to market demand. As a result of studying and analyzing foreign experience in organizing the activities of the innovative enterprises [9, 16-19], the following functions of its management system can be shown (Figure 1).

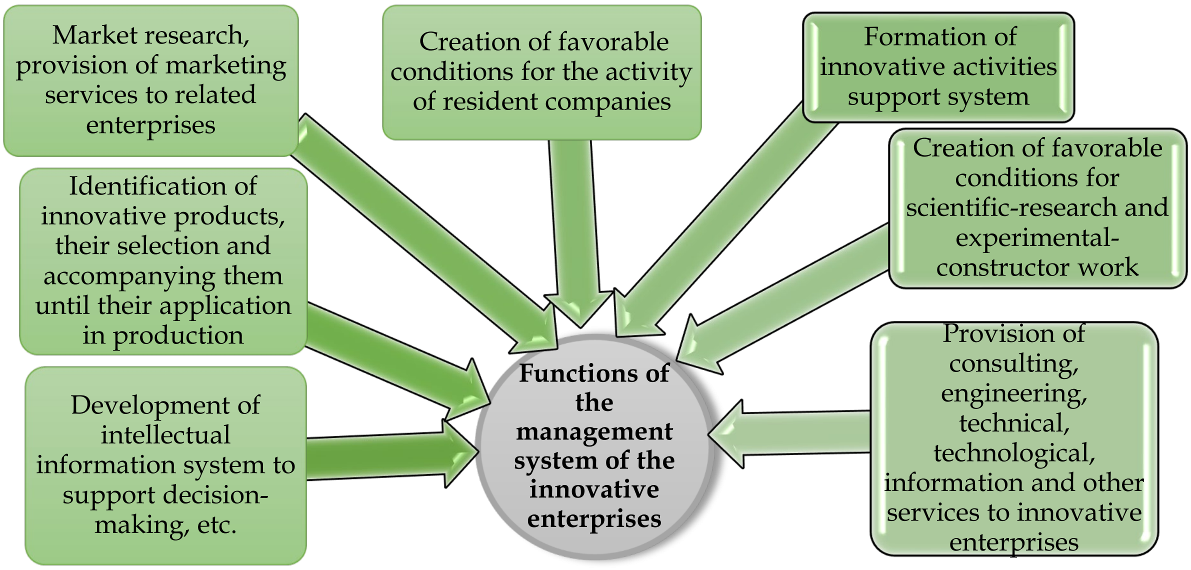

Fig.1. Functions of the management system of the innovative enterprises

Based on the above, the most important problems in the management of innovative enterprises were identified (Figure 2). In other words, there are management problems that need to be addressed in innovative enterprises such as.

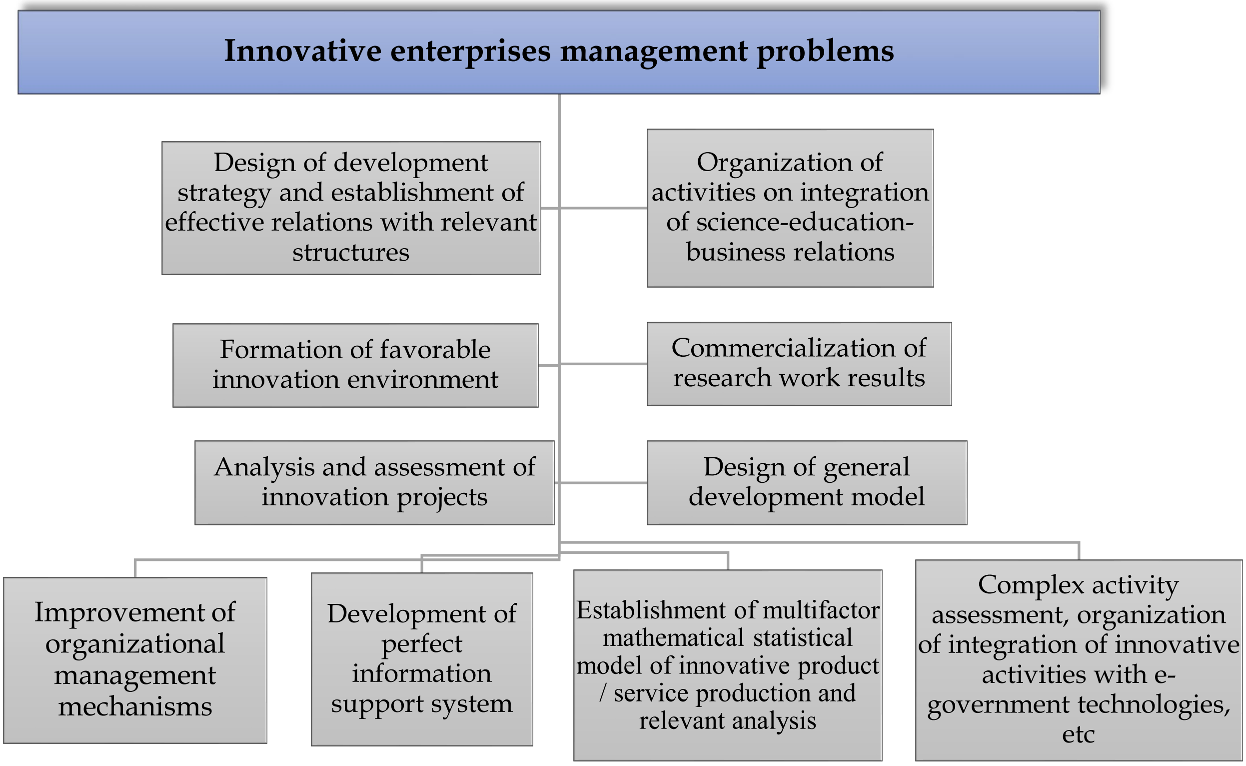

Fig. 2. Innovative enterprises management problems

The model of activity of modern innovative enterprises [20] can consist of the following components (Figure 3).

Certain requirements are set for indicators and criteria characterizing the activity of innovative enterprises such as being flexible, complex; the dynamics of the system of efficiency indicators, i.e. the ability to review the development process under the influence of internal and external factors, to reflect the results of technical and organizational improvement of production.

In addition, efficient governance indicators such as tax and customs benefits, scientific-innovative and educational activities, scientific-technical, technological and resource potential, financial-investment sources, level of development of residents, higher education and research institutions, integration level of scientific research and educational institutions, level, compliance of the specialization of the innovative enterprises with the priorities of regional policy, best practices in the field of technology commercialization, etc. should be taken into account [9, 13].

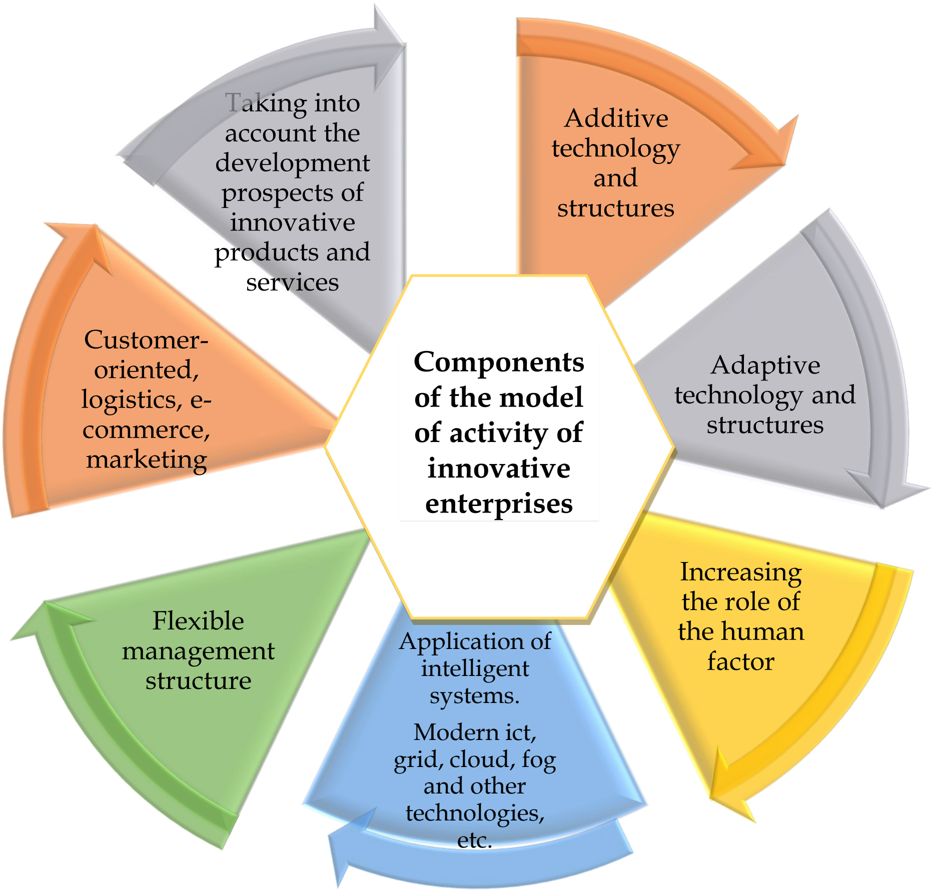

Fig. 3. Components of the model of activity of innovative enterprises

Indicators characterizing the activity of innovative enterprises can include investments, loans, number of innovation infrastructure entities, benefits, cost structure of the implementation of innovation projects, production of innovative products and services, budget funds and other payments, jobs, salaries, total funding of innovative enterprises from the budget, number of resident companies, the number of jobs created, the volume of products and services produced by residents, human and technical potential, ICT potential, activities on commercial and other services, consulting, experimental, production activities of innovative enterprises, etc.

4. Development of a comprehensive assessment methodology for the efficiency of innovative enterprises

Attempts to develop a complex system of indicators for the analysis of activities in innovative enterprises are rare. In the existing studies, various researchers have proposed incomplete groups of indicators. In other words, the formation issues of a system of indicators in the field of assessment of performance in innovative enterprises are important issues. Therefore, for some time now, the wide use of so-called composite indicators in the measurement process has begun. They are a useful tool for evaluating, analyzing and comparing innovative enterprises depending on the level of formation and development [21-23].

The so-called composite index must be able to be divided into other indices, subindices, indicators and quantities that are part of it. Appropriate work should be done to determine the relationship between the composite indicators and the indicators associated with it, as well as the regression relationship [7, 21, 24, 25]. Composite indices should also be visualized by various means and prepared for the next process. The composite index allows to assess the degree of efficiency of the innovative enterprises, technopark, both directly and indirectly.

Due to the complex nature of the complex evaluation of the efficiency of innovative enterprises, the development of a system of indicators, criteria, and indices required for the development of its methodology is considered to be a particularly important issue. One of the issues complicating the methodology is to analyze the current situation on the comprehensive approach to evaluating the efficiency of innovative enterprises both individually and in comparison with others and to work out methodological recommendations for the creation of a system of indicators in the relevant field. For this, first of all, it is necessary to summarize the requirements for the formation of the system of indicators that allow the implementation of the indicated assessment and to work out the methodological base and scientific-theoretical foundations of that system. Also, the composition and content of the system of indicators should be determined. Since the system of indicators is represented at different levels and groups, a corresponding calculation method should be developed for them, as well as a method that allows determining the weight or influence coefficients corresponding to each indicator. In principle, it is necessary to work out such calculation methods so that they can be applied independently, and it is possible to create a computer model of it. At the same time, various information security issues that complicate the calculation of the composite index and are necessary for the calculation of the indicators included in its composition should be investigated and resolved in a timely manner.

The stages of creating a system of composite indicators and the requirements imposed on them should be determined. Various scientific studies have been conducted on the development of a system of indicators for independent and comparative evaluation of the activity of innovative enterprises and technological parks [26]. Although many different scientific articles are devoted to this field, in general, it is rare to find a comprehensive development of the system of indicators of the activity of innovative enterprises. In those works, various authors proposed incomplete groups of indicators. This once again confirms that the development of a system of indicators for evaluating the activity of innovative enterprises and technological parks is one of the most urgent and important issues. In general, the reason for the widespread number of indicator systems developed to evaluate the modern development period of society and economy is that they can provide an easy interpretation of the data obtained as a result of the analysis of socio-economic phenomena. In recent times, composite indicators are also been widely used in the measurement system. Composite indicators are a useful tool for evaluating, analyzing, and comparing the level of development of society and the economy. According to the official explanation of the Organization for Economic Cooperation and Development (OECD), composite indicators are created by combining individual indicators measured on the basis of multidimensional criteria into a single index.

Although composite indicators or indices are one of the tools and mechanisms that allow comparing the performance of innovative enterprises, their construction is complicated. This process combines a number of stages that require careful study. So, initially, a theoretical base should be developed to provide the basis for selecting and combining the indicators included in the composite indicators.

Aggregation and weighting of indicators should be carried out according to theoretical principles [26]. Indicators should be selected based on their analytical stability, measurability, comprehensiveness, and interrelationship. The research system should clarify the general structure of the indicators, the evaluation of the suitability of the database, and the selection of the methodology. Different approaches should be considered for imputing missing data.

They should be normalized so that the possibility of comparison of the mentioned indices and indicators provides a basis for decision-making in the enterprise, for taking effective measures to improve the innovation environment. According to the importance of each indicator, its corresponding weight should be calculated and summation should be done to get the final index based on the developed methodology. It is necessary to carry out analyzes to verify the reliability of the composite indicator from the point of view of inclusion or exclusion mechanisms of individual indicators, normalization mechanisms, imputation of missing data, and selection of weights. Composite indicators must be transparent and have the ability to be divided into indicators and quantities included in their composition. Relationships of composite indicators with other declared indicators, as well as relationships based on regression should be clarified [21, 27-29]. Composite indices should be visualized and presented in different ways. Of course, the specified stages are conditional and may be subject to certain changes depending on the real situation and the research subject.

The authors proposed a multi-criteria Expert evaluation method in the development and analysis of the model for determining the efficiency level of the activity of innovative enterprises. It should be noted that in this process, in some cases, there may be a need to describe the expert procedure that provides agreed assessments. For this, many relevant approaches have been proposed by various authors [30].

Thus, in (Gubanov D., Korgin N., Novikov D., Raikov A.) the organization and mechanisms of support for expert decision-making using modern information and communication technologies, as well as information analysis and collective intelligence technologies (electronic expertise) were considered. Here, the role of e-expertise in decision-making processes is described, the procedures of e-expertise are classified, their advantages and disadvantages are determined and efficiency conditions are considered. Electronic expertise and decision-making, classification of electronic expertise procedures, capabilities, limitations, conditions of application of electronic expertise, and efficiency conditions of electronic expertise were considered. Particular attention was paid to the features of electronic expertise. In addition, the expediency and basics of using known methods and approaches in e-expertise were studied. Some examples of state-of-the-art technologies for performing electronic forensics are described.

Electronic formation of expert opinions, electronic expertise with semantic differential scales, electronic brainstorming, networked strategic conversation, networked strategic congress, normative and legal support of electronic expertise, financial support of electronic expertise, motivation of experts, etc. issues were considered.

Researchers distinguish the following characteristics of collective expertise [30]:

- to guarantee the maximum possible perception of a situation;
- detecting competitive decisions;
- detection of true "theoretical" judgments and assumptions;
- obtaining objective assessments with substantial evidence;
- obtaining higher reliability expert evaluations.

Objectivity or elimination of "conflict of interest" between participants of expert activity. The following rules define contraindications to the involvement of specific subjects in independent expertise:

- experts do not consider objects with which their representatives have a well-established relationship as a community/conflict of interest;
- representatives of the evaluated object do not participate in its expertise as experts or coordinators;
- representatives of expertise clients do not participate in solving issues of personal interest;
- the number of employees in the expert commission (here, the term employee means a representative of the organization that ensures the activity of such an expert commission or a representative of a subordinate organization), decisions in favor of this organization are not determined in advance. In other words, expert forecasting can be considered both a forecasting method and a type of expertise [30].

Therefore, electronic forensics can serve for prediction. Unfortunately, network technologies are still not intensively applied in forecasting problems, although a number of research studies have shown that collective intelligence, crowd or group wisdom, etc. demonstrates its efficiency.

The extent to which it is important allows us to give reasoning. In order to determine and form a composite index, it is proposed to substantiate the values of the indices with the following symbols and names as a basis (Figure 4).

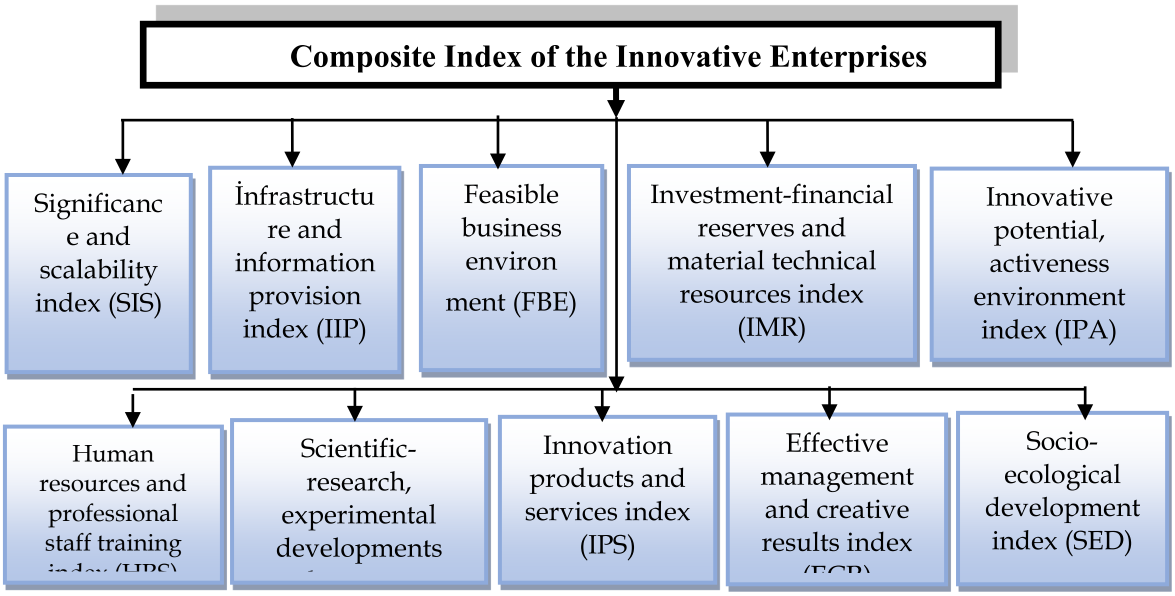

Fig. 4. A group of key indices for assessing the performance of innovative enterprises

The architecture of the Composite Indicator System (CIS) is offered in a multi-level way. The general level reflects the lower levels in a general integrative form, and the parameter that characterizes it is called the Composite Index of the Innovative Enterprises (CIIE) (Figure 5). The composite index has a key position in the analysis of comparisons as an evaluation tool. As a result of its value, innovative enterprises receive an appropriate rating. The value of the composite index varies in the range (0.100). This shows that the calculation of the CIS is expressed in the functional formula as follows:

CIIE = FI (SIS, IIP, FBE, IMR, IPA, HRS, SEI, IPS, ECR, SED)

here FI shows how the composite index depends on others. It can be noted about one of the most important indices that make up the innovative enterprises composite index that the Significance and Scalability Index (SIS) measures the importance of the creation, organization of activities and development of innovative enterprises in the social and economic life of the region to which they belong. It also characterizes the level of participation of the technopark as a whole in the relevant economic sector. Other sub-indices have both direct and indirect influence on its formation. The group includes a total of 12 subindices. These sub-indices are also in the range of (0, 100) and influence the formation of the Significance and Scalability (SIS) index by relevant weights coefficients. The method of formation and evaluation of the Significance and Scalability (SIS) index is carried out by the expert method based on a fuzzy approach. Then, the values of the sub-indices and the corresponding weights of other indicators that affect them are determined in the same way. Each of the 10 indices that make up the composite index is composed of sub-indices of different levels.

The Significance and Scale Index (SIS) includes 12 sub-indices. We suggest to include the following sub-indices in the composition of importance and scale index: compliance of spheres of activity and specialization directions with state programs (SSSP), degree of scale (DS), role and importance in formation of national innovation system (RNIS), impact and importance on formation of knowledge economy (IFKE), level of participation in export-oriented and knowledge-intensive goods production (EOKI), level of participation in competitive goods production (CGP), level of assignment (LAS), priviledgeness and statusness (PS), effectiveness of property relations (EPR), area favorableness (ARFA), comprehensiveness of fundamental, applicative, empirical and innovative research (CFAEI), level of building of various links on development and use of high technologies (DUHT).

Hence, given the symbols denoted above, the building of SIS index and the functional dependence of sub-indices constituting this index can be given as below: The determination of the Significance and Scale (SIS) index on the basis of the above-mentioned conventional notation can be expressed as a functional dependence (F1) on the sub-indices that create it:

SIS= F1 (SSSP, DS, RNIS, IFKE, EOKI, CGP, LAS, PS, EPR, ARFA, CFAEI, DUHT).

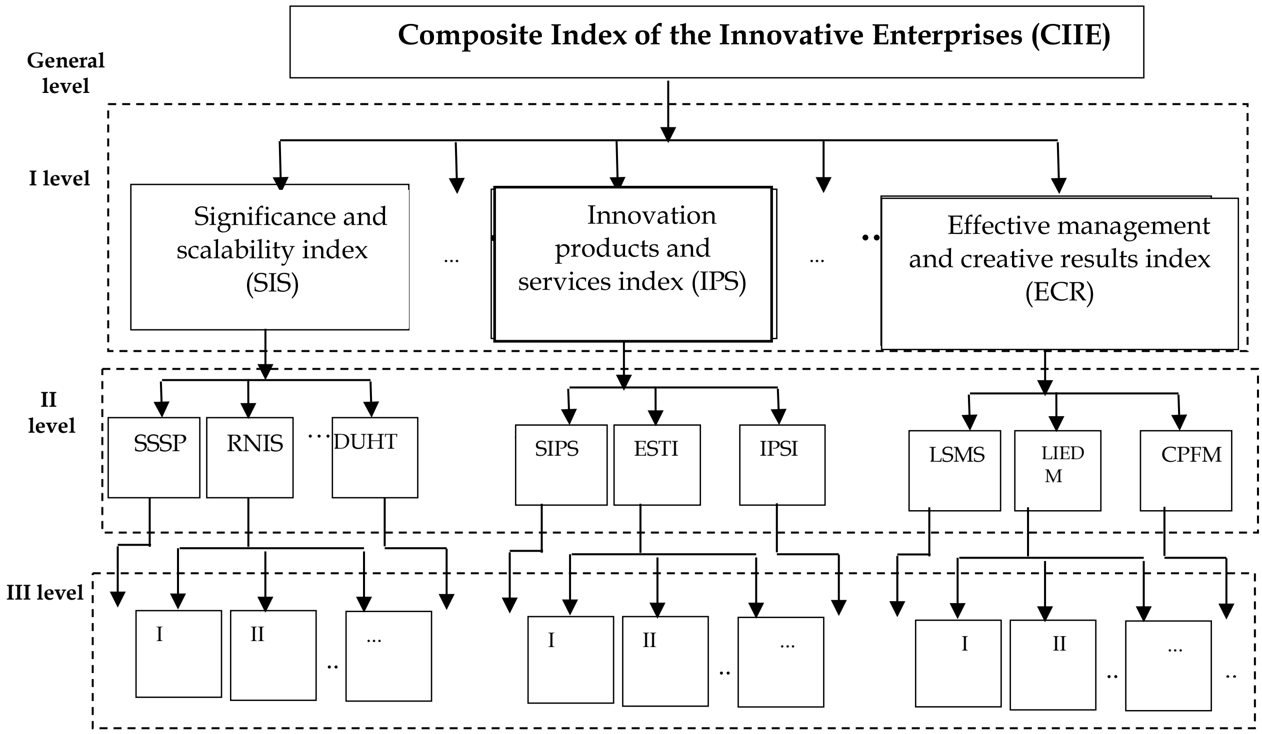

Fig. 5. Level structure of indices and indicators in the field of activity analysis in innovative enterprises

The IIP index, which reflects the level of development of Infrastructure and Information Provision in innovative enterprises, consists of 14 sub-indices [7, 31].

The building of secure information provision of innovative enterprises by using innovative technologies in management of its activity is one of the important conditions of facilitating innovation activity. Following sub-indices can be included in IIP index: level of building links with innovation and business structures (BIBS); level of links with financial-credit and insurance structure (FCIS); level of building relations with production infrastructure (BRPI); level of building links with marketing structures (LBMS); level of opportunities of using and developing modern information technologies (UDMI); level of information protection and security (LIPS); level of automation of work places (LAWP); level of provision with mobile communication tools (PMCT); level of organization of links with ICT and Internet services (ICTI); level of organization of links with intellectual property protection structures (LIPP); level of favorableness of transport infrastructure (LFTI); level of provision with material- technical and municipal resources (LPMM), level of organization of access possibilities to e-libraries and scientific bases (ELSB); level of favorableness of socio-ecological infrastructure (FSEI).

Based on these symbols, the IIP index can be expressed in functional form (F2) as follows:

IIP=F2(BIBS, FCIS, BRPI, LBMI, UDMI, LIPS, LAWP, PMCT, ICTI, LIPP, LFTI, LPMM, ELSB, FSEI)

The Favorable Business Environment (FBE) index consists of 12 sub-indices [7, 32]. Following sub-indices can be included in the composition of FBE index: effectiveness of the activity of institutional structures (EAIS); formation and improvement of legal framework (FILF); opportunities of business development (OBD); functionality of mechanisms of protection of entrepreneurs' interests (FMPE); level of use of new information and communication tools (UNIC); efficiency of activity environment of small enterprises (EASE); opportunities of building business environment (OBBE); functionality of funds and mechanisms of entrepreneurship development (FMED); level of reliability of business environment (LRBE); sustainability and stability level of political and economic environment (SSPE); level of competitiveness of business environment (LCBE); level of implementation of incessant reforms (LIIF).

Based on these symbols, the definition of the FBE index can be expressed functional (F3) as follows:

FBE=F3 (EAIS, FILF, OBD, FMPE, UNIC, EASE, OBBE, FMED, LRBI, SSPE, LCBE, LIIF).

The Index of Investment and Financial Resources and Material and Technical Resources (IMR) consists of 10 sub-indices.

Considering the above mentioned cases, it is suggested to include the following subindices to IMR index of innovative enterprises: functionality of investment funds and mechanisms (FIFM); level of impact of investment resources structure (IIRS); functionality of mechanisms of attracting investment (FMAI); level of state support for investments (LSSP); level of impact of financial resources structure (IFRS); effective functioning financial-investment structures (EFFS); level of effectiveness of financing mechanisms (LEFM); level of efficiency of investment (LEI); level of meeting demand for material-technical resources (MDMR); functional of technical maintenance mechanisms (FTMM).

Above presented sub-indices can be analyzed separately, and it is possible to determine other indicators and variables affecting those sub-indices. As in previous case, these sub- indices are defined within (0, 100) interval by experts' groups. These subindices can also be analyzed separately. Other indicators and indicators that affect them can also be identified. These sub-indices, as in previous cases, are determined by expert groups in the range (0,100). Based on the above symbols, the definition of the IMR index can be functional expressed as (F4) as follows:

IMR= F4 (FIFM, IIRS, FMAI, LLSP, IFRS, EFFS, LEFM, LEI, MDMR, FTTM).

The Innovative Potential, Activity and environment (IPA) index consists of 11 subindices [33-36]. It is suggested to include the following sub-indices in innovative potential, activeness and environment (IPA) index: level of production potential capabilities (LPPC); level of investment potential (LIPO); level of effect of intellectual potential (LEIP); administrative management and institutional potential (AMIP); organizational innovation potential (OIPO); marketing innovation potential (MIPO); innovative activity potential (IAPO); information sources potential (ISPO); environmental potential (ENPO); level of innovation activity (LOAC); favorableness of innovative environment (FAIE).

Based on this, the definition of the IPA index can be expressed in functional form (F5) as follows:

IPA= F5 (LPPC, LIPO, LEIP, AMIP, OIPO, MIPO, IAPO, ISPO, ENPO, LOAC, FAIE).

The Human Resources and Professional Staff Training Index (HRS) Index consists of 10 sub-indices [7, 37].

It is suggested to include the following subindices in HRS index of innovative enterprises: effectiveness of the structure an dynamism of innovative staff potential (EISP); level of staff intellectualization (LSIN); quality level of staff resources (QLSR); sustainability level of staff potential (SLSP); level of management of human resources (LMHR); level of socio-cultural and public activity of human resources (SPAH); level of participation in management and decision-making process (PMDP); level of provision of effective work conditions for personnel (PEWC); level of personnel satisfaction (LPES); level of personnel training (LPTR).

Based on it, the definition of the HRS index can be expressed in the functional form (F6) as follows:

HRS=F6 (EISP, LSIN, QLSR, SLSP, LMHR, SPAH, PMDP, PEWC, LPES, LPTR).

The index of Scientific, Research, Experimental and Innovative Projects (SEI) consists of 10 sub-indices.

It is suggested to include the following subindices in SEI index of innovative enterprises: effectiveness of the structure and dynamics of scientific-research and empirical organizations (ESEO); effectiveness of scientific staff reserves structure (SSRS); level of material-technical base (LMTB); level of financing sources and resource opportunities (FSRO); level of scientificness of innovation (LSIN); effectiveness of the structure and dynamics of innovative projects (ESDI); level of publication of scientific-research (LPSR); level of commercialization of scientific research (LCSR); level of conduction of joint scientific research at international level (CSIL); level of transformation of scientific research to innovation (TSRI).

The definition of the SEI index can be functional expressed as (F7) as follows:

SEI= F7(ESEO, SSRS, LMTB, FSRO, LSIN, ESDI, LPSR, LCSR, CSIL, TSRI).

The Innovative Products and Services (IPS) Index consists of 12 subindices [7, 38-40].

It is suggested to include the following sub-indices in IPS index of innovative enterprises:

1. Effectiveness of the structure and dynamics of innovation products and services (SIPS);
2. Effectiveness of the structure and dynamics technological innovations (ESTI);
3. Level of development of innovation product marketing program (IPMP);
4. Level of commercialization of innovation products and services (CIPS);
5. Export share of innovation products and services (EIPS);
6. Import share of innovation products and services (IIPS);

7. Share of customer-oriented innovation products and services (COIPS);
8. Science intensity of innovation products and services (SIPS);
9. Resource intensity of innovation products and services (RIPS);
10. Rate of the process of promotion of innovation products and services (PIPS);
11. Compliance of innovation products and services with international standards (IPSI).

Based on the above, the definition of the IPS index can be functionally expressed as (F8) as follows:

IPS= F8(SIPS, ESTI, IPMP, CIPS, İMXR, EIPS, IIPS, COIPS, SIPS, RIPS, PIPS, IPSI).

The Effective Management and Creative Results Index (ECR) index consists of 13 sub-indices [7, 41]. t is suggested to include the following subindices in ECR index:

1. Level of effectiveness of management structure (LSMS);
2. Level of staff participation in management processes (LSMP);
3. Level of improving the efficiency of decision-making (LIEDM);
4. Level of application of new and intellectual technologies in management (ANIM);
5. Level of profitability (LPR);
6. Level of stimulation of work outcomes (LSWO);
7. Level of improving of the transparency of activity (LITA);
8. Level of commercialization of scientific-research outcomes (LCSO);
9. Level of formation of creative potential (LFCP);
10. Level of formation of demand for creative products and services (FDCP);
11. Level of development, application and use of creative products and services (DAUC);
12. Level of use of new technologies in generating creative outcomes (UTCU);
13. Access opportunities of creative products and services to foreign markets (CPFM).

Here, the definition of the ECR index can be expressed functionally (F9) as follows:

ECR= F9 (LSMS, LSMP, LIEDM, ANIM, LPR, LSWO, LITA, LCSO, LFCP, FDCP, DAUC, UTCU, CPFM).

The Social and Environmental Development (SED) Index is organized in 14 subindices [22, 42, 43].

Following subindices are suggested to be included in SED index of innovative enterprises: level of durability and sustainability of socio-economic development (DSED); level of development of the standard of living of staff (DSLS); level of raising socio-ecological quality (RSEQ); opportunities of improving the health status (OIHS); opportunities to improve welfare level (OIWL); opportunities to improve work conditions (OIWC); level of improving living standard of work staff (LSWS); level of greening the economy and efficient utilization of natural resources (GEEU); level of protection of environment against pollution (LPEP); level of preventing incurred economic loss on environment (PIEE); degree of environmental investments (DEI); degree of harmfulness of waste and technological processes (DHWT); level of impact of environmental situation on health (LIEH); level of improving the quality of education (LIQE).

Based on the above, the definition of the SED index can be expressed functional (F10) as follows:

SED= F10 (SEİD, PHTİ, SEKY, SSYİ, RSYİ, OIWC, LSWS, GEEU, LPEP, PIEE, DEI, DHWT, LIEH, LIQE).

These F1-F10 functionals (dependencies) can be expressed in the form of multivariate regression equations using numerical values of the subindices on which they depend. The appropriate coefficients of the subindices are determined using the EViews software package.

5. Method of comparative assessment of complex activity of the innovative enterprises

To explain the method of comparative assessment of the complex activity of the innovative enterprises on the basis of the composite index, let's adopt the following symbols.

i – serial number of the innovative enterprises, $i = \overline{1, N}$.

CIT_i Integrative or composite index of the i-th innovative enterprises for comparative assessment of complex activity of innovative enterprises

Suppose that – $CIT_i \in [0,100], i = \overline{1, N}$

j = serial number of other indices required for calculation of composite index, $j = \overline{1, J}$

where J is any natural numbers which indicates the total number of indices.

k_j is the coefficient of influence (weight) of the j-th index on the formation of the composite index (CIT_i).

Here it meets the conditions $k_j \in [0,1]$ and $\sum_{j=1}^{J} k_j = 1$

k_j is determined in various ways, including by a group of experts. S_{ij} – is the value price of the i-th innovative enterprises on the j-th index.

In accordance with the assessment methodology, S_{ij} can receive any of the grades listed in section (0, 100) by the expert group.

The assessment of this index on this scale is determined by experts on the basis of the prices of other sub-indices that make up the index. In this case, a similar methodology can be applied.

Here, $i = \overline{1,N}$, $j = \overline{1,J}$

Thus, composite indices can be determined by making calculations based on the following formula [20]. $KIT_i = \frac{1}{J}\sum_{j=1}^{J} k_j s_{ij}, i = \overline{1,N}$

k_j - to determine the weight coefficients, the expert group should achieve the following sequence by comparing the j-th indices based on the degree of significance and importance:

$$K_1^* \geq K_2^* \geq K_3^* \geq K_4^* \geq K_5^* \geq K_6^* \geq K_7^* \geq K_8^* \geq K_9^* \geq K_{10}^*$$

If significant differences and inconsistencies are found between expert assessments in this process, such cases can be remedied by known methods based on the intervention and recommendation of decision-makers.

In the next stage, it is necessary to note the importance of the one that has the least degree of importance, that is, by accepting $K_{10}^* = 1$ it, and how much more important it is after each of its predecessors. Then it is proposed to take the weighted coefficient for that group as the numerical average of the sum of the values proposed by the experts for each j.

$K_j^* = \frac{1}{E}\sum_{e=1}^{E} K_j^{**}$ $e = \overline{1,E}$ indicates the serial number of the experts, E - the number of experts. K_j^{**} is the degree of significance given by the e-expert to the j-th index.

As you can see, you can have here $K_j = \frac{K_J^*}{\sum_{j=1}^{J} K_J^*}$.

therefore, the condition imposed on Kj, that is, the condition "the weight coefficient is equal to 1" is satisfied.

$$\sum_j K_j = \sum_j \frac{K_j^*}{\sum_{j=1}^{J} K_j^*} = \frac{\sum_j K_j^*}{\sum_j K_j^*} = 1$$

In the next process, the relationship between the values of the composite index according to the rank adopted by the decision-maker and the indices affecting it was mathematically modeled and the relevant results were obtained on the basis of preliminary estimates [4].

KIT__Y (CIIE) = 0.97*KRT1_X1 + 1.88*KRT2_X2 + 4.47*KRT3_X3 + 3.09*KRT4__X4 + 2.82*KRT5__X5 + 4.10*KRT6__X6 + 4.83*KRT7_X7 + 4.61*KRT8_X8 + 6.97*KRT9_X9 + 3.99*KRT10_X10 - 3.71

The values of the statistical parameters characterizing these results can be given as in Figure 6.

Dependent Variable: KIT__Y
Method: Least Squares
Date: 04/24/18 Time: 17:10
Sample: 1 15
Included observations: 15

Variable	Coefficient	Std. Error	t-Statistic	Prob.
KRT1_X1	0.970363	0.575365	1.686517	0.1670
KRT2_X2	1.879834	1.185521	1.585660	0.1880
KRT3_X3	4.473462	1.221823	3.661303	0.0216
KRT4__X4	3.094790	0.948002	3.264541	0.0309
KRT5__X5	2.816139	0.916481	3.072773	0.0372
KRT6__X6	4.100548	0.763130	5.373332	0.0058
KRT7_X7	4.831663	0.811730	5.952303	0.0040
KRT8_X8	4.610298	0.603848	7.634861	0.0016
KRT9_X9	6.970817	0.532072	13.10127	0.0002
KRT10_X10	3.993420	0.617019	6.472117	0.0029
C	-3.707510	7.437603	-0.498482	0.6443

R-squared	0.997484	Mean dependent var	163.1333
Adjusted R-squared	0.991195	S.D. dependent var	25.69843
S.E. of regression	2.411419	Akaike info criterion	4.743219
Sum squared resid	23.25976	Schwarz criterion	5.262455
Log likelihood	-24.57414	Hannan-Quinn criter.	4.737688
F-statistic	158.5996	Durbin-Watson stat	2.190690
Prob(F-statistic)	0.000094		

Fig. 6. Values of statistical parameters of the composite index assessment model of the innovative enterprises

6.Results of expert assessments of weight coefficients of composite indices on comparative assessment of innovative enterprises activity

Comparative assessment of the activity of innovative enterprises was evaluated according to 10 composite indices.

The final score for each index of the weight coefficients given by the experts to the selected indices to form the proposed Composite Index for the comparative assessment of the performance of innovative enterprises was calculated. The indices proposed for the comparative assessment of the performance of innovative enterprises, which have a significant impact on the composite index, and their weight coefficients on the scale (0, 10) were as follows according to the results of expert assessments (Table 1) [12, 17, 44, 45].

Table 1. Results of expert assessments of weight coefficient

№	Name of composite indices	Conventional markings	Weight coefficient
1.	Significance and scalability index	**SIS**	1
2.	İnfrastructure and information provision index	**IIP**	1,5
3.	Feasible business environment	**FBE**	2,7
4.	Investment-financial reserves and material technical resources index	**IMR**	3,2
5.	Innovative potential, activeness environment index	**IPA**	2,9
6.	Human resources and professional staff training index	**HRS**	3,8
7.	Scientific-research, experimental developments and innovative projects index	**SEI**	4,7
8.	Innovation products and services index	**IPS**	5,3
9.	Effective management and creative results index	**ECR**	6,1
10.	Socio-ecological development index	**SED**	4,2

The results of the assessment were considered appropriate by the expert group. The formal writing of the dependencies and the relevant coefficients of the dependent variables may be the basis for subsequent calculations and estimates in the following periods.

Conclusion

Leading countries are putting forward new initiatives in the direction of digitalization by entering a new environment of economic development. Innovative enterprises are the main driving force in the formation of an economy based on digital technologies and innovations in the new conditions and have a significant impact on its development. At present, much attention is paid to the creation of innovative enterprises aimed at the realization of science-based, innovative product manufacturing with the application of the components of the Industrial 4.0 Platform.

The development of the world's fast-growing Internet of Things, 5G, robotics, artificial intelligence application areas makes it necessary to develop and apply the high-tech sector.

This requires solving the problems of increasing the efficiency of innovative enterprises that produce innovative technologies and have a special role in the formation of innovative economic development. Therefore, there is a growing need for information on the necessary indicators in the process of developing appropriate methods for a comprehensive assessment of the activities of innovative enterprises in economic development. The need for a comprehensive analysis of the system of indicators for the analysis of the activities of innovative enterprises has arisen. However, it is almost impossible to get their values directly. In this sense, expert assessments are of topical significance in the context of multi-criteria indicators. The development of support mechanisms for decision-making processes based on the analysis of the performance indicators of innovative enterprises is considered very important.

A comprehensive assessment on the indicators, criteria of performance evaluating and performance efficiency of innovative enterprises should be carried out using modern methods.

In accordance with the above-mentioned directions, a system of composite indices for evaluating the activities of innovative enterprises has been proposed, and its architecture has been developed in a multi-level way. The method of calculating the composite index is presented, its dependence on other subindices is shown. It was noted that each of the 10 important indices that make up the composite index is organized in a way that depends on the sub-indices of different levels. The results of expert assessments of the proposed indices for the comparative assessment of the activities of innovative enterprises and their weight ratios, which have a significant impact on the composite index, were calculated. These functional dependences are expressed in the form of multivariate regression equations.

A method of comparative assessment of the complex performance of innovative enterprises has been developed. The relationships between the values of the composite index and the indices that affect it are mathematically modeled and the results are presented schematically. Values of statistical parameters of the composite index assessment model of innovative enterprises are given. The results of expert assessments of weights of composite indices on comparative assessment of the activity of innovative enterprises are shown. The final score was calculated for each index of the weights given by the experts to the selected indices to form the composite index.

Regarding the usefulness of the obtained result and its application in practice, it should be noted that the developed model for determining the level of efficiency of innovative enterprises can be applied to the activities of various innovative enterprises of other regional economies.

The proposed Composite Index system for comparative assessment of the performance of innovative enterprises, the results of expert assessments of weights can serve as a platform for a comprehensive assessment of the level of efficiency of the activity of innovative enterprises in general. The development of a model for determining the level of efficiency of the activity of innovative enterprises reveals additional opportunities for the sustainable development of the digital economy. The application of modern digital technologies in increasing the level of efficiency of the activity of innovative enterprises creates a basis for making appropriate management decisions in its activities.

As a result of the research, the problems of effective management of innovative enterprises were identified. The proposed methodological approach to a comprehensive assessment of the level of efficiency of the activity of innovative enterprises can be applied in other regional-sectoral economies. In this case, more effective results can be achieved by applying the proposed generalized criteria in assessing the level of efficiency of the activity of innovative enterprises.

The relevant recommendations proposed for the application of models, as well as the application of other modern digital technologies in the development of systems based on the technology of creating prototypes of products/services in innovative enterprises and their activities can make an effective contribution to future economic development.

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РАЗРАБОТКА МОДЕЛИ ОПРЕДЕЛЕНИЯ УРОВНЯ ЭФФЕКТИВНОСТИ ДЕЯТЕЛЬНОСТИ ИННОВАЦИОННЫХ ПРЕДПРИЯТИЙ

Алиев Аловсат Гараджа

Доктор экономических наук
Институт информационных технологий Национальной академии наук Азербайджана, заведующий отделом
Баку, Азербайджан
alovsat_qaraca@mail.ru

Шахвердиева Роза Ордухан

Кандидат технических наук
Институт информационных технологий Национальной академии наук Азербайджана
Баку, Азербайджан
shahverdiyevar@gmail.com

Аннотация

Статья посвящена разработке модели определения уровня эффективности деятельности инновационных предприятий. Обоснована важность цифровизации и расширения применения инноваций. Отмечена актуальность применения Интернета вещей, 5G, робототехники, больших данных, облачных технологий и технологий искусственного интеллекта. Показана особая роль высоких технологий и инновационных предприятий в развитии цифровой и инновационной экономики. Изучены перспективы применения технологий Индустрии 4.0 в деятельности структур технопарка, направленных на реализацию наукоемкого, инновационного производства продукции. Изучена соответствующая работа в этой области, выявлены проблемы эффективного управления деятельностью инновационных предприятий и прокомментированы решения.

Отмечены функции системы управления инновационными предприятиями и предложена модель функционирования современной инновационной науки и технопарков. Разработана комплексная методика оценки показателей, критериев и эффективности оценки деятельности инновационных предприятий. Проведен комплексный анализ системы показателей анализа деятельности инновационных предприятий. Предложена система сводных показателей оценки деятельности инновационных предприятий, разработана ее многоуровневая архитектура. Представлена методика расчета сводного индекса и показана его зависимость от других субиндексов.

Было отмечено, что каждый из 10 важных индексов, составляющих сводный индекс, состоит из субиндексов разного уровня. Эти функциональные зависимости выражаются в виде уравнений многомерной регрессии. Разработан метод сравнительной оценки комплексной эффективности инновационных предприятий. Взаимосвязь между значениями составного индекса и индексами, влияющими на него, математически моделируется, а результаты представляются схематически. Даны оценки статистических параметров сводной индексной модели оценки инновационных предприятий. Приведены результаты экспертных оценок весовых коэффициентов сводных показателей по сравнительной оценке деятельности инновационных предприятий.

Итоговый балл рассчитывался по каждому показателю весовых коэффициентов, присвоенных экспертами показателям, выбранным для формирования сводного показателя. Рассчитаны результаты экспертных оценок предложенных индексов и их весовых соотношений, оказывающих существенное влияние на сводный индекс и предлагаемых для сравнительной оценки деятельности инновационных предприятий. Даны соответствующие рекомендации по применению моделей.

Ключевые слова

цифровая и инновационная экономика, инновационная инфраструктура, высокие технологии, наукоемкая и инновационная продукция, инновационные предприятия, технопарк, сводный индекс, весовой коэффициент, экспертные оценки, платформа Индустрия 4.0.

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