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Principles of Industrial Ecosystem Design: Life Cycle Analysis

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***Abstract* — The subject of research is industrial ecosystems. The purpose of the work is to formulate the principles for ecosystem projects functioning at different stages of their lifecycle. The article systematizes the problem of applying the ecosystem approach in cross-sectoral interaction. The following tasks have been resolved as a result of the study: the need to classify the projects according to the ecosystem levels has been considered and substantiated, the essence and concept of ecosystem life cycle has been disclosed, theoretical principles for industrial ecosystem functioning have been formulated, the main categories have been clarified, the general concept for ecosystem approach implementation has been formulated. The article illustrates this concept using a case study of National University of Science and Technology "MISIS". The role and functions of the ecosystem integrator as "an entry point" to form new ideas, competences, concepts, technological solutions and initiate new projects to develop and test new products and technologies are shown. The practical significance of the research results consists of the possibility to use certain concepts in industrial enterprise management as well as to develop program documents and strategies for socio-economic development of the country and individual regions.**

Keywords — industrial ecosystem, actors, system lifecycle, ecosystem levels, project types.

I. Introduction

Being a major sector of entrepreneurial community, manufacturing is the driver of all innovative processes in the society. Within the frame of the fourth industrial revolution, described by Klaus Schwab, the current trend for development is aimed at the entire digitalization of all the tangible assets and their integration into digital ecosystem together with the partners, forming the value chain.

The ecosystem approach is just being developed in our country, with finance and IT being the priority areas for its implementation. However, successful foreign experience brings our scientists and businessmen to understanding the need to apply the ecosystem approach to other sectors, too. Gaysina Dilyara Valerievna, Director of workshop of FS consulting PricewaterhouseCoopers, stressed the importance to form ecosystems at the 6th annual conference "Designing Business Architecture". She disclosed the following prerequisites stimulating the ecosystem development: technology development that help all participants to interact effectively (for example, complex business digitalization, BigData analysis, API), shorter introduction time of new products to the market, readiness of ecosystem members to share data, appearance of innovative companies on the market [1]. Denis Reimer, Vice-president of LANIT on digital transformation, Director of Digital Transformation Group says that in the nearest two years many companies from different spheres will become participants of ecosystems, obtain new roles and begin to deliver new values to their customers, interacting with each other. Such ecosystems will be based on block chain technologies, IoT, API ideology, Big Data analysis. Accumulating knowledge on how to use these technologies, gaining experience from cases studies give us an opportunity to move on to a new expert level in the world of digital transformation [4]. Ming Zeng, Strategy Director of Chinese technological company Alibaba Group, highlights the necessity to create "Smart Business" [6], he notes that company directors increasingly wish to turn their firms into large-scale platforms with billion dollar capitalization. If such a firm operates in traditional sphere, its management formulates business strategies, with platform creation being one of them, regardless of other business actors or external factors. Meantime the very idea of business ecosystems comes down to the concept of "smart networking", which is developing to solve the intricate problems of consumers.

Russian manufacturers often combine platform approach with classical one that builds short communications with focus on competitive advantage development. We consider such an approach a bit too narrow. We acknowledge the fact, that appearance of ecosystem concept is connected with digital technologies, however, it is now moving on from technological to conceptual level. The main idea is that companies need to radically revise their strategies to successfully develop in unstable and turbulent business environment. The successful companies of today build their strategies on networking, partnership, resource sharing and knowledge overflow, not just compete individually for market advantages relying on their own resources, abilities and knowledge.

Thus, we can conclude, that the theory of ecosystem development is undergoing the stage of methodological formation.

II. Literature review

The concept of ecosystems is not well developed in modern science and is treated ambiguously. We should note that ecosystems have their peculiarities depending on the industry they are used in. V. A. Zaytsev tried to distinguish the concept of industrial ecosystem. He defines it as an interconnected network of companies and organizations in a region, which use side products, waste and energy [2]. When we analyze this definition we think that V.A. Zaytsev limits the scope of ecosystem to both the territory and the set of participants (actors). We believe that the ecosystem can include more diverse participants from different industries, of different structures and sizes. In certain instances even a state can be an actor, when it uses such form of partnership as state-private partnership, which is the partnership between a business and a state. It should be noted that V.A. Zaytsev considered the exchange of resources and cyclical use of products. Returning to the idea of diversity of ecosystem participants, we can presuppose that the greater the variety of actors an industrial ecosystem has, the more stable it is. This hypothesis is based on the natural ecosystem principles, where the variety of species is the underlying principle for its sustainability. G.B. Kleiner offered his concept of industrial ecosystems. He views them as stable socio-economic formations, which naturally combine the features of clusters, holdings, financial-industrial groups, techno parks and business incubators. Considering this definition, we understand that according to G.B. Kleiner, an ecosystem is a collective model for development, which combines the principles of different models [3]. As a result it is flexible and open, which allows transforming and adapting to constantly changing conditions. Jackson D.J. defines ecosystems as dynamic economic models of complex relations formed between the participants or organizations, whose functional aim is to develop technologies and innovations [5]. While agreeing with Jackson D.J., we believe that the main aim to form industrial ecosystems is to successfully implement innovative projects in the sphere of digitalization, technologies and new materials, which means to create an absolutely new value. An important and distinguishing feature of industrial ecosystems, being a development model, is the fact that a new value is created every instance the actors interact with each other.

For example, ISO 15704:2000 «Industrial automation systems» standard defines a system life cycle as stages of the process, comprising different system conditions, a finite set of common phases and stages that a system goes through during its life time [7]. Four main principles modelling a life cycle are described in the Standards:

- The system develops by going through different stages in its life cycle.
- The results planned for each stage can be achieved only if suitable enabling systems are available.
- Such attributes as manufacturability, user friendliness, serviceability, possibility to distance waste must be specified and realized at certain stages of lifecycle.
- Transition to another stage is possible only when the results planned for current stage have been achieved.

Another example is a typical model of lifecycle of the National Society of Professional Engineers (*NSPE)* [8]. This model is aimed at new product development, being the result of technological progress. According to NSPE model, lifecycle consists of six stages:

- Concept.
- Technical realization.
- Creation.
- Commercial validation and preproduction.
- Full-scale production.
- End product support.

According to the US Department of Defense, life cycle model of the logistics system management consists of five stages:

- Analysis.
- Technology development.
- Engineering and industrial development.
- Production and deployment.
- Functioning and support.

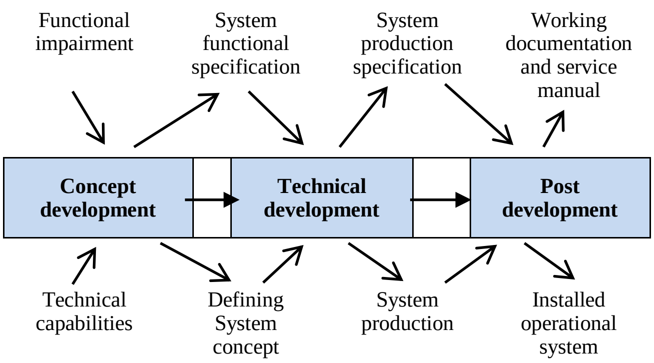

Fig. 1. Principal stages in the system life cycle (Kossiakoff, Sweet, Seymour, Biemer)

Another example of the system life cycle is Kossiakoff, Sweet, Seymour, Biemer model, shown on the figure 1. This model comprises three stages. The first two are developmental stages, the third is post development [9]. These stages show more general transition of the system from one condition to another, as well as changes in the type and the volume of actions.

II. METHODOLOGY

By ecosystem we mean:

1.microlevel — incudes projects related to the behavior of individual economic agents, that is, the actors of such an ecosystem are economic entities of one sector, as a rule;

2.mesolevel — includes cross sectoral projects, based on interactions between economic entities inside a particular sector or region;

3.macrolevel — includes national, supranational and economic entities [10], that is states can act as actors of such ecosystems.

Then, the projects implemented in ecosystems can be classified in two projections:

- ecosystem level;
- complexity of ecosystem structure that will depend on the number of actors, their scale, digital and intellectual potential (fig. 2).

It is important to note that innovativeness of projects, as a type of the interactions between the participants of economic market, is always associated with risks, particularly with risks in the field of economic security even though the relationship between ecosystem actors are based on the principles of cooperation and mutual benefits [11, 12]. In this regard, we analyze the possible risks of economic security for ecosystem participants at the macro-, micro- and meso-levels of the economy. Economic security is a comprehensive concept that can be analyzed at three levels: micro- — individual (company); meso- — enterprises, firms, business structures; macro- — the state, interstate relations and the global economy as a whole.

However, no matter what innovative types of relationships between market participants arise, to ensure the effective functioning of the ecosystem, it is necessary to begin the analysis of economic processes starting from the levels of individual economic units. Economic security risks for ecosystem participants at the micro level represent restrictions on legal protection, violation of legal rights and disclosure of confidential information. At the same time, not all actions that have negative results are considered a threat to economic security. There may be occasions when making risky management decisions to achieve the main goal of the company aimed at its further development are possible.

At the meso level, territorial and regional threats to economic security arise due to local specifics. These include, for example, such factors as socio-economic changes in the region's economy, changes or deficiencies in the regulatory framework, lack or insufficiency of financial support, changes in the level of investment activity, deterioration of the state of infrastructure, decrease in the competitiveness of intellectual resources, and force majeure factors associated with the manifestation of the elemental forces of nature and anthropogenic threats.

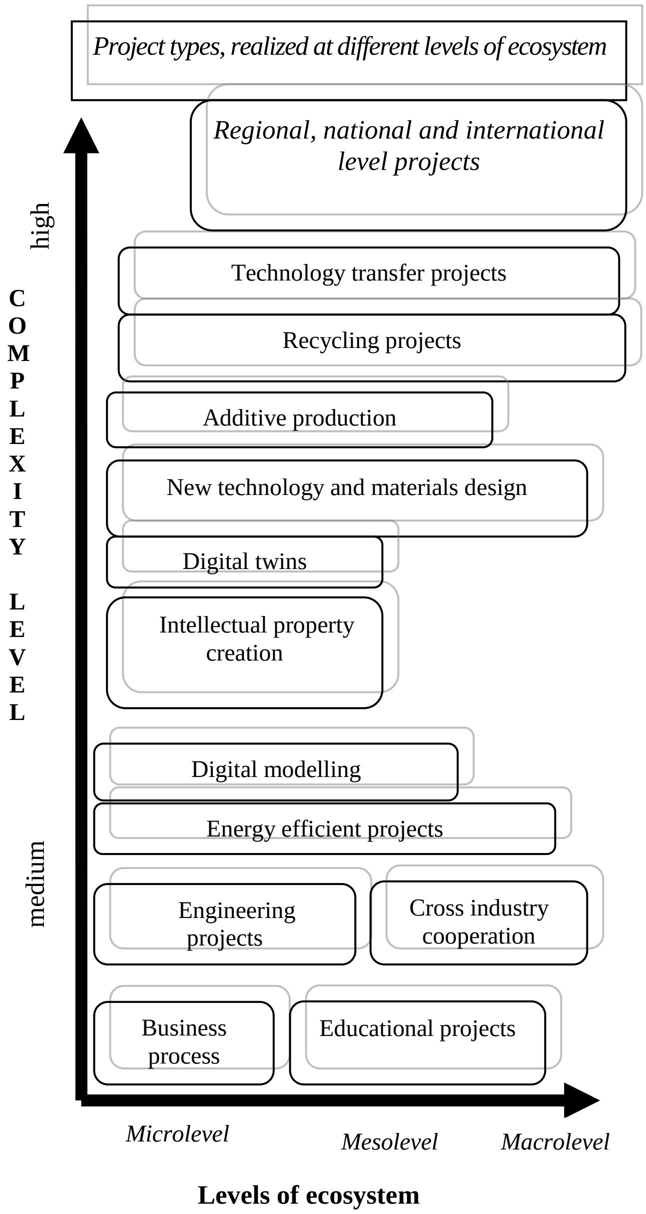

Fig. 2. Project classification based on ecosystem levels

Threats to economic security for ecosystem participants at the macro level are associated with a number of socio-economic, legislative, scientific, technical, informational and political factors. The socio-economic and legislative factors that pose threats to economic security for ecosystem participants include the following: rising inflation; the opacity of the financial system; changes in the demographic situation; rising unemployment; decrease in solvency; the imperfection of legislative norms, changes in tax rates or the emergence of new ones, etc. Scientific and technical factors of economic threats represent changes in the level of scientific and technical potential, including both technological and intellectual potentials [13]. Political factors include the difficulty in interaction and partnership with foreign partners. The information factors include the following:

- ensuring a positive image of the country;
- imperfection of state policy in regions;
- negative media activity.

All of the above threats to economic security for ecosystem participants contribute to the development and transformation of risk management methods. The risk management process, within the ecosystem, will allow participants to ensure the stable development of relationships that contribute to mutually beneficial profit.

We can formulate the basic principles of economic security risk management in an innovative ecosystem:

- informational transparency of all processes taking place in the ecosystem;
- partnership and cooperation based on trust;
- sharing best practices in risk management;
- corporatism and balance of interests;
- synergy of resources;
- a policy of employee motivation and training;
- customer focus;
- process orientation;
- ensuring the quality of the project at each stage;
- timely identification of new threats and communication of information.

Participants at various (micro-, macro-, meso-) levels can help organize a free flow of knowledge in the ecosystem by establishing links using formal and informal channels [15]. At the same time, integration is of utmost importance for various systems to interact with each other and create value from various data streams.

Our work also proposes a classification of principles for ecosystem actors who jointly implement the projects, as presented in Figure 3.

System formation principles		***Growth and development principles***		***Sustainability principles***
• network style of organizational design • collaboration • trust • transparency • corporate maturity of actors		• dynamism • openness • project orientation • customer focus • knowledge as the main source of exchange between actors • balance of goals and objectives		• diversity of actors • resource exchange • cyclicality • flexibility

Fig. 3. Classification of ecosystem principles (developed by authors)

The principles of system formation are the main ones. They support the integrity of the ecosystem and strengthen connections and communication. They include: network style organizational design, collaboration, trust, transparency, corporate maturity of actors [14]. In this paper, the above principles relate to the principles of system formation for the following reasons:

- Network style of organizational design defines the architecture of the entire ecosystem and reflects the relationships between its actors;
- Collaboration is a principle that determines the process of interaction between ecosystem actors;
- Trust is a fundamental principle that affects the speed and clarity of communication between actors, as well as enhances the rapid growth of connections and contributes to the high rate of system formation;
- Transparency is a principle that allows identifying communicational errors at an early stage and contributes to effective system formation;
- Corporate maturity — the absence of this principle creates risks at both levels: of actors and connections in the system, in other words, actors must be prepared to communicate according to the principles of the ecosystem approach.

The principles of growth and development are the driving force for the ecosystems development. They include: dynamism, openness, project orientation, customer focus, knowledge, as the main resource of exchange between actors, the balance of goals and objectives. In this paper, the above principles are identified as the principles of growth and development for the following reasons:

- Dynamism — is a principle that allows the ecosystem to find growth points at different periods in time, as well as change the dynamics and growth rate;
- Openness — due to this principle the ecosystem can quickly change the composition of actors, based on the development strategy in different time periods, which allows managing the growth of the ecosystem effectively;
- Project orientation — this principle allows actors to achieve a common target value, as well as to form development trends, based on portfolio projects currently implemented by the participants in ecosystems;
- Customer focus — defines the consumer as the main customer, identifies the correct interaction with the consumer, the ways to receive feedback; it allows changing the direction of project development in the ecosystem;
- The knowledge, as the main exchange resource between actors — this principle forms the correct resource base, which allows making correct plans in the ecosystem, as well as forming a strategy for growth and development;

- Balancing goals and objectives is the principle of effective project management within the ecosystem, which allows changing the priority of tasks as well as redistribute them among actors.

The principles of sustainability allow maintaining the viability of the ecosystem and effectively responding to external and internal challenges. These include: diversity of actors, resource exchange, cyclicality and flexibility. In the work, we attribute the above principles as principles of sustainability, for the following reasons:

- The diversity of actors is a principle that allows effective response to external and internal challenges, as well as effectively manage risks in the event of unforeseen changes, due to the variability of redistributed roles and efforts, and the diversification of actors;
- Resource exchange is a principle built on the active interaction of actors regarding the exchange of resources, it allows the ecosystem to survive when the inflow of external resources changes;
- Cyclicality is a principle that allows creating effective relationships, as well as developing algorithms that minimize errors, which is the most important factor in managing ecosystem sustainability;
- Flexibility is a principle that is built on effective transformation when either the external or internal environment is changing;

The distinguishing feature of the presented classification is that these principles are dynamic, they can move from one class to another, depending on the stage of the ecosystem's life cycle and its strategy.

III. NUST "MISIS"CASE STUDY AND ANALYSIS

The presented approaches and principles were used for projects implemented by scientific centers and laboratories of NUST "MISIS".

I. ***Ecosystem in the field of "Industrial design and technologies for the re-industrialization of the economy" with integrator NUST "MISiS".***

Project area 1 of the ecosystem. Creation of unmanned agricultural machinery and trucks for the mining industry:

- Creation of an online assessment system for testing computer vision algorithms, including datasets, in the following areas: optical flow, recognition of objects and pedestrians, image-based navigation;
- Creation of a national platform to aggregate real-time map data, automatically generated by on-board vehicle systems, to be used in unmanned vehicle map systems in order to accurately determine the position of an unmanned vehicle and the possible lane in the absence of a signal from global satellite navigation systems;
- Uncontrolled training of an unmanned vehicle control system based on automatic processing of data flow in massive neural networks, partially based on the approach of a cortical computational model of the brain.

Project area 2 of the ecosystem. Technology development projects to produce diamond-based products with increased productivity and durability for various industries: engineering, construction, exploration, etc. Implementation of projects is aimed at increasing the durability of galvanic diamond tools by 2–5 times, drilling and stone processing tools — by 1.3–2 times and the creation of an environmentally friendly integrated industrial technology for producing import-substituting diamond tools based on domestic materials, as well as technologies for creating special purpose tools.

Projects implemented by this ecosystem can be attributed to the following stages of the life cycle:

1. The project "Development of the technology for the production of highly efficient horizontal and directional drilling bits for the oil and gas industry" can be attributed to the stage "Transfer of knowledge and experience", as this project has been fully implemented and has already interested other customers.

2. The project "Creation of an engineering center for prototyping of high complexity" refers to the stage of "Adult life". The center has been created, but this project can not yet be attributed to be fully completed.

3. The project "Development of a high-security truck equipped with a software package based on millimeter-wave radar technology for the detection and classification of obstacles and other vehicles with the braking control function" is in the "Growing" stage.

4. The project "Development of laboratory technology for producing high-energy magnetically hard materials based on nanostructured alloys of the R-Fe-B system for high-performance permanent magnets using high-energy influences" has not yet left the "Birth" stage with problems arising from this stage. The ecosystem "Industrial Design and Technologies for the Reindustrialization of the Economy", is at the Operation and Maintenance stage, self-organizing processes searching for the optimal system configuration for adaptation to external and internal challenges.

Ecosystem in the field of "Materials and Technologies for Increasing Longevity and Quality of Life" with integrator of NUST "MISiS".

Project area 1 of the ecosystem. Nanotechnology development for targeted drug delivery in the treatment of diseases. The use of nanocarriers allows overcoming the limitations inherent in traditional treatment regimens for malignant neoplasms with chemotherapeutic drugs, including overcoming drug resistance of cells and reducing side effects and complications associated with the effect of chemotherapeutic drugs on all cells of the body due to the encapsulation of the drug into the carrier and its release inside the cell.

- Development of efficient and adaptable laboratory methods for the synthesis of new hybrid materials based on magnetic nanoparticles for the needs of biomedicine.

- "Development of porous composite materials modified with functional nanostructures for biomedical and structural applications "

Project area 2 of the ecosystem. Development of new systems for disease diagnosis. The creation of new test systems based on metal nanoparticles and their bioconjugates will reduce the cost, increase the efficiency and accuracy of diagnosis, which will make it possible to make prompt and personalized decisions about the treatment, which corresponds to the global trend of personalizing medicine.

- Physical methods, acousto-optical and laser equipment for the diagnosis and treatment of cancer

The ecosystem "Materials and Technologies for Increasing Longevity and Quality of Life" is at the stage of "development and establishment" (Build), as it is underdeveloped but strategically important in Russia.

V. Discussion and conclusion

The new paradigm for designing and modeling industrial ecosystems allows quick development and creation of globally competitive products of a new generation. The new paradigm is based on the transformation of the processes of interaction between economic agents and the construction of industrial ecosystems with high economic efficiency. At the same time, integration is of utmost importance, within the framework of which various systems interact with each other and create value from various data streams. The mechanisms responsible for this are complex and constantly evolving.

The effect of the ecosystem is manifested when technologies stimulate the transfer of knowledge in the business environment, and also lead to increased productivity within the company, in the supply chain and between industries, and to the sustainable development of each of the participants in the industrial ecosystem.

The use of the example of the MISiS National Research Technological University approaches to the implementation of the functions of an integrator of a cross-industry ecosystem as an "entry point" for generating new ideas, competencies, technological solutions, initiating projects for the development and testing of new technologies and products are shown. New formats for creating the necessary competencies for the industrial ecosystem are presented.

The theoretical significance of this article lies in the development of the emerging theory of ecosystems in terms of enhancing understanding of the processes of creating and sharing knowledge between actors at different stages of the life cycle. The practical significance of the research results lies in the possibility of using certain provisions in the practice of managing industrial enterprises, as well as in the development of program documents and strategies for the socio-economic development of the country and individual regions.

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