

FEDERAL STATE UNITARY ENTERPRISE «CENTRAL
AEROHYDRODYNAMIC INSTITUTE NAMED
AFTER PROF. N.E. ZHUKOVSKY»

As a manuscript

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METHODS OF INNOVATIVE TECHNOLOGIES MATURITY ASSESSMENT
TAKING INTO ACCOUNT THEIR SYSTEM INTEGRATION AND
ECOLOGICAL FACTORS BY EXAMPLE OF AIRCRAFT INDUSTRY

08.00.05 – Economics and National Economy Management
(Innovation management)

ANNOTATION OF THE DISSERTATION
for the degree of candidate of economic sciences

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Moscow 2020

The relevance of the research topic is related to the need of development new methods for managing the promising innovative projects (IP) implementation, taking into account their system integration and environmental impact assessment. Such projects are characterized by increased risks and require special approaches to managing their implementation.

Effective management of system of innovative technologies (SIT) readiness level is an urgent problem of the entire business process of IP development and implementation. In the end, the final commercial success of IP is largely depends on it. Effective management of system readiness level, along with additional methods for integrated support of the process of assessing the innovative technologies maturity, provides developers with the opportunity to identify potential difficulties in a timely manner and quickly make the most competent decisions that reduce the risk of financial losses. In the Russian science-consuming industries the process of introducing advanced project management methods in knowledge-intensive sectors of economy, in particular, methods for assessing technology readiness level (TRL) is underway. Their adaptation to the conditions of the Russian economy is a complex scientific and practical problem.

In the realities of modern global competition, the environmental excellence factor of new products can have a noticeable impact on the economic efficiency of socially significant IP. Therefore, environmental aspects need to be taken into account when assessing large IP, especially in knowledge-intensive sectors of economy affecting the environment. It is difficult to apply the traditional criteria of IP efficiency assessment, since even a technologically promising product may have negative environmental consequences after its implementation, or, in order to avoid such an outcome, undergo serious changes in the development process, which, in turn, can lead to additional financial costs.

An example of science-consuming industry in which the ecological factor plays an important role in assessing the efficiency of IP is aircraft engineering. The relevance of solving the environmental problems related to the activities of civil aviation is evidenced by various adopted international instruments, a number of

legislative initiatives, some projects, programs, protocols, conventions, agreements and reports of regulatory agencies that are valid at the international level.

Noise and harmful environmental emissions pollution result in various operational restrictions, penalties and airfield charges («environmental tax») that reduce airline profits and may make the future use of certain types of aircraft even unprofitable. In this regard, in knowledge-intensive sectors of economy, including civil aviation, it is objectively necessary to develop adequate methods for IP implementation management taking into account ecological factors. Thus, the development of a method for IP technologies maturity assessment, taking into account the «ecological readiness level», is an urgent scientific problem of great practical importance.

The degree of development of a scientific problem. One of the promising approaches to IP management is the modern methodology associated with the TRL method. The works of Bilbro J., Mankins J. and Nolte W. discussed the problems related to the correct determination of innovative technologies status, based on the proposed TRL expert and test methodology. The proposed methodology allows you to more efficiently, with less risk, manage the process of developing technological innovations. However, these studies did not address the problem of taking into account the influence of ecological factors on the efficiency of IP management already in the early stages of development, what is especially relevant when implementing large IP in science-consuming industries, for example in the civil aircraft construction industry. The dissertation developed an improved methodology for managing IP for the case of the introduction of socially significant scientific and technical IP that affect the environment. The improvement is based on the developed modified TRL system, which additionally introduced a special circuit – the ecological readiness level.

IP in knowledge-intensive industries, as a rule, rely on a large number of separate innovative technologies integrated into a single system. The works of Sauser B., Verma D., Ramirez-Marquez J., Gove R. and others are devoted to the SIT maturity assessment. Kujawsky E. noted the imperfection of the approach,

proposed in these works, namely, improper consideration of the impact of integration readiness level on the final value of entire system maturity level. In dissertation, it is proposed a new methodology for assessing the SIT maturity level, based on the introduced concept of the matrix of subsystem mutual integration included in the IP.

The purpose and objectives of the research. The purpose of the dissertation is to develop improved methods and techniques for assessing the readiness level of the product of innovation activity in knowledge-intensive sectors of the economy that significantly affect environment aspects, by way of example of the aircraft industry. Achieving this objective involves:

- to justify the need for further improvement of methods and techniques for research of innovative processes in knowledge-intensive industries; to propose, in addition to well-known TRL system new additional level of readiness «Ecology» and to improve the IP management methodology by the use of an expert and test approach to SIT assessment in relation to knowledge-intensive industries affecting environmental aspects;
- to develop methods and tools for assessing innovation results in knowledge-intensive sectors of the economy by developing an improved method for assessing the SIT maturity level, included in the IP, taking into account the readiness level of subsystems mutual integration; to identify additional tools for integrated SIT maturity assessment;
- to propose a conceptually new eco-innovative approach to the management of knowledge-based products with a long life cycle and with a significant environmental impact based on the improved TRL methodology;
- to assess the damage for public health caused by the emission of harmful substances and noise generated by aircraft; to identify the stimulating role of the «environmental tax» in the civil aviation innovative development;
- to justify the economic feasibility of applying the developed eco-innovative approach to the IP management on the specific example of the Russian aviation industry project for cryoplane aircraft creation.

Object and subject of research. The object of the research is knowledge-intensive industries that significantly affect environmental aspects. The subject of the research is the mechanisms for managing projects for the creation of innovative technologies and knowledge-based system products.

The theoretical basis of the research. The theoretical basis of the dissertation was monographs and scientific articles by domestic and foreign authors on the topic of the research.

The methodological basis of the research. In the process, the author used such methods of scientific research as systematic and logical approach, structural analysis, generalizations, the construction of mathematical models, the method of expert assessments, graphical analysis and forecasting.

The information base of the research was the materials of scientific and technical reports of the federal state unitary enterprise «Central aerohydrodynamic institute named after prof. N.E. Zhukovsky (TsAGI)», legislative and regulatory acts of the Russian Federation, data from the Federal State Statistics Service, the Ministry of Economic Development and Trade, the Ministry of Education and Science, the Russian Academy of Science, the United Nations, the International Monetary Fund, the World Intellectual Property Organization, as well as materials from Russian and international scientific conferences, seminars and symposia.

The research area is determined by the following paragraphs from the passport of the scientific specialty 08.00.05 «Economics and National Economy Management (Innovation Management)» of the Higher Attestation Commission of the Russian Ministry of Education and Science: 2.1. «Development of theoretical and methodological provisions of innovation; improvement of forms and methods of innovative processes research in economic systems; 2.15. «Research of drifts and means of development of new technological structure of economic systems»; 2.16. «Ensuring balanced development of innovation and investment activities of economic systems; 2.22. «Development of a methodology for a project management of innovative development of economic systems».

The validity and reliability of the research results is proved by the results discussion on the international scientific and practical conferences, by publications in the peer-reviewed scientific journals.

The scientific novelty of the research is as follows:

1. Development of a new additional ecological readiness level and formulation of the necessary requirements and evidence for it within the framework of expert and test methodology of IP management.

In the dissertation, as part of the improvement of the modern expert and test methodology for assessing the maturity of innovative technologies, included in IP, a new additional ecological level of readiness was developed. After successfully proving the correctness of the chosen concept and obtaining confirmation of critical functions and its characteristics (TRL3-TRL4), the author proposes and important stage of environmental and economic examination in order to determine the feasibility of further development of technology and preparation of the production line. The modified TRL scheme in this case has the following form:

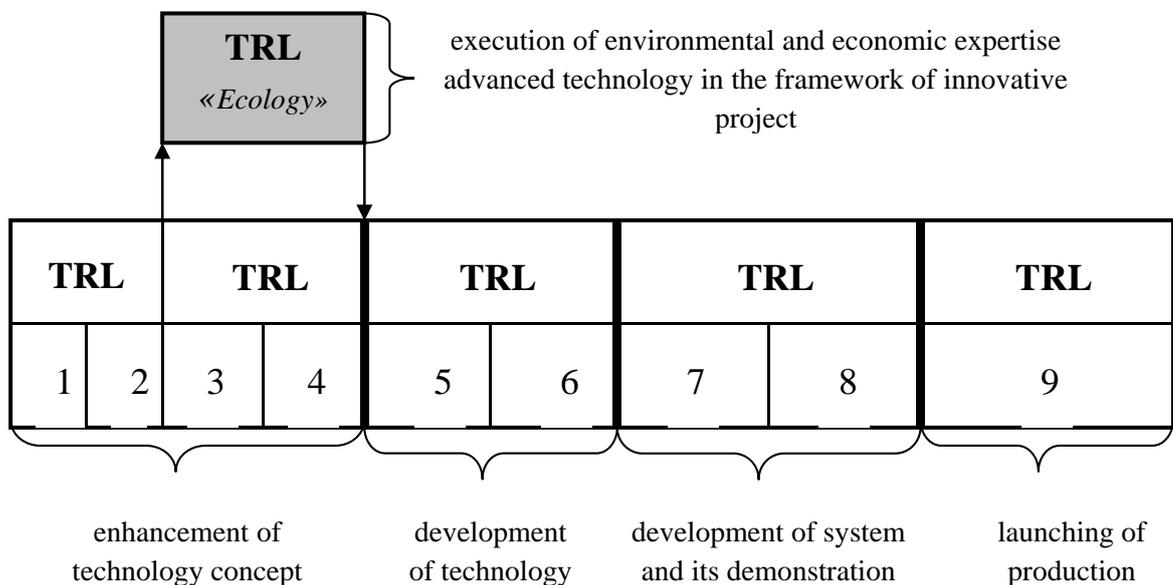


Fig. – The TRL chain taking into account environmental factors

2. Development of an author`s method of IP implementation risk management, based on SIT maturity levels calculation taking into account

the readiness levels of individual components and their integration based on the concept of a matrix of mutual integration introduced into consideration.

A system IP can consist of a set of subsystems that have reached a high level of readiness, but at the system level this set can be poorly integrated, and therefore the entire system can have a low level of readiness with high technical risk. The dissertation shows that the correct approach is to evaluate each subsystem separately, taking into account the possible benefits from their joint use. A new concept of a matrix of mutual integration of individual technologies was introduced and a unified formula for calculating the maturity level S of the entire system was obtained:

$$S = \frac{\sum_{i=1}^n \text{TRL}_i + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \alpha_{ij} \text{IRL}_{ij}}{n + m},$$

where n is the number of subsystems with TRL_i readiness level, m is a number of non-zero interconnections with IRL_{ij} integration readiness level. Note that the resulting formula takes into account both the readiness level of individual components of the system and the readiness levels of their mutual integration.

3. Development of universal procedure of the work of expert groups engaged in assessing the maturity levels of systems and their individual components within the framework of the overall methodology for IP management.

The dissertation proposes a procedure for the work of expert groups engaged in assessing the maturity level of individual innovative technologies, subsystems and entire final system. The practical value of the proposed new approach lies in the possibility of regulating the work of the expert groups on the assessment of technological maturity.

4. Development of a new eco-innovative approach to managing the creation of knowledge-based products that have a long life cycle and significantly affect environmental issues.

It has been found that for the knowledge-based products with a long life cycle, the innovative methodology of IP management («eco-innovative approach») is economically more justified than the traditional consistent approach, which does not take into account the possible influence of environmental factors in the early stages of development. It should be noted that the eco-innovative approach accumulates a larger amount of resources (which is more costly) at the design stage and at the beginning of the operation phase compared to the traditional approach. However, in the future it makes it possible to avoid high costs associated with trying to reduce the negative environmental impact during the subsequent operation and disposal phase.

5. Valuation of natural damage to public health from emission of harmful substances created by aircraft.

In the structure of integrated economic damage from environmental pollution, about half of the damage is occupied by public health. Its evaluation is a complex interdisciplinary problem. For that, it is necessary to define natural damage, which should be understood as the immediate negative social consequences, in particular, an increase in the incidence of the population. The work found that an increase in harmful emissions by 2,5% leads to an almost 0,7% increase in the number of respiratory diseases. Taking into account the data on the number of people in Russia exposed to this negative impact, it is obtained that the increase in the number of illness cases is approximately 20 thousand people. When assessing the economic damage from the increase in morbidity, the main parameter is the increase in additional costs for treatment, medical care, as well as payments from social insurance funds. An approximate calculation showed that the minimum annual damage for public health from harmful emissions could be about \$25 million.

Theoretical and practical significance of the research. The theoretical significance of the dissertation research consists in the development of an expert and test method for assessing the technology maturity levels of innovative technologies taking into account environmental restrictions, which allows reducing financial risks associated with the IP implementation in knowledge-intensive sectors of the economy that affect environmental aspects. The practical importance of the work is the development of a methodology for effective management of the development of innovative technologies in knowledge-intensive sectors of the economy, taking into account their integration into a whole system and environmental factors. The developed methods of TRL assessment and managing decision-making process on the IP implementation process, taking into account the impact on the environment can be used by the relevant scientific and industrial enterprises to compare the economic efficiency of IP and the feasibility of its implementation.

Testing the results of the research. The main provisions and results of the work are presented in 10 Russian periodicals from the list recommended by the Higher Attestation Commission, 1 article in publication included in the international bibliometric database Web of Science, 3 publications in other periodicals and 10 publications in the proceedings of international and national conferences.

The structure and volume of work. The dissertation consists of an introduction, three chapters and a conclusion, as well as a list of literature, including 187 titles. The total volume of work, taking into account the availability of 26 figures and 4 tables – 191 pages.