Failure Mode and Effects Analysis of the Consequences of the Life Cycle of the University Educational Services

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***Abstract*— The article deals with the issues of ensuring the quality of engineering education. An analysis of current trends in the quality of education through the implementation of formal and informal methods of quality management is presented. The short positions of application of the FMEA-analysis of the life cycle of the educational service are given. The analysis of literature and the scientific publications devoted to questions of risk management in the higher education are presented. Approaches to risk management in higher education institution are defined. The structural-component model of the process of "the provision of educational services" has been developed. The structuring of the educational process in accordance with the methodology is carried out.**

I. INTRODUCTION

The education system is an important component of modern society, which directly forms the quality of human capital. In addition, the quality of education directly affects the competitiveness of countries in the world community. The need of society, the economy, the state and employers to increase the requirements for the level of intellectual, moral and social development, as well as the professional training of university graduates, is the main driving force behind all innovations in higher education. In such conditions, the competitiveness of a university depends on the successful application of quality management requirements to its processes. The uncertainty factor reinforces this circumstance and necessitates the systematic management of risks that may arise at various stages of the educational process.

Today the problem of improving the quality of training of engineering personnel is receiving considerable attention not only from university leaders, but also from the leadership of countries. The main global trends in the field of guaranteeing the quality of education are reduced to the following provisions:

- development of common criteria and quality standards;
- creation, development and harmonization of national systems for accrediting educational programs with the European Community;
- development and implementation of quality management systems based on various models;
- the transition from external quality control procedures of the educational process and its results based on national certification and accreditation systems to the internal self-assessment of educational institutions, which, in turn, ensures the transfer of responsibility for quality directly to the educational institution.

Along with this, today there is no clear definition of the concept of the quality of engineering education. Each category of stakeholders (student, employer, parent, teacher) has its own understanding of quality. Thus, in the educational institution there is no single system-forming factor orienting all elements of the system towards the achievement of the main goal - ensuring the quality of education.

A comparative analysis of theory and practice has revealed the main trends in higher education: the transition to a knowledge society in new, unknown conditions of the digital economy; low competitiveness of the university in the world market, due, inter alia, to the mismatch of the measured quality indicators; increased pressure from social change and from the requirements of modern production and innovative processes [1-4].

This is relevant for the Russian Federation [5]. Global trends are realized in Russia through the modernization of Russian education, taking into account the full participation of Russia in the Bologna process, the implementation of state policy in the field of guaranteeing the quality of higher education and the creation of a mechanism for assessing education quality systems in universities.

The concept of universal quality management (TQM) requires a change in approach to the development of new products or services, since the question is not just maintaining a certain level of quality, but high customer

satisfaction [6-7]. In the case of higher education, we are talking not only about the quality of the services provided, but also about the damage to the state and society caused by a graduate who has finished a university but works not in the field of training. Therefore currently, there is an increasing interest in quality management systems (QMS) in all areas of activity, including education. The risk management is a special direction in the development of the QMS. The International Organization for Standardization has proposed an effective approach to risk management in the organization based on the consideration of the positive and negative consequences of risks. The standard provides guidance on the selection and application of systematic risk assessment methods.

II. THEORY AND RESEARCH METHODOLOGY

An analysis of the literature and scientific publications showed that today special attention is paid to risk management in higher education related to the quality training of specialists and the formation of relevant competencies. This is the study of A.Brochado [8], M. Huth, C.Vishik and R.Masucci [9], I.N.Mavrina and A.D. ingaleva [10], A.M.M. Mukaddes with colleagues [11] and others. There are studies on the use of failure mode and effects analysis (FMEA) for university risk studies. So, Andan K. Joshi and V.D.Kenchakkanavar from the Indian Institute of Management proposed using the FMEA method to improve the quality of engineering education. He proposed a methodology for determining RPN (priority number of risk) based on the probability of occurrence of risk, the significance of risk, and the complexity of detection using an example from a study at the Faculty of Engineering [12]. D.Albertivan with colleagues in their study show how failure analysis (FMEA) can be applied to education to identify different failure modes and its potential failure effect [13]. A group of researchers from Iran studied how to use the FMEA method to assess the quality of educational services at the University of Val-e-Asr in Rafsanjan [14].

Russian researchers also pay great attention to improving the quality of education. The most relevant for our study are the works of the authors on the problems of risk management in educational institutions, including universities: V.Ya. Dmitriev, T.P. Kostyukova, E.A. Opfer, M.A. Belyaeva, VYu.V. asilkov, L.S., Gushchina O.I. Chubarova etc. [15-18]. T. P. Kostyukova and I. A.Lysenko defined the structure of external and internal risks of the educational institution that affect the quality of education, described the risk management model, proposed the use of the “cost-break-even analysis” method [16]. N.Sh.Nikitin and P.E.Scheglov in their work identified potential risks that could negatively affect various stakeholders [17]. Opfer O. A., summarizing the existing risk classifications, identified and described the groups of external, internal and border risks of university when interacting with employers, the risks of teacher education in the context of the unification of universities, described the levels of managerial decision-making [18].

The research methodology includes the selection of the research object and research methods.

The objects of analysis in this study are: the processes of the quality management system, university projects, any other activity (research, extracurricular, etc.), as well as the environment and infrastructure in which this activity is carried out. The allocation of these groups of objects is made for the purposes of risk management in higher education on the basis of universities.

The research method is FMEA. The objectives of the implementation of FMEA: improving the quality of educational activities and increasing the competitiveness of the university, as well as increasing customer and stakeholder satisfaction. The PMEA method can be used in the evaluation of products (educational services, in this context) or process (the process of providing educational services) [19]. In contrast to the traditional FMEA approach, the authors propose conducting the FMEA educational services life cycle. This will save time on the analysis and help to avoid risks associated with the fact that the FMEA study of the service or the FMEA study of the process does not cover other phases of the life cycle of the educational service.

To conduct FMEA, a structural-component model of the process of “the provision of educational services” was developed. This model is a structural analogue of the

life cycle of educational services. The identification of the process structure will allow to determine in detail the points of risk, taking into account the implemented educational programs and quality management processes.

TABLE I.
STRUCTURAL-COMPONENT MODEL OF THE PROCESS OF "THE PROVISION OF EDUCATIONAL SERVICES"

Subprocesses	№	The elements of subprocesses
1.1 Student Admission	1.1.1	Search and attraction of consumers
	1.1.2	Organization of preparatory courses
	1.1.3	Organization of the selection committee
	1.1.4	Entrance examinations
	1.1.5	Student enrollment
	1.1.6	Registration of documents on admission
	1.1.7	Student Group Formation
1.2 Preparation of the educational process	1.2.1	Development of co-established standard
	1.2.2	Educational program development
	1.2.3	Development of methodological support for laboratory and practical work, as well as for course design
	1.2.4	The acquisition of the necessary educational literature
	1.2.5	Preparation of laboratory and experimental equipment
	1.2.6	Preparation of the classroom fund
	1.2.7	Calculation and distribution of the workload and staff of the scientific and pedagogical workers and the teaching and auxiliary personnel between the departments
1.3 Planning of educational and extracurricular (educational) processes	1.3.1	Providing an up-to-date curriculum
	1.3.2	Curriculum development
	1.3.3	Schedule development
	1.3.4	Load sharing between teachers
	1.3.5	Filling in individual teacher plans, approval
	1.3.6	Planning and organization of extracurricular activities
1.4 Conducting training sessions	1.4.1	Lesson planning
	1.4.2	Class organization
	1.4.3	Organization of feedback with students
	1.4.4	Development of improvement measures and correct actions
	1.4.5	Improving lecture material
1.5 Certification in disciplines (modules)	1.5.1	Certification Preparation
	1.5.2	Certification
	1.5.3	Improving valuation tools
1.6 Organization and conduct of practice	1.6.1	Practice planning
	1.6.2	Distribution of letters to enterprises
	1.6.3	Student distribution by enterprises
	1.6.4	Practice Report Monitoring
1.7 Conducting state final certification	1.7.1	Preparation for final certification
	1.7.2	Updating of materials on state final certification and state exam
	1.7.3	Certification
	1.7.4	Improving valuation tools
1.8 Development of new educational services	1.8.1	Decision-making on opening a new direction of training (specialty)
	1.8.2	Applying to the Licensing and Accreditation Department
	1.8.3	Planning the development of a new educational program
	1.8.4	Development of a new educational program
	1.8.5	Licensing of a new direction of training (specialty)
	1.8.6	Accreditation of a new direction of training (specialty)
	1.8.7	Improving existing educational services
1.9 Customer Satisfaction Rating	1.9.1	Questionnaire development
	1.9.2	Updating the methodology for assessing satisfaction
	1.9.3	Newsletter profiles
	1.9.4	Collection and analysis of profiles
	1.9.5	Satisfaction Index Calculation
	1.9.6	Reporting to senior management

Structuring the process allows you to take into account the largest number of all elements, as a result of which various

inconsistencies and risks may appear. As some authors note, the border between the concepts of “inconsistency” and “risk” is rather narrow, therefore, conclusions should be carefully made when formulating the risk [15]. When structuring the main process, subprocesses (total 9) and its elements (from 3 to 7) are distinguished. The structural-component model of the process of “the provision of educational services” is presented in Table 1.

An analysis of educational activities based on the FMEA method was carried out on the basis of the Perm National Research Polytechnic University (PNIPU). The quality system of the university was identified as the main element of the analysis. The quality system of the university is certified in accordance with the requirements of ISO 9001: 2015.

Russian national standards (GOST R) were also used as a source of information. They contain about twenty documents on risk management, among which it is worth noting quite universal, the provisions of which can be applied “non-standard”, for example, in the field of education [24].

III. Research and results

At present, advanced universities determine and shape modern views on the quality of education. The quality of engineering education is a multidimensional concept and largely depends on the consumer himself, the direct participant in educational activity is the student. It is important for national research universities how well its graduates are prepared. Current trends dictate the use of formal and informal models, methods, means and tools to improve the quality of engineering education. Formal quality management methods include certification of a university's quality management system for compliance with the requirements of the international standard ISO 9001 [3-4]. But no less important is the use of non-traditional tools, such as lean manufacturing methods, strategic cards, Taguchi methods, “simple” quality management tools, “complex” quality management tools (FMEA analysis), etc. [20].

While analyzing the process of "the provision of educational services" using the FMEA method, the following tasks are solved:

- obtaining information about the risk of various process options
- identify the “weaknesses” of the process and measures to overcome them
- reducing the volume of experimental-technological work
- identify opportunities for improvement;
- ensuring the visibility (transparency) of the actions of specialists in ensuring quality
- change in the quality content of labor of process developers
- ensuring a favorable environment for cooperation in the implementation of the process

The process of applying the FMEA of the life cycle of an educational service includes the following steps:

1. Formation of a team of analysts, which includes practical specialists in the stages of the life cycle of educational services.
2. Identification of all processes, subprocesses and elements that are entered in a special form for FMEA analysis. To do this, an additional column is entered in the form, in which the code of the phase of the life cycle of the educational service is indicated, for which (phase) the FMEA analysis will be carried out.
3. Analysis and formulation of conclusions.

The FMEA methodology involves calculating the priority risk factor Kr. We made a modification of this indicator and offer to calculate Kr as a product of Kp, Ko and Kn, where:

Kp – coefficient taking into account the value of the consequences of non-compliance for the consumer (the severity of the consequences of manifestation of the causes of non-compliance);

Ko – coefficient taking into account the probability of occurrence of discrepancies (causes of discrepancies);

Kn – coefficient taking into account the probability of non-detection of non-compliance or its cause before the consequences of non-compliance (failure) directly from the consumer.

The coefficient Kp is calculated based on the results of a survey of consumers and other interested parties on the questionnaire "Identifying the importance of the consequences of risks", i.e. covers the phase of "customer satisfaction assessment".

The coefficient Ko is calculated by the formula, which includes quality indicators at the following phases of the educational service life cycle: student enrollment; preparation of the educational process; planning of the educational process; conducting training sessions; development of new educational services.

The coefficient Kn is calculated according to a formula that takes into account the control phases of the life cycle: certification by disciplines (modules), conducting final certification, other types of control for the study period.

The values of Kp, Ko and Kn vary from 1 to 10.

The full FMEA of the life cycle of educational services is currently being conducted on the basis of PNIPU and covers 9 sub-processes (phases), 46 operations (elements). As a result of risk analysis and assessment, it will be possible to identify the most dangerous risks and the consequences of their impact, and the developed measures to reduce the level of danger will significantly reduce the value of the priority risk coefficient [21].

Risks may affect a separate process, subprocesses and elements of a subprocess, as well as other activities at the university. Different types of risks can be interconnected with each other. In this case, a situation may arise that the occurrence of one risk will increase the likelihood of other risks. When the process is divided into components, the task of assessing the need for FMEA for individual elements arises. This problem is solved on the basis of ranking the criteria for conducting FMEA. Table 2 shows an example of such a ranking based on an analysis of the training of engineers in PNIPU. To this end, an expert

commission was set up at the university (a group of experts for conducting FMEA), whose members rated the criteria for each subprocess. The selection of ratings is as follows:

- if the characteristic of the criterion is found especially often, then put a rating of 2
- the characteristic is infrequent - rating 1
- characteristic not found - score 0

TABLE II.
DETERMINING THE SEQUENCE OF ANALYSIS OF SUBPROCESSES

Criteria	Subprocess number (see table 1)								
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
1	2	3	4	5	6	7	8	9	10
FMEA Product Requirements	1	2	2	2	2	2	2	2	1
Customer requirements	2	2	2	2	1	2	1	2	2
Requirements of the federal state educational standard	1	2	2	2	1	2	2	1	1
Stakeholder requirements	2	1	1	2	1	2	2	2	2
Requirements for the use of modern technology	2	1	1	2	1	2	2	2	1
Requirements for the scientific and pedagogical workers and the teaching and auxiliary personnel	1	2	2	2	2	2	2	2	1
Requirements for the use of modern equipment	1	1	1	2	2	2	2	1	1
Environmental safety requirements for process operation	1	1	0	1	1	1	1	0	0
Availability of critical indicators	1	2	0	2	2	0	2	2	1
Sum of ratings	12	14	11	17	13	15	16	14	10

The sequence of analysis is identified according to the results of work on the estimates. Based on the results of the study and expert assessment, the following analysis procedure was determined Fig.1

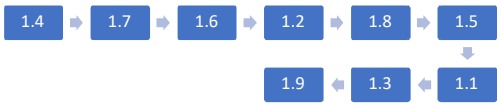

Figure 1. The sequence of FMEA on the main subprocesses of the process of "providing educational services"

As can be seen from Fig. 1, in our example, the analysis should begin with subprocess 1.4 ("conducting training sessions"), then proceed to assess subprocess 1.7 ("conducting state final certification"), etc. The analysis ends with the evaluation of subprocess 1.9 - "customer satisfaction assessment" [22].

A special list of criteria for evaluating the process of "providing educational services" has been developed. These are the following criteria.

1. Requirements of the FMEA analysis - during the FMEA analysis, the characteristics of the process are taken into account.
2. Consumer requirements - the degree of influence of consumer requirements in the process under consideration is assessed.
3. GEF requirements - takes into account the degree of influence established by the GEF requirements in the process under consideration.
4. Requirements of interested parties (state, employer) - the degree of influence of the requirements of interested parties in the process under consideration is assessed.
5. Requirements for the use of modern technologies - the degree of acceptability of the applied modern technologies in the process under study is assessed.
6. Requirements for research and development work and management - assesses the degree of influence of the quality of work in the study process.
7. Requirements for the use of modern equipment - the degree of acceptability of the use of new equipment in the process under study is assessed.
8. Requirements for the safety of the environment for the functioning of processes - the degree of influence of existing conditions and infrastructure on the implementation of the process under study is evaluated.
9. The presence of critical indicators - if critical indicators exist in the subprocess, this can lead to disruption of the functioning of the whole process.

Also, risk management principles were developed at each level of the "educational services" process. The main principles include the following.

1. Value-targeted principle. Identification and assessment of risks with a view to their relevance to the university's target indicators will help to prevent / minimize strategic risks in time (for example, risks affecting quality goals).
2. Sufficiency principle. It is necessary to ensure the sufficiency of resources at the university to ensure the normal process of risk management in the field of education, research, extracurricular, experimental design and other activities. This principle also manifests itself in the fact that risk managers have been appointed.
3. The principle of performance. It means the need for a systematic collection and analysis of information on the effectiveness of risk management.

As a result of the systematic conduct of the FMEA, corrective measures are developed, and the effectiveness of measures related to risks and their consequences is analyzed directly by the person responsible for quality. Continuous FMEA and monitoring of the quality of education system allow us to accumulate data for a number of years and provide a more reliable analysis of the quality of training of specialist engineers in accordance with modern economic requirements [23].

IV. CONCLUSIONS

A comparative analysis of theory and practice has revealed the main trends in higher education: the transition to a knowledge society in new, unknown conditions of the digital economy; low competitiveness of the university in the world market, due, inter alia, to the mismatch of the measured quality indicators; increased pressure from social change. The revealed contradiction allows us to formulate an urgent task, which consists in the scientific justification and development of a methodology for analyzing and assessing the risks of the life cycle of educational activity by implementing a management mechanism based on FMEA analysis.

The paper presents a structural-component model of the process of "the provision of educational services", which is a structural analogue of the life cycle of educational services. The identification of the process structure will allow to determine in detail the points of risk, taking into

account the implemented educational programs and quality management processes.

Serious work is needed to increase the importance of the profession of an engineer, his business culture, and professional competencies for a general improvement in the quality of educational services in engineering universities. The use of special technologies for the development and analysis of risks in the field of education allows us to ensure a high degree of taking into account the requirements of employers and other interested parties as a training for modern engineers.

In the course of the study, it was proved that the application adapted to Russian conditions

Firstly, it is the possibility of proactively identifying the "weaknesses" of the current educational process at each phase of the life cycle of the educational service and developing measures to prevent or overcome them.

Secondly, it is obtaining information about the risk of alternative options for the provision of educational services.

Thirdly, this is the identification of opportunities to improve the quality of educational activities; increasing the responsibility of developers for the quality of their activities, preparing an empirical base for the application of analytical and statistical methods for managing the quality of educational processes.

Fourth, this is a reduction in the number of experiments on the introduction of new educational programs and services, the identification of shortcomings in new developments.

Thus, the application of the analysis will be continued and supplemented by further studies of risks in the field of education, primarily while working in the international market for educational services and expanding work with foreign students.

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