Economic Model for Assessing the Return on Investments in Structural Health Monitoring Systems

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Abstract: *Purpose*: The purpose of this article is the description of the approach to the economic assessment of a highly-effective system for state monitoring of structures ensuring an increase in safety and economic efficiency for utilization of complex engineering structures and buildings considering all existing risks.

Design/Methodology/Approach: The essence of the approach is in obtaining the state control data of these structures and buildings from sensors, which detect hidden damages and cracks, monitor consequences of shocks, corrosion, tension, and overheating.

Findings: All the collected data make up the predictive analysis using artificial intelligence, which can and must analyze this data in real-time mode.

Practical Implications: Such a way for monitoring allows for assessing the state of the structures and repairing or replacing them before the critical moments occur, thus significantly reducing the cost of servicing data from complex engineering objects, as well as it ensures their reliability and safety. Digitalization should be introduced in all of the industrial sectors, including aviation, where effectiveness, reliability, and safety are closely interconnected.

Originality/Value: Thanks to the development of the state monitoring systems and the economic efficiency of their use in critical structures, the possibility, and intensiveness of their improvement are growing. This has great value and pushes modern productions forward.

Keywords: Operation of aviation equipment, construction facilities, economical efficiency, product lifecycle cost, condition-based operation, structural health monitoring systems.

1. INTRODUCTION

The development of international economic policy in the last decade has forced our country to build up national production of a wide range of products with characteristics that are not inferior or superior to the world level. This is a unique opportunity to realize a new technical level of the production facilities being built up with the introduction of the most advanced technologies and systems of automation and control, including structural health monitoring systems, eventually intended not to accumulate a huge amount of data but based on these data to issue remaining lifetime assessments and recommendations on the conditions of operation, repair or decommissioning of critical facilities. The solution to these problems is particularly connected with the development of intelligent systems of artificial intellect and data collection systems on the state-of-health of responsible structures. In their turn, intellectual systems of artificial intellect provide safety and reliability of objects' functioning, further improvement of technical and functional characteristics of products, and cost reduction relating to the operation or elimination of failure effects.

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2. LITERATURE REVIEW

The market of monitoring systems is formed already more than 20 years at the intersection of the markets of non-destructive testing and the industrial Internet. The rapid development of communication and data transmission systems, as well as the composite materials industry, has led to the emergence of new, powerful in terms of volume and dynamics segments related to all aspects of data processing, storage, and analysis. The sources of monitoring systems market growth are the development of products in the following adjacent markets: microelectronics, nanotechnology (nanosensors with $133 million volume of sales in 2017 and compound annual growth rate (CAGR) of 80% with $4.6 billion volume of sales in 2023) and photonics. These markets stimulate the emergence of new high-sensitivity, miniature, and multifunctional sensors, as well as data collection systems from these sensors; industrial Internet and Internet of Things which provide the development of data transmission systems with high speed and performance; big data which provide the development of storage systems for huge volumes of stream data concerning the structural health and influencing factors; and artificial intelligence which provides for predictive analysis tools of big data. Implicit, but the important factor of growth of the monitoring systems market is caused by the

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development of the composite materials industry. The "explosive" (hard-to-predict) character of the destruction of composite materials is predetermined by their very long history at all stages of the product life cycle – from production to materials storage, assembly, and operation of structures.

According to the report by MarketsandMarkets™ in 2017, sales volumes in the global market of structural health monitoring (SHM) systems amounted to $1.24 billion with a forecast growth to $3.38 billion by 2023 (CAGR 17.93% between 2018 and 2023). In 2018, the market volume was $1.48 billion.

The trend of the market structure is the decrease (from 61% to 53% in 2023) of the equipment share and the increase of the services share (up to 21%) and software share (up to 26% in 2023). The wireless monitoring systems segment (the forecast of growth is from 37% in 2016 to 45% in 2023) displaces products in the wired systems segment, specifically as a result of the elimination of cable systems and services for their installation, as well as price dumping of products in the wired systems segment.

Areas of monitoring systems application are civil engineering (bridges are the main market, as well as dams, tunnels, highways, and buildings) with 60% share of the market and $2.5 billion volume of sales in 2023 and growth rate of 18.7%; aerospace industry with $572 million volume of sales and growth rate of 21.2%; defence industry with $258 million volume of sales and growth rate of 19.8%; energy production and mining with $259 million volume of sales and growth rate of 18.1%; wind power engineering and marine energy with $175 million volume of sales; and other industries (mechanical engineering, automotive industry, shipbuilding, and transport).

Technological barriers to monitoring systems are identified by existing challenges that need to be overcome for further development and growth of the market:

1) Price barriers: the high price of sensors and their installation, depending, among other things, on the type and design of sensors as well as availability;

2) Measurement system: energy independence, sensor lifetime, amplifiers for remote element monitoring systems, and the need for accurate synchronization of various sensors;

3) Data analysis: the large volume of heterogeneous data, poor communication, storage systems, and data transmission.

In this regard, in the medium-term perspective, the target directions (trends) of adjacent markets development determine the shape of the future product on the market of monitoring systems, whose architecture today represents a complex composition of the following components:

- Universal platform for data collection from sensors of different architectures and manufacturers;
- Data transmission using 5G wireless technology;
- Intellectualization of data collection systems and sensors by transferring initial processing functions (filtering and preliminary analysis) to them;
- Further decrease in the mass dimensional characteristics of the sensors relative to the "volume" of the monitored structure and extension of the functionality (the measurement of different types of data by one device);
- Expansion of the analyzed data spectrum through integration with data collected by manufacturing systems (manufacturing process data at different stages of the product life cycle and test data);
- Expansion of operational capabilities through the access to data and the results of their processing with the help of personalized devices (such as a notebook or smartphone) and application of technologies of "cloud-based" platforms;
- Increase of predictive abilities of software tools for the analysis of the collected data due to the development of artificial intelligence systems;
- Production technologies for manufacturing new and composite materials and structures with integrated sensors of their condition, "hinged" sensor-based systems.

To ensure the advanced development of domestic monitoring systems, it is necessary to develop technical solutions in all the above-mentioned areas. Priority efforts should be made in those areas where the highest market response (demand) is expected and in which Russia has significant competencies. First of all, these competencies have been and exist in academic, high-tech, and engineering knowledge areas such as mathematical science, strength calculations, system and mathematical programming, and materials science, including the field of composite materials.

Aviation and construction industries are considered as key industries. The aviation industry is one of the most high-tech industries, where both the weight efficiency of an airframe and operating costs come to the foreground. Optimization of maintenance procedures is required to reduce operating costs, which is achieved by the introduction of preventive maintenance procedures. The construction industry is characterized by a long service life and a significant housing stock in operation.

"The Strategy for the Environmental Safety of the Russian Federation until 2025" (President of Russia, 2017), as the main challenges, besides the existing facilities of accumulated environmental damage, lists technology-related risks associated with a high wear degree of fixed assets of production facilities and insufficiently rapid modernization of these assets.

The central document covering the necessity of transition to new digital technologies in all spheres of state activity is the National Project "Digital Economy of the Russian Federation". A separate block of tasks within the framework of this project specifies the introduction of digital technologies and technologies of industrial "Internet of Things" in the activities of private businesses and government companies working with complex systems. The national project is intended to stimulate the development of the regulatory environment for the formalization of intellectual property relations. A separate objective has been set to create a universal digital platform for the monitoring of energy resources of state and municipal facilities, as well as to implement Smart City technologies.

Another important platform for the support and diffusion of high-tech products and solutions, which are expected to determine the structure and quality of the world economy in the near future, is the National Technology Initiative (STI) (n.d.). The STI brings together representatives of companies and leaders of high-tech markets into communities to discuss and create road maps for the development of these industries. Among the innovative markets identified by the STI, there are:

- AutoNet. It is the market that combines solutions to create smart vehicles and smart transportation and logistics services for people and companies. Consolidation and analysis of data in these areas will help to minimize wear of vehicles and infrastructure, time expenditures, expenses for storage of goods in warehouses, as well as to optimize costs in advance and minimize risks associated with untimely maintenance or repair of infrastructure or transport facilities;

- EnergyNet. This market combines efficiency growth technologies in traditional energy sectors, development of technologies related to renewable energy sources, distributed energy, smart grids, and devices;

- TechNet. It is a market of design, consulting, and educational services in the field of selection and application of digital and intelligent technologies to create high-tech manufacturing facilities;

- SafeNet. It is a set of companies and technologies in the field of cybersecurity.

The need for technical re-equipment and modernization of production equipment and infrastructure can be indicated in national projects and sector strategies. For example, according to the National Project "Safe and Quality Roads" (TASS, 2019), the proportion of urban and regional roads in the standard condition is 43%. Within the framework of the project here is also a challenge to equip 60 routes of regional importance and 120 routes of federal importance with elements of intelligent transport systems by 2024.

To reduce the cost of transition to the new model of the economy, Russia must increase the efficiency of resource use, and this is possible thanks to the development of technologies and the introduction of innovations (Shtiller *et al.,* 2018).

The possibilities of digitalization for optimizing transport and logistics chains can hardly be overestimated. These include the use of unmanned transport, minimizing transport costs and resource losses by forecasting demand based on analysis of large volumes of data, transport sharing - car sharing and carpooling, and much more. Taking into account the projected growth in demand for transport services in developing countries, such optimization is important not only for optimizing the time and resource costs of enterprises using transport services but also for slowing down the wear of transport infrastructure. Digitalization can also solve the problem of monitoring the aging infrastructure condition. Such pilot projects are taken over by the leading players in the market of information and communication technologies and consulting, as demonstrated in the paper (O'Shea, 2019).

One of the stages of digitization also includes increasing the informative value of operation facilities and managing processes of their maintenance. As part of this area, the volume of information collected and the development of forecasting methods should be significantly expanded. The condition-based operation approach allows for the significant reduction of operating costs while maintaining the required safety level and increasing it in the future through the development of mechanisms for predicting the behavior of the object under investigation.

Examples of the safe operation approach development are life-cycle contracts, which involve the purchase of working hours rather than the object of the operation itself. The development of such an approach is impossible without the introduction of a permanent system for key indicators monitoring and forecasting, because otherwise, the risks of equipment failure are too great, which makes such contracts ineffective for suppliers.

3. MATERIALS AND METHODS

In the modern global economy, information technologies are not only the basis for economic development in many countries of the world but also qualitatively improve people's lives. While many countries still make a profit from physical infrastructure investments, electronic infrastructure investments have a stronger positive impact on job creation (Jelnova, 2013; Minakova and Anikanov, 2013; Saleh *et al.,* 2020).

The G20 countries invest over a trillion dollars annually in construction and machinery manufacturing. The main types of investment projects were the construction of broadband highways and highway-over crossings, the development of intellectual machine-building, and intellectual non-destructive testing technologies. Between 2003 and 2017, about 200 billion dollars were invested in aviation development projects in the United States, which enabled to profit the same 200 billion from additional sales, first of all to Asian countries.

To have the most complete picture of investments in machine building and instrument manufacture, it is necessary to consider the structure of investments in foreign countries. Thus, in the structure of China's investment, investment in this area constitutes 35% of all investments. According to data for 2017, China is the most active investor in this area.

According to the Treasury Board of Canada, this country has a wide range of investments in machine building, instrument manufacture, and IT (hereinafter referred to as MIIT). 1.7 billion dollars have been allocated for fundamental research in the IT area; 790 million dollars have been invested in instrument manufacture and IT; 205 million dollars have been invested in the general development of robotization.

France's priorities in the areas of MIIT are aviation ($13 billion for 2003-2017) and intelligent management systems ($4.13 billion).

Germany annually invests 58 billion dollars (2008-2017) in the development of MIIT. This program requires full country coverage.

Japan at the moment is an especially highly developed country. However, the country's leadership has decided to continuously invest in the development of technical infrastructure and artificial intelligence. Mostly all investments in the MIIT sector are made by business entities and partnerships supported by grants from the government (Vasileva and Fedorova, 2011). Total investment in Japan's sector is $122 billion, and this investment covers all kinds of projects in this area.

Saudi Arabia has invested $2.1 billion in the development of science and technology.

South Korea is allocating $22.7 billion in investments for the development of machine building and instrument manufacture based on "green systems". This program has received this name because it implies the development of intellectual energy and the transport system.

The United States invests $41 billion annually in areas closely related to MIIT.

Having analyzed the investment structure of the countries under consideration, it is possible to conclude that the most active investments abroad are made in the improvement of information and technological infrastructure of machine building. It gives the chance to more rapidly develop innovative projects capable to provide a considerable increase in GDP.

Considering basic methodologies of formation of the accounting and analytical support in the management of projects in the sphere of MIIT, it is possible to conclude that in this case, it is a question not only of a quite certain volume of works with the beforehand known result. This has focused on a kind of innovative project, in which various methodologies based on specially developed libraries of electronic algorithms and software and hardware complexes are used. In general, MIIT projects should be seen as transforming potential scientific and technological progress into real, representing completely new technologies for processing materials and information to achieve a significant economic effect of the transition from routine maintenance to predictive operation.

Expenses associated with the development of the structural health monitoring system and electronic passport of complex engineering products using artificial intelligence algorithms for the benefit of the aircraft building and construction complex directly depend on the time of the development itself (the range between the beginning and the end of planned activities). Thus, in the reporting year of development completion, the expenses of this year and the expenses of previous years, which form the common cost of design and development of the software and hardware complex, are taken into account.

The following indicators are used to manage the cost efficiency of software and hardware complex development:

- Expenditures related to research and development;
- Integral costs associated with the development of the product itself;
- Income from the distribution and sale of the MIIT product;
- The estimated value of intangible fixed assets on average for the period;
- The value of fixed assets on average for the period;
- Net income, taking into account discounting;
- The average number of staff.

Today the interweaving of machine building and software and hardware complexes is of great interest to investors. Investments in information technologies of machine building and construction continue to be profitable regardless of the situation on the stock market. The Russian market has one of the biggest capabilities in the world.

The national geospatial feature of Russian developments is such that at the beginning complex small series software and hardware systems of complex technical products are developed in aviation, rocket, and space equipment (it is the policy of the largest corporations such as Roskosmos and Rostekh state corporations). After that, new technologies penetrate the mass cheaper segment, and the rate of technology transmission is growing in all industries. The prospects for development are very great, especially for systems of structural health monitoring of complex technical products. Compared to the end of the first decade of the XXI century, the penetration rate in Russia has increased by more than 30%. At the same time, hardware and software systems are gaining popularity in machine building and construction.

The most promising for investments is the transition from routine to predictive operation, first of all, oriented on the introduction of structural health monitoring systems and electronic passport of complex technical products with the use of artificial intelligence. Until now, there is superiority in the direction of sales of specialized equipment. However, due to the saturation of the infrastructure market, the demand for residual resource forecasting services will increase in the near future, and the structure of both Russian and world markets will change.

To avoid the problems faced by the new Russia in its transition from planned to the market economy (namely, the problems of underdevelopment of financing mechanisms, high exposure to risks, and low level of investment activity), especially in the field of MIIT, it is necessary to apply a systematic approach to investment.

Today the main feature of investments is their efficiency. The system approach used allows for a new look at the assessment process of return on investment in the area of MIIT.

The cost-effectiveness analysis of the MIIT seems to be a rather complicated process. Until the mid-1980s, there was a paradox of economic efficiency of the MIIT, associated with the fact that large investments in civil MIIT did not pay off, which resulted in subsequent denial of their funding. However, the transition to world standards and awareness of real possibilities of software and hardware complexes significantly changed the situation in favor of informatization and investment in the MIIT. These studies have shown that technology in the MIIT sectors is much more efficient than in any other investment project.

Investments are always accompanied by risks. Therefore, an investor should always know what he is doing, what all possible risks are, and how to avoid them. Thus, the concepts of risk and investment returns in the entrepreneurial activity of an investor are strongly interconnected.

For investment risk analysis, methods are used that can be divided into two groups: qualitative and quantitative.

The main objective of qualitative analysis is to identify all types and forms of risks. The main objective of quantitative analysis is the numerical measurement of the probability of occurrence and the degree of influence of changes in risk factors of the project, tested for the risk, and the behavior of the project performance criteria.

There are several approaches to project risk analysis. For identification, ranking, and qualitative assessment of risks at the initial stages of design, the expert assessment method is used. This approach is based on the use of a complex of logical and mathematical-and-statistical methods used by the expert. The main disadvantage of this method is the subjectivity of assessment and dependence on the qualification of the expert, which may become one of the main advantages in case of high professionalism and experience of the expert.

The most common methods of expert assessment are SWOT-analysis, the rose (star), and a spiral of risks.

The analog method is used when assessing the risks of often-repeated projects. This method is based on risk assessment of already completed projects and allows for taking into account the potential risk of new projects.

For additional consideration of risk factors, the risk-adjusted interest rate method is used in calculating the project's effectiveness. In this case, the risk-free interest rate increases by the amount of the risk premium. The market risk premium is estimated based on past and forecasted rates of short-term government bonds using statistical packages.

The Critical Values Approach is used to monitor risks in the process of project management under conditions of risk and uncertainty. With this method, the value of risk factors or project parameters is determined, which bring the calculated value of the corresponding project performance criterion to a critical limit.

Quantitative risk analysis includes modeling the selection task with the help of a "decision tree" for project management and risk analysis of the virtual project. The method is based on statistical decision making based on one of the alternatives, using complex probability distributions.

In the quantitative analysis of criteria indicators of behavior in the event of a change in one risk factor, a sensitivity analysis is used; in the event of a change in the spectrum of risk factors a scenario approach is used. A statistical approach is used to quantify the risks of multiple projects or multiple variants of one project, based on the use of numerical values of dispersion indexes and standard deviation.

The assessment of the investment project efficiency obtained as a result of the analysis can be considered reliable if the necessary indicators are discussed, and possible risks are taken into account.

At present, there are two approaches to the assessment of MIIT effectiveness: mathematical and economic. However, the most interesting and actively developed is the mathematical approach.

The monographs (Dubrov, 2002; Burlak *et al.,* 1989; Ivanilov and Lotov, 1979) could be attributed to the category of mathematical systems of indicators. The authors in their writings demonstrate how based on the theory of probability and mathematical statistics, and the mass service theory it is possible to quantitatively estimate such parameters of computational systems as the computational power (potential volume of information that the system is capable of processing) and speed of information processing. However, despite the wealth of the proposed tools, in the modern market conditions, it is difficult with the help of these methods to determine the overall economic effect for a particular enterprise, because the risk of investment is taken into account.

To calculate the effectiveness of a project, it is necessary to familiarize yourself with all expected risks:

Management Risks

1. Risk of the incorrect statement of technical specifications (TS);
2. Risk of errors in budget planning;
3. Risk of errors in scheduling deadlines;
4. Risk of errors in the task distribution among personnel;
5. The risk of inappropriate choice of the promotion strategy;
6. The risk of erroneous assessment of promotion time frames;
7. The risk of mistakes in the assessment of promotion costs;
8. The risk of incorrect determination of personnel (contractor) qualifications;
9. The risk of a situation when personnel are not aimed at the result;
10. The risk of low staff responsibility;
11. The risk of insufficient product quality;
12. The risk of failure of the project's deadline and exceeding the allocated funds;

Market Risks

13. The risk of erroneous assessment of the market capacity and changes in the market dynamics;
14. The risk of inaccurate determination of the sales value of the product;
15. The risk of erroneous assessment of the expected market share and the dynamics of its change;
16. The risk of inaccurate determination of the competitor's product quality and competitor's behaviour;

Internal Technical Risks

17. The risk of incorrect capacity planning resulting in system overload;

External Technical Risks

18. The risk of complete or temporary interruption of service delivery by contractors;
19. Risk of sanctions policy of partner States participating in the project;
20. Risk of unauthorized network intrusion;

External Risks

21. The risk of late payment for the work performed and services provided;
22. The risk of nonpayment for the work performed;
23. The risk of lack of specialists and an increase in the general level of specialists' fees and salaries of this qualification;
24. Legal risks;

Macroeconomic Risks

25. Foreign exchange risks;
26. The uncertainty of legislative changes;
27. The risk of political instability;
28. Risks of force-majeure circumstances.

Based on the comprehensive analysis, it is proposed to choose an enterprise, which can be a partner in the implementation of a pilot project to develop the structural health monitoring system and electronic passport of complex technical products using algorithms of artificial intelligence for the benefit of aircraft and construction industries. The integrated economic analysis serves as a means of obtaining comprehensive knowledge about economic activity, business knowledge, and understanding of the activities of a market participant.

Leading academic experts distinguish the following concepts of the comprehensive analysis: the completeness and comprehensiveness of analysis, systematicity of analysis, existence of the shared objective, consistency, and simultaneity of analysis.

Integrated Economic Analysis (IEA) involves the study of all aspects of business activities of the enterprise (supply, production, sale of goods, and their consumption) and all types of analysis of the enterprise. These can be production and financial analysis, continuous and selective analysis, prospective and retrospective analysis, current, periodic and operational analysis, analysis of the organization as a whole and internal, inter-farm comparative analysis, analysis of foreign economic relations, socio-economic analysis, factor and balance analysis, horizontal, vertical, trend and ratio analysis, deterministic and stochastic analysis, functional and cost analysis, technical and economic and other types of analysis. However, to characterize economic analysis as an integrated analysis, it is not enough to define it as a complete analysis, i.e. analysis of all aspects of business activities using all types of analysis. Another necessary condition for the integrity of the analysis is the use of a shared objective, which makes it possible to combine separate areas of analysis, indicators, and factors of production in an integrated system.

The IEA system is proposed for a better perception in the form of a diagram presented below (Figure **1**).

As can be seen from the diagram, the IEA is conducted in three stages:

Stage 1 – Preliminary review of summarizing indicators is carried out (readings of reports);

Stage 2 – In-depth analysis of all indicators by blocks in their interconnection is carried out (including analysis of non-current assets (Block 2) as part of the investment analysis);

Stage 3 – A generalized assessment of the company's operating efficiency is provided based on the results of a deep analysis of all indicators and all aspects of business activities.

The following cases of system analysis application are highlighted in the cases if:

- There is a growing crisis of confidence between owners/potential investors (possible owners) and management.
- Coordination of efforts of many different divisions, departments, services of the company is required.

Thus, investment analysis is an integral part of both integrated and systematic analysis.

Thus, "Block 1" of the IEA system is developed, highlighting the innovative block. The proposed development of the IEA system is because investments do not solve the problems of innovation because not all investments involve innovation. The main idea of this development is that innovation in the MIIT area represents a platform for value creation, creating factors (drivers) that generate cash flows. Thus, based on the cause-and-effect relationship, the allocation of the innovation block in the head end (Block 1) of the IEA system is justified. Along with the analysis of the technical-organizational level, analysis of foreign economic, social, and natural conditions, as well as innovative analysis, is an integral part of micro- and macroanalysis.

In general, investment decisions are determined by the strategic development plans of the military-industrial complex enterprises. Their adoption often requires the use of the significant stock of capital, raw materials, and human resources, which are generally insufficient for the full implementation of investment programs. As noted by many major academic practitioners, since investment decisions affect both capital expenditure and income and operational costs, the investment decisions are usually made based on formal project appraisals, because they can lead to serious negative results in the case of an error.

Thus, a component of any project appraisal is the analysis of project risks, which can reduce the probability that the important results from investments will not be delivered. In calculating efficiency, it is generally assumed that the proposed project is the best investment option available, and funding will be provided under the best conditions. In this case, the real possible conditions of financing a particular project do not affect its assessment, but the possible options are simulated in the analysis of project risks.

It is important to note that the reassessment of the economic effect should be done continuously however, this is possible only if accounting and analytical support are provided.

The accounting and analytical support will make it possible to carry out a continuous IEA of the project and to identify potential problems in the design of machine-building products and construction structures taking into account the availability of the structural health monitoring system. Accounting and analytical support will enable the recalculation of cash flows at any time taking into consideration changes in economic indicators and risks.

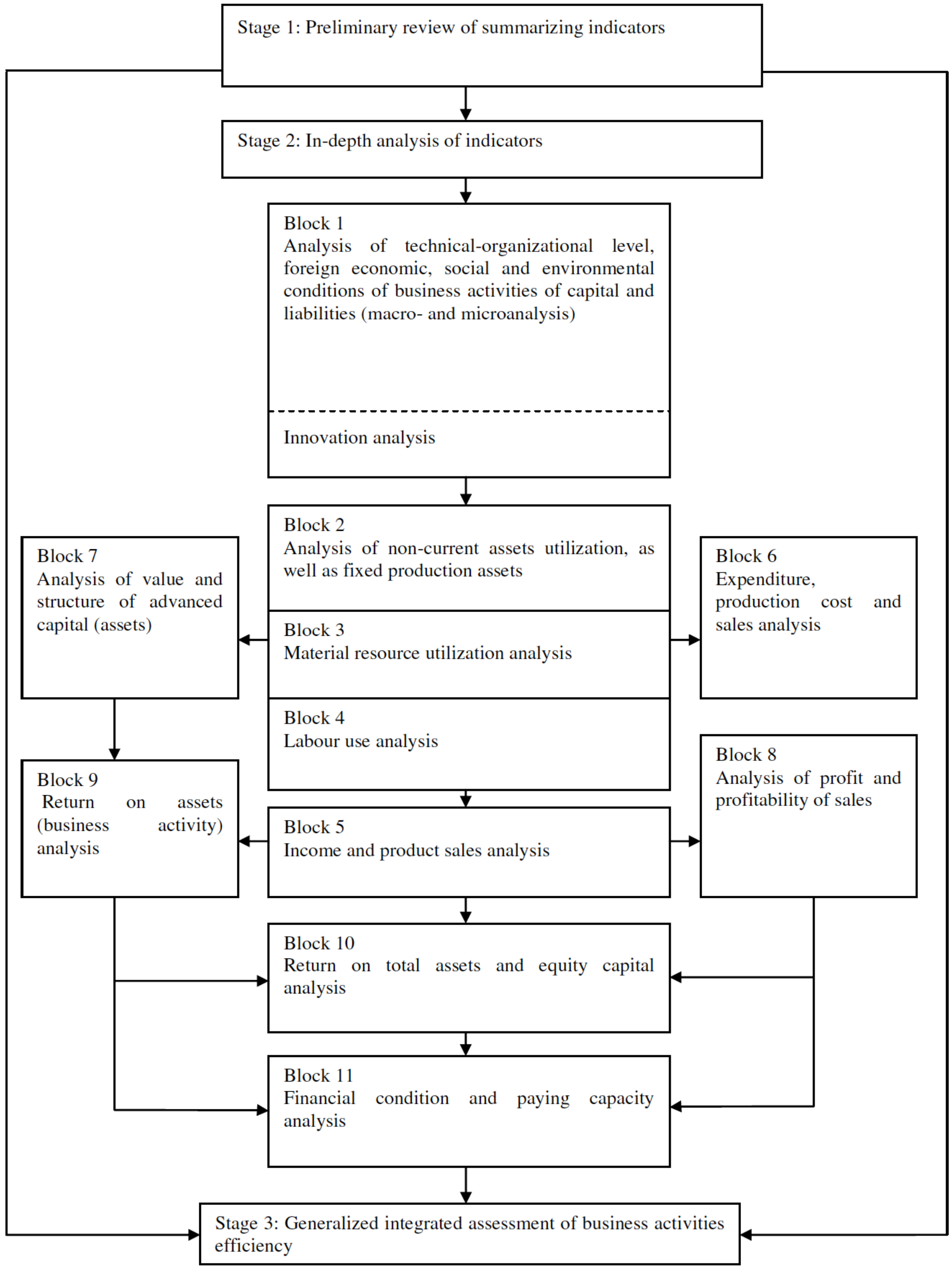

Figure 1: IEA system by A.D. Sheremet.

The function of the accounting and analytical support system is to continuously take into account and process information obtained at various stages of decision-making and implementation of decisions.

At the *first* stage, the goals and objectives of economic analysis are defined as part of investment process management.

In the *second* stage, the investment needs are quantified and the external socio-economic and ecological environment is studied.

In the *third* stage, the analysis of technical-and-economic and financial conditions of implementation of the identified investment options is performed. In this case, accounting and analysis of statistical indicators of market conditions and technological processes of the SHM are performed. The analysis is performed, taking into account the specific risks and their recording in the accounting and analytical support system.

At the *fourth* stage, the assessment of the possible implementation of the structural health monitoring system and electronic passport of complex engineering products with the use of algorithms of artificial intelligence for the benefit of aircraft and construction industries is carried out. Cash flows are simulated and analyzed in this case, taking into account all possible risks grouped in economic and financial parameters, which will be discussed below.

The project is analyzed in the *fifth* stage. The project is calculated by various methods, such as the Net present value **(**NPV) method, which takes into account the mathematical expectation of probability processes of risk manifestation, and the method of real options, which involves the calculation of deviation indicators expressed in the projected volatility. Volatility is understood as a statistical indicator characterizing the trend of price variability. Volatility is expressed in absolute or relative values against the initial cost.

The *sixth* stage consists of investment proposals that complete the development and validation stage of the project.

At the *seventh* stage, through the accounting and analytical support system, the control of the project implementation on the development of the structural health monitoring system and electronic passport of engineering complex products with the use of artificial intelligence algorithms is carried out for the benefit of the aircraft industry and construction complex. It is carried out together with the retrospective analysis of deviations of the obtained results with subsequent identification of the reasons for deviations. Reasons for deviations are recorded in the accounting and analytical support system.

Plus, the *eighth* step consists of monitoring and adjusting the initial stages to allow for the implementation of risk mitigation measures.

In the study [Identifying Indicators of Household Independence by Provinces/ Rezzy Eko Caraka, Silvi Hafianti, Sri Hidayati, Bryan Wilie, Muhammad Rheza Muztahid, Technical Report, November 2019. DOI: 10.13140/RG.2.2.17238.19528] colleagues reveal the indicators of the financial vulnerability of households. To identify signs of debt, a large array of primary data has been analyzed, which is then processed using the following methods: logistic regression, feature selection using Boruta, Random Forest, and text mining. As a result, the reasons for requests and structure information within the region have been determined. As a part of our research, presumably using logistic regression, it is possible to identify indicators for accounting and analytical support of the process of evaluating the effectiveness of the project implementation of the monitoring system, both at the development stage and at the operational stage. Besides, the random forest method in the framework of performance assessment not only allows you to build excellent forecasting models but also perform such work as selecting a set of all informative features (finding all relevant variables), which in turn increases the level of reliability of forecasting. Thus, the use of modern methods of working with data in conjunction with classical analytical approaches makes it possible to predict efficiency with a slight increase in the complexity of the evaluation process.

In the study [Impact of COVID-19 large scale restriction on environment and economy in Indonesia/ R. E. Caraka, Y. Lee, R. Kurniawan, R. Herliansyah, P. A. Kaban, B. I. Nasution, P. U. Gio, R.C. Chen, T. Toharudin, B. Pardamean, DOI: 10.22034/GJESM.2019.06.SI.07] using the R-core (R core team, 2008) and emputeTS (Moritz *et al*., 2017) analyze, compare, and predict a set of ecological parameters of the region, correlating with data on population mobility in the context of Covid-19. The impact of large-scale restrictions on economic growth in certain sectors of the economy is also estimated based on statistical data. It is important to note that the researchers used powerful computational tools, which, however, are applicable in cases where there is access to a wide array of data in a historical context of sufficient depth. In the case of our study, it is important to note that the object of evaluation-the effectiveness of the development and implementation of monitoring systems is the latest phenomenon in terms of data availability, so the historical reconstruction of the dynamics of certain indicators used in assessing risk or effectiveness is possible only on the example of similar industries or processes. This feature imposes restrictions related to the use of tools similar to those listed by colleagues. Despite this, the impact of COVID-19 on the development and operation of the monitoring system is obvious, and the effectiveness assessment should take sufficient account of current global events. Thus, within a certain object, the assessment of the economic efficiency of the development and application of a monitoring system should include the necessary and sufficient number of tools for retrospective analysis of influencing factors, as well as the impact of current events using modern data processing tools.

The study [a Preview of Total Quality Management (TQM) in Public Services, Avia Enggar Tyasti, Rezzy Eko Caraka, E-Jurnal Ekonomi dan Bisnis Universitas Udayana 6.9 (2017): 3285-3290, DOI: 10.24843/EEB.2017.v06.i09.p04] reveals the problems of implementing Total Quality Management (TQM) in public services. The results of our colleagues showed that despite the positive impact of the presented approach, such factors as the system structure, customers, employee perception, and culture have a significant impact on the implementation results. Concerning the subject of our research, we can safely assume that in the context of the identified issues – evaluating the effectiveness of monitoring systems in the development and operation process, the introduction of private practices of TQM or its ideology, in General, will allow to some extent reduce the identified risks, increase the efficiency of functioning, and in certain cases reduce costs. Such conclusions are valid due to the client-oriented approach between the developer and the operator at the development stage, as well as between the operator and the end-user (user) in the case of using a monitoring system, but the effect of a particular case has to be evaluated separately and depends on its unique system and external factors.

In the study [Analisis Kemiskinan Di Provinci Jawa Tengah Dengan Pendekatan Spatial Autoregressive Model, Rezzy Eko Caraka, Department of Statistics Diponegoro University, DOI: https://doi.org/10.24843/JEKT.2018.v11.i01.p04] the Spatial Autoregressive Model (SAR) is also called Spatial Lag Model (SLM) and other models that take into account the influence of spatial lag on dependent variables were used to identify and analyze factors that affect people in the poor category. As a result, the researcher identified the most and least influencing factors when using different models. Since Ordinary Least Square (OLS) allowed us to identify a small number of parameters that did not have a significant impact, within the scope of our research, this method, along with others, can be used to filter out insignificant factors. This maneuver will allow us not to waste resources when evaluating the effectiveness of the monitoring system and reduce the parameters for further manipulations. The SAR study showed that the delay factor of the dependent variable plays an important role in modeling the amount of the desired parameter, so if such a model is used in evaluating the effectiveness of a project to develop and use a monitoring system by analogy, it can make a significant contribution and ensure the accuracy of predicting the impact of factors and risks that have a delayed-action effect.

Summarizing the above, it is proposed to use a set of the listed tools, methods and models at the appropriate stages of evaluating the effectiveness of directly defined projects.

4. DISCUSSION

In the discussed paper the answer was given to the question *"Are investments in structural health monitoring systems in aviation and construction are profitable?"* to which it is possible to give with confidence the affirmative answer. From the practice of these systems applications in developed countries (China, USA, etc.), it is evident that the benefits from financial investments are sometimes multiple. Russia, with its capabilities and potential, should not lag behind its foreign colleagues in this area. The results of the paper provide the cost-benefit analysis of structural health monitoring systems application in aviation and construction of the Russian Federation.

The market for monitoring systems has grown dramatically along with the development of communication and data transmission systems, as well as the use of composite materials in aviation and construction, the nature of the destruction of which is unstable and requires constant monitoring to predict any damage due to the emergence of defects and therefore timely maintenance to reduce operating costs and increase reliability. The introduction of digitalization is also effective in structures made of simpler materials (metals, concrete, etc.).

The main problems and inhibiting factors at present are a high price, energy independence, large distance, and inaccurate synchronization of sensors embedded in the objects, as well as a large amount of processed data. These problems are actively being worked on with the purpose of technical development and market growth.

An important part of the cost-benefit analysis is to identify all the risks of the project. Methods and ways of their determining have also been described in this paper.

Structural health monitoring systems of operational facilities actively began to be introduced only in the XXI century as a result of the development of the Internet and digital technologies. Therefore, these systems are still at an early stage in their development. Realizing the importance of these projects, the G20 countries are investing and will continue to invest a lot of money in such systems, which in the future will lead to accelerated development of technologies and digitalization in all areas of industry, including aviation.

5. RESULTS

Below is the expert cost-benefit analysis of monitoring system application (a combination of savings in aircraft operation and revenue due to increased sales value) for the aircraft fleet of the Russian Federation:

- For civil aviation, the effect is expected to be 1 billion rubles per year.
- For military transport aviation (479 aircraft), the economic benefit is estimated at 3 billion rubles.
- For the fighter aircraft, which has 974 aircraft, the average price of the monitoring system will be about 10 million rubles per aircraft. The benefit from the monitoring system application is expected to be 5 million rubles per year per aircraft. Thus, the economic benefit will amount up to 4.8 billion rubles annually with nonrecurrent expenditures of 10 billion rubles.
- For civil helicopters of domestic production (815 pcs.) and foreign production (145 pcs.), the economic benefit of operators is estimated at 1.5 billion rubles.
- For combat helicopters, the economic benefit for the fleet of 990 units is that the monitoring system will cost about 10 million rubles in series, and the effect of the introduction will be 10 million rubles annually per unit. That means the economic benefit is equal to 10 billion rubles per year with the primary input of 10 billion rubles.

As can be seen from the above, for the aviation fleet, the total economic benefit will be 25.3 billion rubles annually, with 20 billion rubles of nonrecurrent expenditures. Taking into account aviation, the benefit in the EAEU will be 28.3 billion rubles of savings annually.

For the housing stock of the Russian Federation, the economic benefit is estimated at a 10% reduction in the cost of inspections, which is 4 billion rubles for 1,000,000 houses, as no more than 20% of the houses need monitoring.

For bridges, annual inspection and instrumented verification costs are 7.5 million rubles for the long bridge and 0.5 million rubles for the highway-over crossing.

By using the structural health monitoring system, inspection costs can be reduced by about 40%. For 4,000 large bridges, the effect will be 16 billion rubles annually. For 24,000 smaller bridges, the reduction will be 15%, which will amount up to 1.8 billion rubles.

In total, the economic benefit for the construction industry is estimated at 21.8 billion rubles annually. Taking into account the EAEU infrastructure, the expected economic benefit may reach 24 billion rubles.

6. CONCLUSIONS

To increase the level of technological development, it is proposed to expand digitalization in all industries. Digitalization allows us to achieve several important objectives in response to the great challenges – improving process efficiency, reducing costs, and ensuring monitoring of the current situation, which leads to the sustainable development of Russia. The development of big data technologies and methods of analysis based on artificial intelligence makes it possible to form reasonably accurate forecasts of the behavior of a complex engineering facility. An expert assessment of the economic benefit of implementing monitoring systems for different classes of aircraft engineering has been obtained.

The cost-effectiveness analysis approach of investment projects for structural health monitoring systems according to the real options method taking into account statistical uncertainty of risks under which the project is implemented has been proposed. All risk classes have been described, and assessment methods have been demonstrated. The accounting and analytical methodology for assessing the effectiveness of projects has been developed. The technology of the introduction of structural health monitoring systems for aviation and construction industries has been determined. The application of the proposed and analyzed analytical methods, approaches, and practices (TQM, OLS, SAR, big data, Boruta, Random

Forest, etc.) within the framework of the assessment of efficiency risks will allow achieving the predicted economic effect in the case of using monitoring systems at specific facilities, reliably and effectively identify the main influencing factors and take into account the context of modern events.

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