National Research University Higher School of Economics

As a manuscript

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EVALUATING THE IMPACT OF BLOCKCHAIN TECHNOLOGY ON THE EFFICIENCY OF PROCUREMENT PROCEDURES

PhD Dissertation Summary
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I. GENERAL CHARACTERISTICS OF THESIS RESEARCH

Problem description. Today, the activities of most financially successful companies, including large Russian companies, are associated with the processes of globalization and digitalization. The volume of money received from the export of goods and services in the Russian Federation, since 2000, has shown a fourfold increase (from 100 to 400 billion dollars). At each stage of the logistics chain, some form of information system is used to track the status of goods in real time. Companies spend billions of dollars and years of development on their implementation, but the issue of efficiency and feasibility of digitalization of business processes, including the process of supplying goods and services, is not yet sufficiently disclosed in scientific papers.

Evaluating the effectiveness of modern information technology is necessary not only for the tasks of global supply chain management, but also for the processes of procurement procedures. Thus, at present, most companies, in which one of the main activities is procurement (both for their own needs and to meet the needs of external customers of the company), use different types of software, the main purpose of implementation of which was to increase the efficiency of procurement procedures, namely, reducing operating costs by reducing the time for processing requests for procurement through the transition from paper to electronic, automation However, information systems (including their software products) used in companies were usually developed in the nineties or early twenty-somethings, and have a number of shortcomings, among which we can highlight the need to purchase and install expensive equipment, the complexity of integration with existing systems, problems with access to data stored on company servers (in the cloud or local databases), data security, the lack of full automation processes and other shortcomings that do not allow to give an unambiguous assessment of the feasibility of their use, and as a consequence, the effectiveness.

With the development of information technology, there are more and more new opportunities to improve the procurement process. One of the most promising technologies is a distributed registry or blockchain technology, in which the interaction between counterparties is realized through a set of automated operations – smart-

contracts[1]. Blockchain technology is based on a distributed database, is fully protected from possible hacker attacks, supports a full-fledged electronic document flow and allows to automate most processes related to procurement procedures. Based on these characteristics, we can assume that blockchain technology (including smart-contracts) has the potential for use in various areas of business, but the question of the prospects of this technology and the need for its use in procurement procedures remains understudied, as a consequence, has great potential for study.

Brief literature review. The issue of the need to use modern information technology in supply chain management and procurement procedures is considered in the works of such authors as Akaba T.I., Alkebi A., Banerjee A., Barata J., Cerulo G., Gane E., Helo P., Hao Y., Jeppsson A., Kamali A., Kagerman H., Koteska B., Korpeta K., Maestrini V., Mearian L., Monk E.F., Notari R., Pang C., Parikh T., Parung J., Swan M., Song J., Tribis Y., Tonnissen S., Teuteberg F., Westerkamp M., Yli-Huumo J., Arefieva AS, Bochkarev P.A., Brodetsky G.L., Drevs Yu, Kinsburgskaya V.A., Korepin V.N., Lukinsky V.S., Lukinsky V.V., Kosyang N.G., Milkina I.V., Pletneva N.G., Sergeev V.I., Sterligova A.N. and others.

When analyzing these works, we can conclude that their list is limited, and works published in this area usually do not contain information on the specific efficiency indicators and criteria of using modern information systems in the business processes of companies. Most papers also lack any economic substantiation of the feasibility of implementing innovative technologies. At the same time, if we analyze the works related to procurement procedures, the majority of Russian authors consider the use of innovative technologies only in relation to work within the federal law 44 (Federal Law "On contract system in the sphere of procurement of goods, works and services for state and municipal needs") and do not assess the prospects of such technologies in the procurement activities of Russian private and public companies, which conduct procurement by internal regulatory documents, rather than federal law 44.

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[1] Szabo, N. Smart Contract [Online] / N. Szabo. – 1994. – Available from: http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart.contracts.html [Accessed 15 September 2020].

Object and Subject of Research. *The object of the research* in the thesis is procurement procedures where modern information technology can be applied. *The subject of the study* are models, methods, criteria and indicators of the effectiveness of procurement procedures, including the evaluation of the effectiveness of technologies such as industrial internet of things, big data, blockchain, smart-contracts and other.

The aim of the research. The aim of the dissertation research is to develop and validate models and algorithms for management decisions aimed to improve the efficiency of procurement procedures using blockchain technology.

In accordance with the formulated goal, the main objectives of the thesis research are:

- Conducting a critical comparative analysis of existing approaches to assessing the effectiveness of the use of modern information technology in procurement procedures;
- Formalizing models, methods, criteria and indicators of effectiveness of procurement processes;
- Forming approaches to justify the feasibility of using modern information technology in procurement procedures;
- Development of an algorithm for evaluating the effectiveness of information technology used to automate procurement processes;
- Forming practical recommendations for the calculation, justification and implementation of models, algorithms and indicators of the efficiency of information technology in assessing its impact on the processes of procurement procedures and related management decisions.

The methodological basis of research includes the scientific foundations of systems analysis, management, the theory of multicriteria choice, as well as models, methods and algorithms for the study of operations and business processes.

Methods of expert evaluation and simulation modeling in the software environment of AnyLogic information product are used as tools for testing hypotheses in the dissertation. The basis for expert evaluation is the method of multicriteria analysis

proposed in work of Pavlov A. N.[2] which involves the construction of a generalized index using fuzzy probabilistic convolution, which is based on fuzzy measurements and fuzzy integrals. This method allows flexible consideration of the non-linear nature of the private performance indicators (indicators) on the values of the generalized performance indicator.

The scientific novelty The scientific novelty of this study consists in the development of methodological and methodological foundations for evaluation and multi-criteria analysis of the effectiveness of modern information systems in procurement procedures, such as:

1. The analysis of scientific papers published in the field of evaluating the effectiveness of the introduction of information systems, based on which a list of poorly explored problems.

2. Systematized information on possible approaches to assessing the effectiveness of using information systems in procurement procedures and on this basis justified the approach to solve the tasks studied in the dissertation.

3. A critical comparative analysis of different information systems used in the implementation of procurement procedures, including innovative software products that include the use of blockchain technology and smart-contracts, describing the advantages and possible limitations of these technologies are described, and their areas of application are identified.

4. Formalized and justified a set of criteria and performance indicators that can be used to select the most preferable software for procurement procedures.

5. Proposed algorithm for management decision-making in the process of procurement procedures, which is used to evaluate the effectiveness of blockchain technology and smart-contracts in procurement.

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[2] Pavlov, A. N. The Technique of Multicriteria Decision-Making in the Study of Semi-structured Problems / A. N. Pavlov, D. A. Pavlov, A. A. Pavlov, A. A. Slin'ko // Cybernetics and Mathematics Application in Intelligent Systems: Proceedings of the 6th Computer Science On-line Conference (CSOC2017), Vol.2. Series "Advances in Intelligent Systems and Computing, Springer International Publishing AG, 2017. – P. 131-140.

6. Developed agent-based simulation model of the process of procurement procedures, including business processes based on blockchain technology and smart-contracts, and allowing to simulate different variants of the process of procurement activities, and to evaluate its effectiveness.

7. Conducted an economic feasibility analysis of the implementation of blockchain technology and smart-contracts in procurement procedures for different scenarios of disturbing influences.

The main results

1. The systematization of existing approaches to assessing the effectiveness of procurement processes;

2. An algorithm for decision-making regarding the use of information technology in procurement procedures was developed;

3. Developed and implemented an agent-based simulation model to evaluate and analyze the effectiveness of blockchain technology and smart-contracts in procurement procedures;

4. Formed and substantiated the set of indicators and criteria for evaluating the effectiveness of the business process of procurement procedures for the implementation and using blockchain technology and smart-contracts;

5. Conducted economic justification of the economic feasibility of technology blockchain and smart-contracts in the implementation of procurement procedures for different scenarios of realization of the disturbing influences.

The theoretical implication of the research is to systematize information about the models and methods for assessing the effectiveness of the use of modern information technology in procurement procedures; formation of an algorithm for decision-making in companies regarding the use of blockchain technology and smart-contracts in procurement procedures; formalization of criteria and indicators of effectiveness of blockchain technology and smart contracts in procurement procedures. The models, methods, criteria and performance indicators presented in this paper will contribute to making economically proven managerial decisions.

The empirical results confirm the validity of applying the method of expert evaluation to rank the criteria for evaluating the effectiveness of modern information technologies in procurement procedures and indicate that not all the potential benefits claimed by the developers of information systems (IS) are evaluated by business as IS qualities of real value in relation to the task of improving the efficiency of procurement procedures.

Practical implications of the research consists in the fact that the results of the thesis research can be used in substantiating the need to use modern information technologies (including blockchain technology and smart-contracts) by the procurement departments in domestic and foreign companies, including:

- in modeling information and financial flows in the process of procurement of goods and services;
- in calculating the indicators of labor costs depending on the software used in the procurement procedures;
- in the forming and ranking criteria and indicators that are used for evaluating the effectiveness of information systems for supply tasks.

The results of the thesis research show that there are a number of cases for which the use of modern information technologies in procurement procedures (in particular the use of blockchain technology and smart-contracts) may be unjustified and lead to additional costs, which will offset the entire positive effect of the automation of business processes in this area.

Approbation of research results. The results of the thesis research were presented at the following conferences:

1. XIX International Scientific and Practical Conference "Logistics: Current Development Trends". Report "Analysis of efficiency procurement procedures based on blockchain technology" (April 2, 3, 2020, Saint Petersburg, Admiral S. O. Makarov State Marine Engineering University).

2. Conference – The 2nd Computational Methods in Systems and Software 2018. Report "Comparison of ERP Systems with Blockchain Platform" (12.09.2018-13.09.2018, online).

3. XVII International Scientific and Practical Conference "Logistics: Current Development Trends". Report "Application of Blockchain technology in procurement procedures" (April 12, 13, 2018, St. Petersburg, Admiral S. O. Makarov State University of Marine Engineering).

Separate results of the dissertation research in terms of developing a process model of procurement procedures were used in Gazprom Neft for the development of regulatory documentation.

Dissertation structure. The dissertation consists of an introduction, three chapters divided into paragraphs, a conclusion, a list of 209 references and 4 appendices. The work contains 22 tables and 29 figures. The total volume of the thesis is 178 pages.

Chapter 1 analyzes the literature on the effectiveness and feasibility of information systems and digitalization and automation in procurement procedures; formalizes and systematizes the problems that are not reflected in the studied works; analyzes modern information and management solutions; describes their advantages and disadvantages. Works devoted to the prospects of development of blockchain technology and smart-contracts are researched to evaluate the potential of using this technology in procurement procedures.

Chapter 2 is devoted to the formation of a management decision-making (performance evaluation) algorithm based on multi-criteria analysis in procurement procedures. In sections of this chapter models and methods of data analysis in procurement logistics are considered; justification of the application of multicriteria analysis and simulation modeling methods to evaluate the effectiveness of blockchain technology and smart-contracts in procurement procedures is given; The algorithm of efficiency assessment based on the functional cycle of supply logistics and the models and methods using to evaluate the effectiveness of logistics processes is proposed.

Chapter 3 assesses the effectiveness of blockchain technology and smart-contracts in procurement procedures. For this purpose, the description of the algorithm of procurement in the framework of the open competitive selection is carried out with further detailing and specification; several possible options for its implementation are analyzed, including the use of blockchain technology and smart contracts; the results of simulation

of this algorithm under three scenarios (standard, risky and optimistic) are presented; indicators and performance criteria for using blockchain technology and smart-contracts in procurement procedures are peoposed; an example of calculating the indicators based on data from the procurement department of a leading Russian company is given.

II. ARGUMENTS OF THE RESEARCH TO BE DEFENDED

1. Analysis of the literature devoted to using modern information technology in procurement procedures

Summarizing the analysis of scientific papers on assessing and improving the efficiency of business processes in procurement procedures through the use of modern information technology (Industry 4.0 technologies - big data, machine learning, Internet of things, blockchain, smart-contracts and others), a number of problems can be identified that need the most attention. Such problems may include:

first, the lack of authors' attention to current trends in digitalization (these include blockchain technology and smart-contracts, big data, the Internet of Things, digital twins and other modern other modern and advanced information technologies and systems);

Secondly, the lack of comprehensive and reliable information available to business analysts and managers on the possibilities of using "digital" technologies in procurement;

Thirdly, not enough attention is paid to the issues of economic justification of the effectiveness of the implementation of such technologies related to procurement process.

Fourthly, there is a lack of methods to assess the impact of external factors, such as imperfect technologies, the existence of a comprehensive legislative framework, tax regulation and others.

It is also worth paying attention to the fact that limited set of methods and information systems of data analysis is used to evaluate the effectiveness of IT-systems; the data are generated based on the results of expert surveys in which the number of respondents does not exceed one hundred persons; the results of calculations are usually presented in the form of correlation and do not allow to evaluate the actual contribution of information technology to business development, denominated in financial indicators.

Thus, from a generalized analysis of the literature we can conclude that the most pressing problems of research in the field of information technology implementation in procurement are: the lack of economic justification for the effectiveness of technologies; the imperfection of technology and the influence of external factors; the high speed of technological change; the limited scope of applied models and evaluation methods, which will be focused on.

2. Formation of decision-making algorithm in procurements

To assess the effectiveness of modern information technology and ensure effective management decisions in procurement procedures, various models and methods are used. The choice of specific models and methods depends on the process according to accepted a management decision. The process of making decisions in supply logistics can be represented as follows:

1. Determination of the procurement phase that requires an organizational and management decision;
2. Determining the models and methods that can be applied to analyze the specified phase;
3. Performing an analysis of possible decision-making options;
4. Preparation of a justification for the organizational and managerial decision based on the results of the analysis;
5. Adoption and implementation of the approved decision.

Thus, the totality of functional cycles and models and methods, decomposed to the specific stages of procurement procedures can be represented as the algorithm of managerial decision-making (Figure 1).

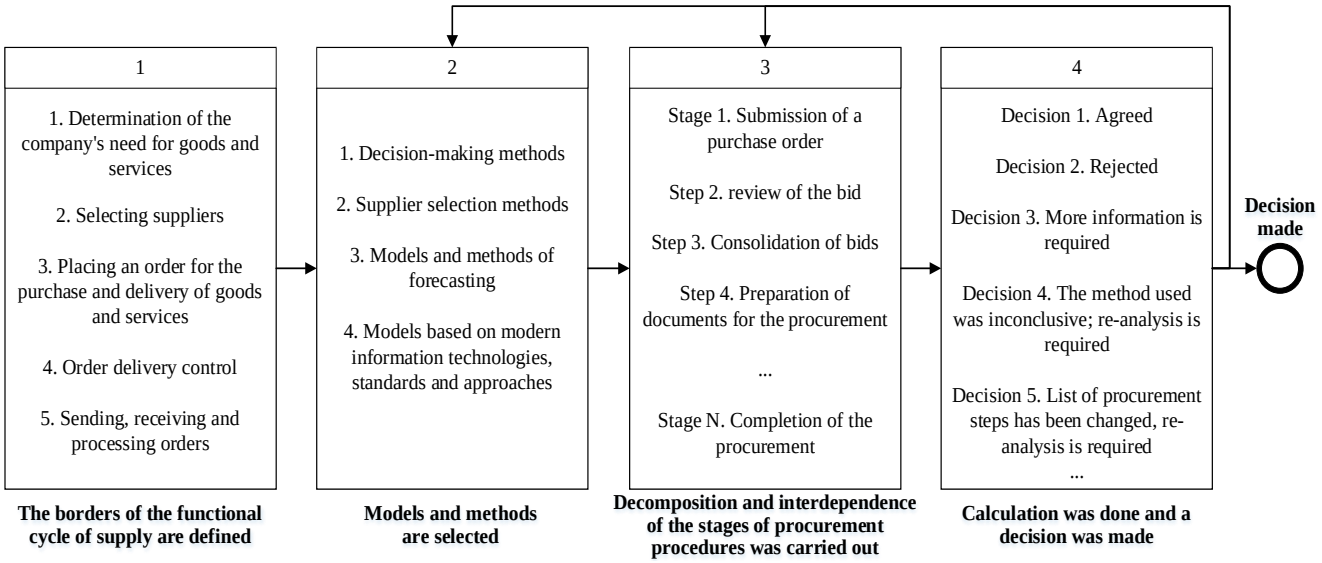

Figure 1 – The main stages of implementation algorithm of managerial decision-making in the process of procurement procedures

The source: made by author

Within the proposed decision-making algorithm, it is possible to return to the previous stages, as the transition to the decision-making stage may bring new information that was originally not taken into account or the initial data and information received do not have the required degree of completeness, certainty and reliability, which makes it necessary to clarify and detail them. It is also possible to change the set of investigated stages of procurement, or the results do not give a clear answer to the question under research. Depending on the situation, it is possible to return both to the choice of a particular method of making a management decision, and to the analysis of specific stages, after which the question of making or not making a particular management decision will be reconsidered.

The algorithm for decision-making can be used in procurement procedures, and in other areas, for example, to make optimization decisions in the economic activity of the company.

It is necessary to take into account that for some logistics processes, the proposed models and methods may not be applicable, or will require significant labor costs, which may lead to an increase in the timing of decision-making. Processes that involve a high level of uncertainty and variability of possible solutions can be attributed to them. In this case, it seems more appropriate to use multi-criteria models and methods of problem solving, as well as simulation modeling tools.

3. Implementation of multi-criteria analysis methods to evaluate the effectiveness of blockchain technology in procurement

Concretization and verification of the developed algorithm for managerial decision-making in this paper is proposed using a combined method of multi-criteria evaluation and analysis of complex objects and processes (COP) presented in the study of Pavlov A.N.[2] The theoretical significance and practical value of the proposed method are as follows:

firstly, the use of qualitative (fuzzy) information on the effectiveness of COP functioning, along with quantitative information, proposed in the framework of this

method significantly increases the validity of conclusions and management decisions made;

secondly, the developed approach makes it possible to formalize the explicit and implicit expert information presented in the language natural to the expert by introducing linguistic variables, which provide an opportunity to represent more adequately an approximate verbal description of objectively existing criterial uncertainty, and to process expert knowledge by methods of experiment planning theory;

thirdly, the proposed method provides an opportunity to formalize the experience of an expert (group of experts) in the form of predictive models in the multidimensional space of quantitative and qualitative indicators of COP effectiveness.

In the dissertation this method is applied to select the best software product focused on blockchain and smart contracts technologies using appropriate criteria and indicators formed on the basis of the reviewed literature sources. This list includes qualitative and quantitative indicators and criteria that allow to constructively evaluate the system properties of procurement processes such as reliability; elaboration of business logic; data integrity; process transparency; integrability. The data for the analysis were obtained by conducting an expert survey, in which 12 specialists involved in the implementation of modern information technology (including blockchain technology in procurement), with experience of at least 5 years, were involved. The results of the expert survey are shown in Table 1. The calculation of the λ coefficients is presented in Table 2. The results of the calculation of F_{res} resulting index are shown in Figure 2.

Table 1 - Results of the expert survey

№	Blockchain system	CC 1	CC 2	CC 3	CC 4	CC 5
1	Cuber Wallet	1	1	1	-1	-1
2	Public Notary.	1	1	1	1	1
3	Guardtime	1	1	-1	-1	1
4	Crypto Valley	1	-1	1	1	1
5	Земельный кадастр Грузии	1	1	1	1	1
6	GOV.UK	-1	1	-1	1	-1
7	Dubai Smart Government	1	1	1	1	1
8	Cool Simply VitalHealth	-1	-1	1	-1	-1
λ_0	-	0,51	-0,24	0,46	0,31	0,34

The source: made by author

Table 2 - Calculation of the λ coefficients

№	λF_1F_2	λF_1F_3	λF_1F_4	λF_1F_5	λF_2F_3	λF_2F_4	λF_2F_5	λF_3F_4	λF_3F_5	λF_4F_5	$\lambda F_1F_2F_3F_4F_5$
1	-0,7	0,7	-0,7	-0,7	-0,7	0,7	0,7	-0,7	-0,7	0,7	-0,7
2	-1	1	1	1	-1	-1	-1	1	1	1	-1
3	0,8	-0,8	-0,8	0,8	-0,8	-0,8	0,8	0,8	-0,8	-0,8	0,8
4	-0,9	0,9	0,9	0,9	-0,9	-0,9	-0,9	0,9	0,9	0,9	-0,9
5	-1	1	1	1	-1	-1	-1	1	1	1	-1
6	0,7	0,7	-0,7	0,7	0,7	-0,7	0,7	-0,7	0,7	-0,7	0,7
7	1	1	1	1	1	1	1	1	1	1	1
λ_0	-0,21	0,49	0,29	0,66	-0,26	-0,41	-0,04	0,34	0,31	0,46	-0,21

The source: made by author

Figure 2 – The results of multicriteria analysis of blockchain systems

The source: made by author

Based on the analysis of the expert evaluation results, represented by fuzzy-production statements and processed by methods of the theory of planning experiments, the values of the generalized performance indicator F_{res} were received, the most preferred blockchain system Crypto Valley was selected, and the three main positive effects for business from the use of blockchain technology and smart contracts were identified:

1. Improving the reliability of storage of procurement information, which minimizes the risk of its loss or falling into the hands of third parties, as a consequence of possible business interruption or financial, time and reputational losses.

2. Increasing the level of information integrity, allowing to maximize the level of its security and minimize the risk of falsification. Integrity also means guaranteed technological impossibility to change the stored information without notification of the supply chain participants and unambiguous detection of falsification attempts.

3. Integrating various information flows into a single information system based on blockchain technology and smart contracts, increasing the speed of interaction between participants in the logistics chain and the quality of data for further analysis and forecasting of events in the chain, including in procurement procedures.

The obtained results show the feasibility of using the offered method of multicriteria analysis in the tasks of making management decisions in procurement procedures, and the positive effects of using blockchain technology and smart-contracts. However, the calculation of quantitative performance indicators is also required to improve the level of their validity.

4. Formalization the algorithm of procurement procedures

To evaluate the effectiveness of blockchain technology and smart contracts in the process of procurement procedures, according to the previously proposed algorithm, the studied process must be presented as a set of stages. The paper identifies the following stages of procurement procedures:

Stage 1. Formation of procurement documentation, including specific procurement criteria.

Stage 2. Approval of documents and procurement criteria.

Stage 3. Publication of the purchase on the company's official website (or an electronic trading platform) and informing the counterparties.

Stage 4. Registration of counterparties on the official website (or electronic trading platform) for participation in the purchase procedure.

Stage 5. Forming counterparties' bids for the published purchase procedure.

Step 6. Accepting and opening of counterparties' bids.

Phase 7. Evaluation and comparison of counterparties' bids and selecting the winner of the procurement procedure.

Stage 8. Forming a final report on the results of the procurement and signing a contract with the winning company.

Step 9. Preparation of analytical data on the results of procurement procedures.

These stages can be decomposed and divided into three groups: general process stages; process stages using blockchain and smart-contracts technology; process stages without blockchain and smart-contracts technology (Table 3).

Table 3 - Groups of stages in the process of purchasing goods/services

№	General process steps of procurement	Process steps of procurement with blockchain and smart-contracts technology	Process steps of procurement without blockchain and smart-contracts technology
1	Approval of documentation	Making a record in the distributed procurement register	Verification of prepared documentation
2	Feasibility analysis of procurement	Verification of the record by the auditor node	Correction of documentation
3	Market analysis	Generation of a smart-contract for procurement	Publication of information about the procurement on the company's website
4	Formation of terms of reference and selection criteria	Correction of record	Notification of contractors about the procurement by phone
5	Formation of selection project	Approval of the record	Sending tender notifications to the contractors by e-mail
6	Definition of type and form of purchase	Automatic mailing of procurement announcement to the counteragent (CA), registered in the blockchain-based system	Manual registration of counterparties' bids in the company system.
7	Signing selection documents with the manager	Automatic registration of CA offers in the blockchain network	Manual checking of submitted offers for compliance with the documentation conditions
8	Initialization of purchasing process	Automatic bid verification for compliance with smart-contract terms	Ranking of the submitted proposals, manually
9	Generation of documentation	Automatic bid ranking	Selecting the winner, manually
10	Opening of submitted proposals	Automatic selection of the winner, based on the terms of the smart-contract (SC)	Drawing up a contract, manually
11	Correction of offers, manually	Forming the contract, based on the template from the SC	Sending the contract for CA signing, by mail
12	Process completed	Automatic sending of the agreement for signing by the CA	Sending the contract for CA signing, by mail
13	Process completed	Signing the contract by the counterparty, using the electronic digital signature	Signing the contract manually
14	Process completed	Automatic report tracking on fulfillment of contract terms, by means of the SC	Tracking reports on the fulfillment of the contract, manually
15	Process completed	Automatic agreement of the work/service acceptance report	Approval of the work/service acceptance report, manually
16	Process completed	Process completed	Archiving of procurement documents

The source: made by author

Based on the data in Table 3, we can conclude that the process of procurement of goods and services using blockchain technology and smart-contracts has a high degree of variability, with a large number of parameters should be considered at each stage, what makes it necessary to determine a specific method of analysis, allowing to consider several criteria and performance indicators at once. On this basis, the decision of using modern computer modeling automation tools for agent-based simulation model research of blockchain technology and smart-contracts in procurement procedures was made.

The simulation software AnyLogic was used to evaluate the effectiveness of blockchain technology and smart-contracts in procurement procedures. The developed simulation model is presented in Figure 3.

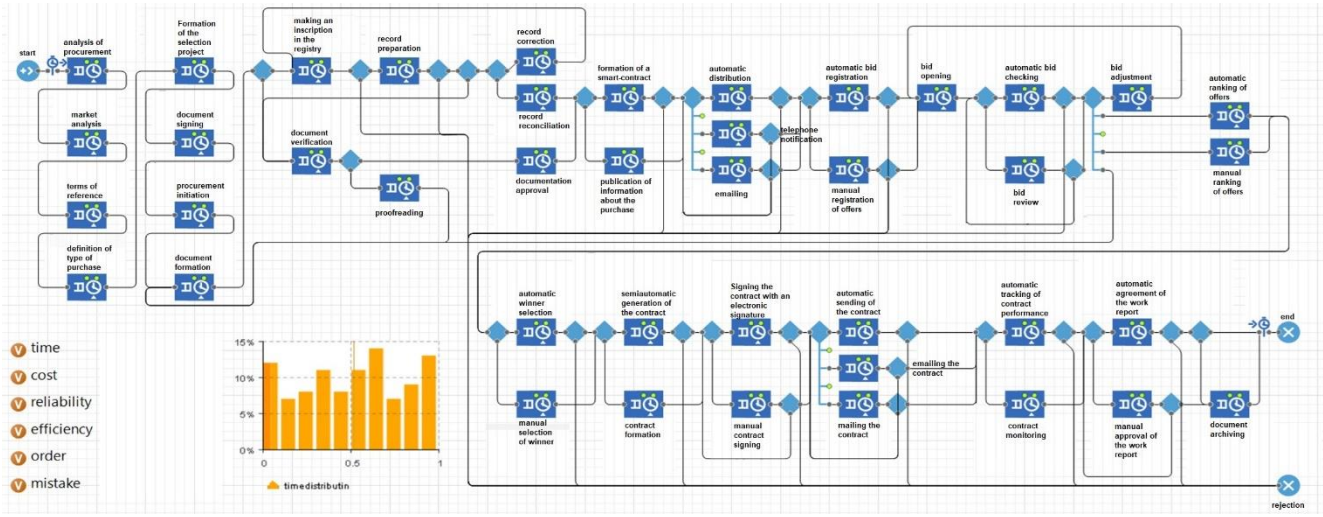

Figure 3 – A simulation model of the procurement process using blockchain technology and smart-contracts

The source: made by author

With the help of simulation tools 8 different scenarios were developed: Standard with blockchain technology (SwBT); Standard without using blockchain technology (SwoBT); Standard with partial use of blockchain technology (SwBT(p)); Risk with blockchain technology (RwBT); Risk without blockchain technology (RwoBT); Optimistic with blockchain technology (OwBT); Optimistic without blockchain technology (OwoBT); Optimistic with partial use of blockchain technology (OwoBT(p)).

The standard scenario allows to evaluate the effectiveness in the first year after the introduction of a new information system, when business processes of its maintenance are not fully adjusted, and business users have not yet adapted to the changes and can't independently (without the involvement of system and application programmers) solve problems that arise in the process. The risk scenario simulates a threefold increase in the likelihood of return flows relative to the standard procurement scenario. The optimistic scenario evaluates the efficiency of business processes in the case when all information system maintenance operations are performed according to the approved regulations, and users are trained and can independently make changes to the procurement procedures.

The calculation of efficiency indicators in scenarios using blockchain technology and smart-contracts takes the total capital costs of the information system implementation and operating costs of its maintenance under consideration, and in scenarios without the use of these technologies, only the costs of the payroll of procurement department employees are considered. The simulation results are summarized in Table 4.

Table 4 - Results the simulation process of procurement procedures in the standard, risk and optimistic scenarios

Scenario	**Time, thousand hour**	**Costs, million rubles**	**Completed procurements, items**	**Failures, items**	**Number of adjustments, items**	**Procurements completed on time, %**
SwBT	106,1	138,7	771	229	492	77,1%
SwoBT	165,8	183,2	652	348	759	65,2%
SwBT(p)	141	167	593	407	687	59,3%
RwBT	114,7	159,7	650	350	3298	65,0%
RwoBT	**254**	**272,3**	**535**	**465**	**3737**	**53,5%**
OwBT	**106,9**	**144,2**	**782**	**218**	**238**	**78,2%**
OwoBT	164,1	181,1	667	333	664	66,7%
OwoBT(p)	142,6	168,7	681	319	342	68,1%

The source: made by author

The aggregate of the results obtained under risk conditions demonstrates the greater efficiency of blockchain and smart-contracts based systems compared to classical information solutions that require direct human involvement, which proves the justification of their implementation in a particular scenario. The results of the optimistic scenario also demonstrate the high potential of the technology in the near future, when all

initial problems will be eliminated and the system will work completely without human involvement within the process. In this case, time and cost savings could range from twenty to fifty percent, and the number of adjustments would more than halve.

With appropriate company goals (minimizing risk, implementing new technology, automating processes, and making them more efficient), the results presented above may lead executives to make the decision to implement blockchain and smart-contacts in procurement processes.

5. Forming the criteria and indicators for evaluating the effectiveness of using blockchain technology in procurement procedures

To validate the effectiveness of blockchain and smart-contracts in procurement procedures and to increase the credibility of simulation results, it was necessary to develop an independent set of criteria and performance indicators that can be used for management decision-making in the field of procurement. The study of the Ministry of Digital Environment of the Russian Federation shows that the information systems that use blockchain and smart-contracts technology should correspond to market expectations in terms of such indicators as the level of system throughput; data storage security, availability of resources and tools needed to create and audit smart contracts, system integration time and other indicators[3].

Based on this study, and expert survey of employees of information technology departments involved in the implementation of blockchain technology and smart-contracts, a set of criteria for the effective use of blockchain technology and smart-contracts in procurement procedures was formed, and formulas for calculating the corresponding indicators for these criteria were proposed. The list of criteria and calculation dependencies for calculating the values of the corresponding indicators are shown in Table 5.

[3] Ministry of Digital. A roadmap for the development of "end-to-end" digital technology "Distributed ledger framework" [Online]. – 2019. – Available from: https://digital.gov.ru/ru/documents/6670/ [Accessed 15 August 2020].

Table 5 – Estimated dependencies of the quantitative assessment of the effectiveness indicators of blockchain technology and smart contracts in procurement

Efficiency criterion	**Calculation formula**
1. Reducing the timing of the procurement process, %	$R = 1 - \frac{t_1 * Q_1}{t_2 * Q_2}$, where Q – the total number of operations; t – average throughput time; *1* – indicator produced by the application of blockchain technology; *2* – current indicator.
2. Reducing the labor intensity of the procurement process, %	$R = 1 - \frac{N_1}{N_2}$, where N – the number of production-staff units (can also be expressed in value terms using information on the payroll or through the calculation of the full-time equivalent).
3. Decrease the level of "defects" in the procurement process, %	$R = 1 - \frac{Q_1}{Q_2}$, where Q – the average number of errors per procurement during the implementation of the process.
4. Decrease in operational costs of the procurement process, %	$R = 1 - \frac{N}{N + \Delta ФОТ_{(Z)} + \Delta ФОТ_{(IT)} + Q}$, where N – the amount of costs incurred by the unit to maintain the Procurement function; $\Delta ФОТ_{(Z)}$ – change in the Procurement function's payroll due to a reduction in labor costs for the process due to the introduction of technology; $\Delta ФОТ_{(IT)}$ – changes in the IT function's payroll due to the need to hire additional IT specialists to make blockchain technology work; Q – the amount of additional costs of using blockchain technology.
5. Increasing the audience coverage of potential contractors involved in the procurement process, %	$R = 1 - \frac{N_2}{N_1}$, where N – total number of procurement participants.
6. Reduction of the total cost of purchased goods and services, %	$R = \frac{Q_2}{Q_1}$, where Q – total expenditures on purchases.
7. Increasing the quality of contractors and acquired services in the procurement process,%	$R = 1 - \frac{N_2}{N_1}$, where N – the average number of repeated procurements.

Based on the formulas proposed in Table 5 to calculate the above indicators, the calculation was made based on the raw data provided by a major Russian company operating in the oil and gas industry, in which blockchain and smart-contact technologies have been implemented. The staff of procurement department in this company exceeds 500 people, and the payroll amounts to more than one billion rubles. About 30 percent of procurements in this company are carried out repeatedly. To confirm the correctness of the evaluation, the expert survey also obtained the target values of the indicators for the

performance criteria. The results of the calculation and the target range for the criteria are presented in Table 6.

Table 6 – Results of calculating the effectiveness of blockchain technology and smart-contracts in procurement procedures

Efficiency criterion	**Result**	**Target level (range)**
Reducing the timing of the procurement process	Decreased by 28.6%	Decrease by 25-80%
Reducing the labor intensity of the procurement process	Decreased by 13.5%	Decrease by 10-65%
Decrease the level of "defects" in the procurement process	Decreased by 6%	Decrease by 5-40%
Decrease in operational costs of the procurement process	Decreased by 9.3%	Decrease by 0.5-7%
Increasing the audience coverage of potential contractors involved in the procurement process	Decreased by 4.3%	Increase by 0.5-3%
Reduction of the total cost of purchased goods and services	Decreased by 1.3%	Decrease by 1-3%
Increasing the quality of contractors and acquired services in the procurement process	Decreased 18.8%	Increase by 1-10%

The source: made by author

The results show that the expert estimates for the criteria of reducing the time required to perform operations, reducing labor intensity, reducing defects and reducing the total cost of procured goods and services were reliable (they fell within the specified range). At the same time, the result obtained for the indicator of reduction of operating costs exceeded the experts' expectations, which indicates the conservatism of the expert assessment in this area. However, according to the indicators of increasing audience coverage and improving the quality of contractors, we can state a negative result, which is most likely due to the novelty of this technology and the lack of willingness of individual companies to pay it for the purpose of one or more transactions.

Based on the above results, the potential economic effect arising from the implementation of this technology in procurement was also calculated. The direct economic effect obtained by optimizing operating costs (labor costs) was 39 million rubles a year; the implicit economic effect achieved by reducing the level of

"defectiveness" and reducing the labor intensity and time of operations was estimated in the range from 78 to 112 million rubles a year. The calculation of investment attractiveness was carried out on a horizon of five years and accounted for a discount rate of 9% per year.

In addition to the above criteria and performance indicators, the research also presents criteria and performance indicators for the feasibility of using blockchain technology and smart-contracts in procurement, based on the volume of goods turnover and total costs of ownership (TCO), arising in the process of procurement procedures. The feasibility of using the mentioned technologies appears only in the interaction of several large companies (three or more) with a total turnover of billions of rubles (at least four or five) and the TCO of the procurement procedures more than two hundred million rubles. At the same time, experts rate the minimum cost of implementing an information system based on blockchain technology and smart contracts at 50-70 million rubles.

Thus, the use of blockchain technology and smart contracts in some cases increases the efficiency of procurement procedures, but to make the appropriate management decision it is necessary to calculate performance indicators, or to develop a simulation model to assess changes in the quantitative and qualitative characteristics of the optimized business process. Excluding these steps the company may incur significant financial and reputational costs associated with the novelty and imperfection of this technology.

III. THE MAIN CONCLUSIONS OF THE RESEARCH

1. Existing approaches to assessing the effectiveness of the implementation of information systems are based on methods for analyzing data obtained in the course of an expert survey. The use of other sources of information is not possible due to the novelty and speed of the emergence of modern information technology.

2. Digitalization of procurement procedures involves not only the transition to new information technologies (in particular, blockchain and smart-contracts), but also changes in the business processes themselves, because the quality of the implemented software products directly depends on them.

3. The high level of information technology dependence on the quality of business processes makes it impossible to unambiguously assess their contribution to improving the efficiency of companies' production processes. Therefore, to increase the reliability of assessing the effectiveness of their implementation, it is necessary to use quantitative and qualitative indicators and relevant models together, and subjective assessments obtained from experts.

4. The proposed decision-making algorithm for procurement procedures allows to evaluate the effectiveness of stages in the procurement of goods and services with and without the application of new information technology, and also contributes to the economically based management decisions in the procurement.

5. Analysis of the results of traditional approaches, models and methods for assessing the effectiveness of business processes in procurement does not provide the necessary level of validity and reliability in assessing the effectiveness of blockchain technology and smart-contracts in procurement procedures. This assessment requires the development of multi-criteria agent systems using simulation modeling tools.

6. The method of multi-criteria analysis proposed in the work of Pavlov A.N.[1] can be used to make decisions about the choice of software products based on blockchain technology and smart-contracts in procurement procedures.

7. The main benefits of blockchain technology and smart-contracts in the digitalization of procurement are increasing the reliability of the data storage system; improving data quality and data security; minimizing the risk of data falsification.

8. The use of blockchain technology is appropriate for companies where the turnover of goods and services purchased is more than four to five billion rubles, and the total cost of procurement procedures is no less than two hundred million rubles.

9. Applying blockchain technology and smart-contracts in business processes of procurement procedures may be appropriate for solving problems of reducing the time of operations; reducing their labor intensity and the level of "defectiveness"; reducing operating costs and the total cost of purchased goods and services.

10. The results obtained by using the developed algorithm for evaluating procurement procedures using blockchain technology and smart-contracts, created agent-based simulation model of the procurement process, and calculations based on the proposed indicators and performance criteria confirm the novelty and practical significance of the scientific and methodological framework for management decisions in the implementation of procurement activities presented in the dissertation work.

IV. PUBLISHED PAPERS

A. Papers published by the author in scientific journals indexed in Scopus:

1. Kolosov, A. Blockchain technology as a platform for integrating corporate systems / A. Kolosov, B. Sokolov // Automatic Control and Computer Sciences. – 2021. – Vol. 56. – No. 3. – P. 234-242 – 0,79 p.s. (personal contribution – 0.6 p.s.). (Q3, 2020, SJR[4]).

B. Papers published by the author in scientific journals included in the list of high-level journals prepared by the Higher School of Economics:

1. Kolosov A.M. Improving supply logistics efficiency based on blockchain technology // Logistics and Supply Chain Management. – 2020. – № 3(98). – P. 51-56. – 0,77 p.s.

2. Kolosov A.M. Prospects of blockchain technology in the automatization of procurement // Logistics and Supply Chain Management. – 2018. – № 6(89). – P. 31-38. – 0,81 p.s.

C. Other works published by the author in scientific journals on the topic of dissertational research:

Kolosov, A. Comparison of ERP systems with blockchain platform / B. Sokolov, A. Kolosov // Advances in Intelligent Systems and Computing. – 2019. – Vol. 860. – P. 240-247.

[4] URL: https:// www.scimagojr.com/journalsearch.php?q=24906&tip=sid&clean=0 (Accessed 20 May 2021).