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Alexey Beskopylny
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Contents

Engineering Technologies for Precision Agriculture

Digital Technologies Adoption in the Agro-Industrial Complex as a Priority of Regional Development in the Conditions of Global Macroeconomic Changes

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Abstract. The article analyzes digital technologies adoption in the agro-industrial complex using the example of the Rostov region as a geostrategic territory and one of the promising regions in terms of economic development for the formation of world-class scientific and educational centers in the context of global macroeconomic changes. The growing world population and changing dietary patterns are increasing the demand for food. Crop yields are declining in many parts of the world, oceans are deteriorating, and natural resources, including soil, water and biodiversity, are becoming dangerously small. The trend of digitalization of the economy before the start of the COVID-19 pandemic, as well as its rapid development immediately in 2020, is described. It is concluded that the COVID-19 pandemic has accelerated the formation of a new high-tech food production market and pushed for investments in promising directions for the development of the agro-industrial complex in the context of macroeconomic changes in Russia and the world.

Keywords: Agro-industrial complex · Digital Economy · Digital technologies in the agro-industrial complex · Regional development · Big challenges and threats · COVID-19 pandemic

1 Introduction

According to the Food and Agriculture Organization's 2020 Report, 690 million people—or 8.9% of the world's population—go hungry. The problem of food security will only get worse, as the world will need to produce about 70% more food by 2050 to feed an estimated 9 billion people [1].

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The problem is compounded by the extreme vulnerability of agriculture to climate change. The negative impacts of climate change are already being felt in the form of declining yields and an increase in extreme weather events affecting both crops and livestock. Substantial investment in adaptation will be required to maintain current yields and achieve the required increases in production.

Today for farmers is an issue: how to collect from one hectare and more crop to spend the less resources both human and material? Increasing yields and production efficiency requires a large-scale task to increase agricultural exports. According to the Decree of the President of the Russian Federation of May 7, 2018 No. 204 "On national goals and strategic objectives of the development of the Russian Federation for the period up to 2024", the export of the agro-industrial complex should almost double, to 45 billion US dollars [2].

Digital transformation has been increasing and becoming a reality today over the past ten years due to the actual Internet use by more than the half of the world's population. The production and the socio-economic spheres of society digitalization is becoming the most important criterion for the countries, business and people inclusion in the global agenda and life in general. This became especially noticeable during the coronavirus crisis and self-isolation [3].

The 2020 pandemic accelerated the digital economy growth rate, which had an impact not only on enterprises, the economies, but also on virtually every individual. Not only many business entities, but also entire states were not ready for a sharp transition to the digital plane caused by the need for home office due to the coronavirus infection spread, which was associated with additional investments and the introduction of crisis plans.

2 Materials and Methods

The literature review on economy digitalization allows us to note the following.

Tapscott and Tapscott [1] in their research "How blockchain will change organizations" [4] focus on three main areas: "the new economy and the factors that shape it; interconnection and its relationship to business and government and, finally, the need for strong progressive leadership that will be responsible for transformation or will be the agents of change in this new era".

In turn, economists Jacobsson et al. [2] in their research "A risk analysis of a smart home automation system" come to the conclusion that "the new or digital economy is a dynamic, not static efficiency."

As for now, the program "Digital Economy of the Russian Federation" in Russia takes place, which determines the country's economic sphere development till 2030.

Parviainen, Päivi and others [3] in their research [6] come to the conclusion that modern digitalization trends are changing the usual state, business and society environment. These changes, on the one hand, bring new opportunities for increasing the competitiveness of work efficiency, and on the other hand, they destabilize the current processes of both individual companies and the global business environment organizational structure.

The main promising financial technologies are: Big Data and Data Analysis; Mobile Technologies; Artificial Intelligence; Robotization; Biometrics; Distributed Ledgers; Cloud Technologies.

In his work [4, 7], he comes to the conclusion that the ongoing process of digitization not only leads to an increasing automation of processes.

Leveraging Mobile Cloud Computing (MCC), which enables mobile users to benefit from cloud computing in an environmentally friendly manner, is an effective strategy to meet current industrial needs. However, the limitations on wireless bandwidth and device capacity create various barriers such as additional power wastage and latency in the deployment of the MCC. The authors [5, 8] in their work propose a dynamic mobile cloud computing model (DECM) focused on solving the problem of additional power consumption during wireless communication through the use of a dynamic cloud computing (DCL) model.

The COVID-19 pandemic is accelerating the formation of a new high-tech food production market and prompting investments in promising areas. Analysts predict that by 2035 the global market for food production technologies will amount to about USD 5.9 trillion, with Russian companies forecasting 4–8% of this amount.

3 Results

In accordance with the Strategy of Socio-economic Development of the Rostov Region until 2030, the goals of sustainable development of the region are:

- ensuring the social well-being of the population (person);
- increasing the competitiveness of the Rostov region in the external environment;
- playing the role of a supporting region of the "new economy" of Russia;
- implementation of the functions of the scientific, technological and political and administrative center of the South of Russia;
- preservation of the unique ecosystem of the Don region.

The conceptual basis of the Strategy of the Rostov Region is the idea of sustainable development—coordinated and balanced economic, social and spatial development, taking into account and respecting the interests of the present and future generations of residents of the Rostov Region.

In the Rostov region, a powerful research and development sector has been formed, which is engaged in the production of innovative ideas and new technologies.

The city of Rostov-on-Don, in turn, is defined as one of the promising centers of economic growth, in which conditions have developed for the formation of world-class scientific and educational centers, and the Rostov region is a border geostrategic territory of the Russian Federation.

The concept for the development of the Southern Scientific and Educational Center "Digital Transformation of the Agro industrial and Industrial Complex" (hereinafter referred to as the Southern REC) involves the creation of a center of attraction for highly qualified personnel, innovations and world-class scientific research. Cooperation in the format of the Southern REC creates conditions for hyper-concentration and multiple growth in the rate of commercialization of innovations in the context of the economic specialization of the region—the development of digital solutions in the agricultural industry [9].

The mission of the Southern REC is the transformation of the region into an economically efficient ecosystem of digital highly productive and risk-free world-class agriculture through the technical modernization of the agro-industrial complex through the introduction of revolutionary digital models and technologies in the fields of crop production, animal husbandry and industrial aquaculture, as well as complexes of intelligent autonomous agricultural machines.

The global task of South REC is to make the region visible on the global resource map and scientific world landscape to attract investment, talent flow and create high-tech startups [10].

The Rostov Region accounts for half of all domestic R&D expenditures in the Southern Federal District. The region is distinguished by a developed scientific and educational complex.

The specialization of Yuzhny REC is justified by the region's leading position in agricultural machine building, especially taking into account the country's largest enterprise, Rostselmash. The region is actively developing aircraft and helicopter manufacturing (PJSC Rostvertol, The PJSC Beriev Aircraft Company), electric locomotive building (The PJSC Beriev Aircraft Company) [11].

The largest industrial enterprises in the region have their own research base, design potential, large production facilities, a wide dealer network, significant experience in export activities (including PCF Atlantis-Pak LLC, *OJSC Krasny Kotelshchik*, and a branch of CJSC AEM Technologies (Atommash)) and others.

The region maintains a positive dynamics in the development of the agro-industrial complex. To solve the problem of increasing exports, the Rostov region, among other things, focused on the development of port infrastructure. Currently, seven port projects are being implemented on the Don with a total investment of over 10 billion rubles [12].

The flagship of the Russian agricultural machinery industry—the leading partner of the Southern REC—the Rostselmash company, sees its aim to increase production and technological indicators, as well as the introduction of digital technologies that allow bringing the national agricultural industry to the world level [13].

However, despite the existing potential, available resources and government support for the national agro-industrial complex, Russian companies have a significant lag behind the leaders of the global agroindustry and manufacturing giants in North America, in particular the United States, the Asia–Pacific region and Europe [14]. For example, the American machine-building company, the world's largest manufacturer of agricultural, construction and forestry equipment, Deere and Company (John Deere), annually produces agricultural equipment worth 23.3 billion US dollars. Together with road construction equipment—this is US $ 33 billion. Rostselmash—by USD 1 billion, which is 33 times less than that of the American giant.

In this regard, the introduction of digital technologies, robotic devices in agriculture in Russia, public investment in cooperation with the scientific and technical community can turn the tide and make the national sector of the agro-industrial complex a leader.

As of October 13, 2020, the Rostov region came out on top in the country in terms of the harvest of early grain crops, having harvested almost 11.7 million tons. According to the data of Ministry of Agriculture and Food Production of the Rostov Region, the

Rostov Region has the country's largest fleet of agricultural machinery: 29 thousand tractors, 12 thousand combines.

The largest enterprises in the region, leaders of the Russian manufacturing sector and regional agricultural holdings are actively pursuing a policy of digital transformation of production processes, introducing high-precision production technologies and the intellectualization of processes.

Currently, the region has accumulated a critical mass of highly qualified specialists and centers of the IT industry, which is a good foundation for the formation of an IT cluster for the development of end-to-end digital solutions and technologies that are increasingly used by farmers. One of the directions of the IT cluster in the field of big data processing will be solutions to increase yields, based on the analysis and prediction of weather, temperature, humidity, soil condition and other factors critical for agricultural producers.

In the Rostov region, a powerful research and development sector has been formed, which is engaged in the production of innovative ideas and new technologies. The region has a developed network of innovative infrastructure. A member of the Southern REC is the Regional Development Corporation JSC, a specialized organization of the Southern Constellation cluster.

However, there are problems related to the fragmentation in the work of universities, the shortage and migration of young specialists and scientists, the need to raise leaders of innovative research projects, as well as their scientific focus on commercial and state enterprises and centers that are actively developing in the region.

The creation of the Southern REC will give a new impetus to the development of the Rostov region and will transform the region into an economically efficient ecosystem of digital highly productive and risk-free agriculture of the world level.

4 Discussion

4.1 Creation of a National Innovation Ecosystem for the Development of the Agroindustry

The main goal of the scientific and technological development of the agro-industrial complex of Russia is to ensure the competitiveness of Russian products in the foreign and domestic markets, primarily through the creation, distribution and application of the latest achievements of science and technology.

South REC opens up new opportunities for cooperation in the following areas of scientific and technological activities (Fig. 1).

4.2 Global Goals of the Southern REC

Productivity growth agro Russia. World population growth, a decrease in arable land in the world, a decrease in the reserves of minerals for the production of fertilizers, a decrease in the available reserves of fresh water, all this leads to the need to control the resources used in agriculture, no matter where in the world the agricultural enterprise is located. For example, in the United States, arable land per person has decreased from 0.5 hectares to 0.4 hectares in 30 years.

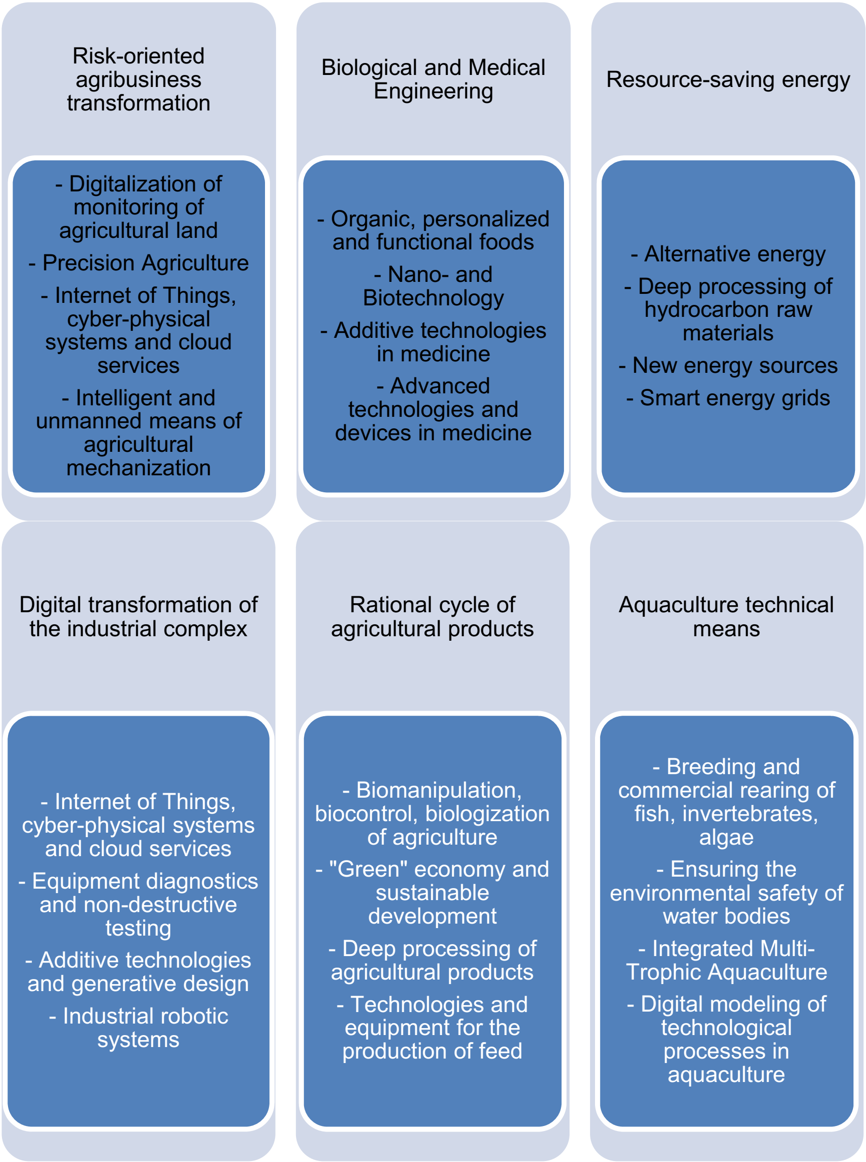

Fig. 1. The main directions of R&D in the Southern REC

Agricultural development is one of the most powerful tools for eradicating poverty, improving overall prosperity and providing food for a growing population by 2050.

But agriculture-driven growth, poverty reduction and food security are threatened: climate change could reduce crop yields, especially in the most food-insecure regions of the world. Agriculture, forestry and land-use change account for about 25% of greenhouse gas emissions. Mitigation in the agricultural sector is part of the solution to climate change.

According to official data from Rostovstat, the area under crops for the harvest of 2020 in the Rostov region in farms of all categories totals 4,701 thousand hectares, which is 1% higher than the level of 2019.

The main producers of grain, sunflower, sugar beet in the region are agricultural organizations and peasant (farmer) households. Their share in the structure of sown areas occupied by grain and leguminous crops is 60.9 and 38.3%, sunflower—60 and 39.5%, sugar beet—76.7 and 23.3%, respectively. The share of households accounts for 65.1 and 77.1% of the area occupied by potatoes and vegetables.

Russian agri-food sector is characterized by the dominance of the major producers.

According to a survey conducted among the largest companies and manufacturers in the agro-industrial complex of the Rostov region, the greatest potential for increasing the efficiency of the agroindustry is seen in grain production (36.5%), vegetable production (36.5%), beef cattle breeding (34.6%), processing of agricultural products (28.8%).

The creation of agricultural technology high accuracy and intellectualization of agro. According to specialized research company AgFunder, in 2019 the volume of investments in agricultural technology has made 19.8 bln. Dollars. USA, which is only 4.8% less than the record in 2018.

AgFunder's report, AgriFoodTech 2019, notes that US $ 19.8 billion was invested in the agri-food technology sector last year as a result of 1,858 transactions and agreements. This is only $ 1 billion, or 4.8% less than in the record 2018 and significantly more than 2017—$ 11.5 billion.

At the same time, the researchers note that the decline in investment in agricultural technology in 2019 occurred against the background of a deeper decline in global venture capital investments as a whole—by 16%. In general, over the past five years, according to AgFunder, investments in the agricultural technology industry have grown by 250%.

The transition to high-performance, high-tech, climate-adaptive, resource-efficient production of agricultural raw materials and products of high processing depth is expected to be carried out at the maximum CAGR from 2020 to 2025 due to significant cost savings associated with the cloud software platform, as well as the increase in the number of farmers, producers and ranchers.

According to a survey conducted among the largest companies and manufacturers in the agricultural sector of the Rostov region, the greatest motivation for the introduction of new technologies is the prospect of higher profitability (47.1%), increased competition in the market (21.2%), and government support (22, ten%) [15].

In turn, respondents see the modernization of agricultural equipment (45.2%), digitalization of the enterprise (40.4%), biotechnology in agriculture (27.9%) as popular areas of "smart agro-industrial complex" for their company and the development of the industry as a whole, professional staff, and accessible market infrastructure (20.2%).

Autonomous agriculture, allowing development in the face of the global threat of a pandemic.

The consumption of food in the world will only grow. However, players have to quickly change their business model and rebuild themselves into online trading. The interface between humans and food manufacturers is undergoing a major transformation, creating new opportunities for innovation.

A change in consumer behavior is taking place in the world. On the one hand, the economic crisis has traditionally forced to reduce consumption and switch to economy class goods. On the other hand, there is a growing demand for a healthy diet that promotes strong immunity. New food biotechnologies must solve the problem of reducing the cost of nutrition while increasing its functionality.

Digitalization will increase the efficiency of farms and create opportunities for the application of optimal technologies in agro chemistry and plant protection, which will intensify the development of the industry and its national and global competitiveness in the context of the transition to Industry 4.0, being one of the main drivers in the agro-industrial complex.

In accordance with the agenda of world agriculture, crops will become more autonomous. The sudden disruption of supply chains, emerging shortages and the declared threats of global hunger should accelerate the development of autonomous technologies in crop production. Urban agriculture is a new trend.

Genetics and rapid breeding are important elements of market strategy.

The world market, regardless of geographic affiliation, is united by common problems of a planetary scale: a shortage of biological resources, a shortage of arable land, reaching efficiency limits at the current stage of development of animal husbandry, large-scale production and logistics losses in the production, delivery and trade of products.

The threat of mass diseases as a result of insufficient resistance of the human body, which is also directly related to the quality of nutrition and the pandemic has exacerbated global problems, thereby accepting the challenge of new operational solutions.

Following COVID-19, the global digital agriculture market is projected to reach $ 6.2 billion by 2021, with a CAGR of 9.9%. The growing demand for agricultural food, changing consumer preferences in favor of higher food safety and quality standards and a lack of workers during COVID-19 are some of the driving factors for the market.

A benchmark for carbon neutrality or net zero carbon footprint. The World Bank Group is currently scaling up sustainable agriculture. In its Climate Change Action Plan, the World Bank committed to working with countries to build sustainable agriculture that delivers a triple win in productivity, sustainability and emission reductions [16].

The 2015 Paris Agreement set a global goal (couched in legalese) to reach net zero emissions in the second half of the century.

An increasing number of governments are translating that into national strategy, setting out visions of a carbon-free future: 66 countries, including Germany, 10 regions, 102 cities, 93 companies and 12 investors, have committed to achieving carbon neutrality by 2050. The corresponding document was signed in New York before the start of the UN Climate Summit on September 23, 2019.

5 Conclusion

Achievement of the set goals of creating the Southern REC will ensure the global leadership of Russia in the market of smart agricultural machines in order to increase the global production of environmentally friendly, safe and healthy food products within the framework of a risk-based approach and digital transformation of the economy.

Within the framework of the national project "Digital Agriculture", developed and implemented by the Ministry of Agriculture of the Russian Federation, it is planned to achieve the following:

1. Implementation of digital technologies and platform solutions to ensure a technological breakthrough in the agro-industrial complex and achieve a twofold increase in productivity by 2024.
2. Identification and analysis of problems and conditions restraining the development of digital technologies in the agro-industrial complex of the regions of the Russian Federation and determination of the main and most promising digital technologies from the position of an agricultural producer.
3. Formation of competencies in the field of digital economy among specialists of agricultural enterprises.

These measures will help to implement the digital transformation of agriculture through the introduction of digital technology and platform solutions for a technological breakthrough in the agro-industrial complex and to achieve productivity growth in the "digital" agricultural enterprises two times by 2024.

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Methodology for Assessing the Efficiency of Measures for the Operational Management of the Technical Systems' Reliability

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Abstract. A generalized analysis of the directions of improving the operational reliability and efficiency of the use of MES in the implementation of technological processes in the agro-industrial complex is performed. On the basis of the analysis, a methodology for evaluating the effectiveness of the implementation of technical service strategies by a comprehensive indicator of the effectiveness of reliability management based on functional operational diagnostics of MES and their structural elements is proposed. A technical and economic assessment of the effectiveness of the proposed methodology was performed.

Keywords: Reliability · Mobile Power Plant · Technical Service · Integrated Performance Indicator · Strategies and Service Trajectories

1 Introduction

Rational organization plays key role in the technical service system under conditions of physically and morally outdated mobile energy vehicle (MEV) fleet.

The main issues that include the organization of technical service are the provision of reference, regulatory and technical documentation; information support; organization and management of human and production resources; provision and use of operational and technological materials; formation of safe working conditions for personnel. The main task of the technical service is, nevertheless, to ensure high level of operational reliability of agricultural machinery with minimal labor and cost [1–8].

The use of methods and means in the process of technical maintenance for diagnosing the technical state of their structural elements in the process of technical operation of mobile energy vehicles (MEV) is one of the most important measures to improve the

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reliability and efficiency of their work. Objective and operational information about the actual technical condition of elements of mobile energy vehicles (MEV) allows to plan the required amount of preventive measures, prevent exploitation under unsatisfactory technical condition, reduce the consumption of fuels, lubricants and operating materials, as well as spare parts and consumables.

The priority areas for improving technical service, along with increasing the operational reliability of mobile energy vehicles (MEV), also include lessening the duration and cost reduction of measures for diagnostics and maintenance.

2 Materials and Methods

In connection with the foresaid, it is necessary to strive to ensure the following conditions:

$$\left.\begin{array}{l} K_{aMEV} \to 1 \\ P_{MEV} \to 1 \\ T_{dMEV} \to \min \\ C_{dMEV} \to \min \end{array}\right\}, \tag{1}$$

where K_{aMEV} vailability ratio of mobile energy vehicle (MEV); P_{MEV}—probability of failure-free operation of mobile energy vehicle (MEV); T_{dMEV}—laboriousness of operations for diagnosing mobile energy vehicle (MEV), person-h; C_{dMEV}—unit operating costs for diagnosing mobile energy vehicle (MEV), thousand roubles.

For systematic assessment of the efficiency of time and money spent on ensuring the required level of reliability of the mobile energy vehicle (MEV) and its elements in accordance with the optimization criteria presented by dependence (1), as well as choosing the optimal strategy (trajectory) of maintenance, depending on the logistics of the operating organization comprehensive performance indicator is needed.

Harrington's desirability criterion is suitable integrated indicator that allows one to reduce the original multicriteria decision-making issue with different-sized criteria to multicriteria issue with criteria measured on the same scale. The criterion proposed by Harrington for describing particular criteria and constraints in solving multicriteria issues makes it possible to establish correspondence between linguistic estimates of the desirability of assessment indicator values and the numerical intervals of preferences [9, 10]. The intervals take on values that increase continuously from 0 to 1. The desirability criterion value equal to zero corresponds to unacceptable value of the optimization parameter, and if it is equal to one it is its maximum possible level.

Advantages of the Harrington desirability criterion consist in possibility to evaluate the effectiveness of the taken measures; the criterion is quantitative; unambiguous, i.e. one criterion value corresponds to given set of values of partial assessment parameters; basis for strategic and operational planning, management and for process optimization can be designed; it is versatile and can be used in various fields.

The complexity and laboriousness of plotting the desirability graph is significant drawback of this method, as well as its low sensitivity due to the visual determination of the result.

- List of partial assessment parameters is determined, i.e. that are criteria by which the process will be evaluated (quantitative, qualitative).
- The boundaries of admissible values are established for all particular parameters of the assessment. When setting the boundary for the admissible values of the particular assessment parameters, it should be borne in mind that the restrictions can be set unilateral or bilateral. Unilateral constraints are established if the desirability criterion improves only with unidirectional change in the indicator (decrease or increase). Unilateral constraints are denoted as $y_i \leq y_{\max}$ or $y_i \geq y_{\min}$ bilateral constraints are denoted as $y_{\min} \leq y_i \leq y_{\max}$
- Efficiency scale is selected. As efficiency scale, it is proposed to use table of correspondences between preference relations in the empirical and numerical (psychological) systems (Table 1) [9, 10].

Table 1. Numerical intervals of the efficiency scale

Linguistic assessment (score)	The intervals of values the criterion of desirability
Very bad (1)	0.00–0.19
Bad (2)	0.20–0.39
Satisfactory (3)	0.40–0.59
Good (4)	0.60–0.79
Very good (5)	0.80–1.00

In accordance with the efficiency scale, the values of the efficiency criterion k_i change in the range from 0 to 1. The value of the i-th particular parameter k_i , converted into dimensionless efficiency scale, is called the partial efficiency (i = 1, 2, 3 … n is the current number of the parameter, n is number of partial parameters). In this case, the value $k_i = 0$ responds to unacceptable value of the parameter $k_i = 1$, corresponds to its maximum possible level.

- For each particular assessment parameter, the values of the efficiency criterion are determined.

The criterion of efficiency of the i-th partial parameter for unilateral constraint is determined by the proposed dependencies:

- in the case when the improvement of the efficiency criterion occurs when the value of the partial parameter rises (K_{aMEV}, P_{MEV})

$$k_i = \frac{y_i - y_{\min}}{y_{\max} - y_{\min}} \tag{2}$$

- in the case when the improvement of the efficiency criterion occurs when the value of the partial parameter declines (T_{dMEV}, C_{dMEV})

$$k_i = 1 - \frac{y_i - y_{\min}}{y_{\max} - y_{\min}} \tag{3}$$

where y_i—current value of the i-th partial parameter;$y_{\min}$—minimum value of the ith particular parameter; $y_{\max}$—maximum value of the i-th particular parameter.

The values of particular efficiency criteria of k_i came down to integrated efficiency indicator, defined as geometric mean of the particular criteria according to the formula

$$CPI = \sqrt[n]{\prod_{i=1}^{n} k_i} \longrightarrow \max \tag{4}$$

The proposed integrated indicator is universal tool and can be used to assess the effectiveness of absolutely any processes.

In accordance with the optimization criteria (1) in relation to the process of managing the reliability of mobile energy vehicle (MEV), the value of integrated performance indicator (CPI), which allows to assess the effectiveness of time and money spent on ensuring the required level of reliability of mobile energy vehicle (MEV) and its elements, is determined by dependence

$$CPI_{MEV} = \sqrt[4]{k_{K_{aMEV}} \times k_{P_{MEV}} \times k_{T_{dMEV}} \times k_{C_{dMEV}}} \rightarrow \max, \tag{5}$$

where $k_{K_{aMEV}}$—efficiency criterion of the interval availability factor of mobile energy vehicle (MEV); $k_{P_{MEV}}$—efficiency criterion of the probability of failure-free operation of mobile energy vehicle (MEV); $k_{T_{dMEV}}$ efficiency criterion of labor intensity of operations for diagnosing mobile energy vehicle (MEV); $k_{C_{dMEV}}$—efficiency criterion of unit operating costs for diagnosing mobile energy vehicle (MEV).

The most effective is the strategy (trajectory) of the technical service that provides greater value CPI_{MEV}.

3 Results

Evaluation of the effectiveness of time and money spent on ensuring the required level of reliability with the proposed integrated efficiency indicator was carried out according to formula (5) for the basic and proposed (new) options using the example of the YuMZ-6AL tractor for strategies «S1», «S2» and trajectories «S1 + general functional operative diagnostics (GFOD)», «S2 + GFOD».

For the basic version, the standard methods of diagnosing mobile energy vehicle (MEV) were taken, and for the new one, the proposed methods that implement functional operational diagnosis (FOD) were taken. In the calculations, there were used the average standard labor intensity values of the diagnostics and unit operating costs [15]. The average annual fuel consumption of the YuMZ-6AL tractor under the conditions of the North Caucasian machine testing station is 7700 kg, which corresponds to 1000 motorcycle hours.

The results of intermediate calculations of the value of the integrated efficiency indicator of the reliability management of the YuMZ-6AL tractor under various maintenance strategies (trajectories) are presented in Table 2.

Table 2. Results of intermediate calculations of the integrated reliability management efficiency indicator on the example of the YMZ-6AL tractor under various maintenance strategies (trajectories)

Indicator	Current value, y_i	Interval values, $y_{\min} \ldots y_{\max}$	Value of the desirability function, d_i	
			Quantitative	Point
Strategy S1				
K_{aMEV}^{S1}	0.70	0.5…1.0	0.4	3
P_{MEV}^{S1}	70.0	50…100	0.4	3
T_{dMEV}^{S1}	259.5	200…300	0.405	3
C_{dMEV}^{S1}	420	100…500	0.2	2
Trajectory S1 + GFOD				
$K_{aMEV}^{S1+GFOD}$	0.99	0.5…1.0	0.98	5
$P_{MEV}^{S1+GFOD}$	91.0	50…100	0.82	5
$T_{dMEVb}^{S1+GFOD}$	273.5	200…300	0.265	2
$T_{dMEVn}^{S1+GFOD}$	266.5	200…300	0.335	2
$C_{dMEVb}^{S1+GFOD}$	370.2	100…500	0.325	2
$C_{dMEVn}^{S1+GFOD}$	345	100…500	0.386	3
Strategy S2				
K_{aMEV}^{S2}	0.91	0.5…1.0	0.82	5
P_{MEV}^{S2}	91.0	50…100	0.82	5
T_{dMEV}^{S2}	234.1	200…300	0.659	4
C_{dMEV}^{S2}	191.7	100…500	0.771	4
Trajectory S2 + GFOD				
$K_{aMEV}^{S2+GFOD}$	0.99	0.5…1.0	0.98	5
$P_{MEV}^{S2+GFOD}$	97.2	50…100	0.944	5
$T_{dMEVb}^{S2+GFOD}$	248.1	200…300	0.519	3

(*continued*)

Table 2. (*continued*)

Indicator	Current value, y_i	Interval values, $y_{\min}\ldots y_{\max}$	Value of the desirability function, d_i	
			Quantitative	Point
$T_{dMEVn}^{S2+GFOD}$	241.1	200…300	0.589	3
$C_{dMEVb}^{S2+GFOD}$	188.7	100…500	0.778	4
$C_{dMEVn}^{S2+GFOD}$	163.5	100…500	0.841	5

Substituting the obtained values of the partial evaluation parameters into formula (5),there were obtained values of integrated reliability management efficiency indicator on the example of the YuMZ-6AL tractor with various maintenance strategies (trajectories) (Fig. 1) [19, 20].

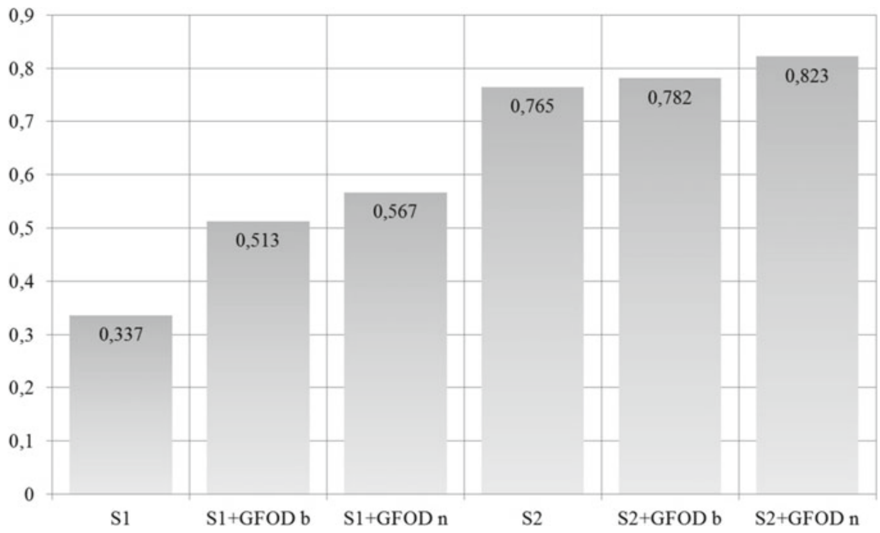

Fig. 1. Histogram of the values of the integrated reliability management efficiency indicator for various strategies and maintenance trajectories of the YMZ-6AL tractor

Strategy «S1»:
$CPI_{MEV}^{S1} = \sqrt[4]{0.4 \times 0.4 \times 0.405 \times 0.2} = 0.337$ (average point – 2.75).
Trajectory «S1 + GFOD» for the basic variant:
$CPI_{MEVb}^{S1+GFOD} = \sqrt[4]{0.98 \times 0.82 \times 0.265 \times 0.325} = 0.513$ (average point – 3.5).
Trajectory «S1 + GFOD» for the new variant:
$CPI_{MEVn}^{S1+GFOD} = \sqrt[4]{0.98 \times 0.82 \times 0.335 \times 0.386} = 0.567$ (average point – 3.75).
Strategy «S2»:
$CPI_{MEV}^{S2} = \sqrt[4]{0.82 \times 0.82 \times 0.659 \times 0.771} = 0.765$ (average point – 4.5).

Trajectory «S2 + GFOD» for the basic variant:
$CPI_{MEVb}^{S2+GFOD} = \sqrt[4]{0.98 \times 0.944 \times 0.519 \times 0.778} = 0.782$ (average point – 4.25).
Trajectory «S1 + GFOD» for the new variant:
$CPI_{MEVn}^{S2+GFOD} = \sqrt[4]{0.98 \times 0.944 \times 0.589 \times 0.841} = 0.823$ (average point – 4.5).
Based on the obtained values of the integrated efficiency indicator of time and money spent on ensuring the required level of reliability of the YuMZ-6AL tractor for different strategies (trajectories) of maintenance according to different methods, it follows that.

$$CPI_{MEV}^{S1} < CPI_{MEVb}^{S1+GFOD} CPI_{MEVn}^{S1+GFOD} < CPI_{MEV}^{S2} < CPI_{MEVb}^{S2+GFOD} < CPI_{MEVn}^{S2+GFOD}, \quad (6.)$$

4 Conclusion

The designed methodology and the proposed integrated reliability management efficiency indicator make it possible to evaluate the implementation effectiveness of strategies for the technical service of mobile energy vehicles (MEV). The values of the integrated reliability management efficiency of the YuMZ-6AL tractor under the conditions of the North Caucasian machine testing station increase with functional reservation of its structural elements along the "GFOD" trajectory of the "S1" strategy from 0.337 to 0.513 according to standard diagnostic methods and up to 0.567 according to the proposed methods, strategy " S2 "from 0.765 to 0.782 and to 0.823, respectively.

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Information and Digital Transformation of the Processes of Monitoring the Episootic Condition of Animals

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Abstract. The article is devoted to actual issues of information and digital transformation of the real economy on the example of monitoring processes for epizootic state of animals. It is assumed that the transformation process, primarily an organizational project, points to the collective and iterative nature of the information and digital transformation process, the core of which is the integration of knowledge, the carriers of which must meet high qualification requirements at each stage of the transformation trajectory. This methodological benchmark contributes to the achievement of the most effective end results with the optimal use of resources. The main methodological approaches, technological methods of creating software and hardware tools for automating production and technological processes for monitoring the epizootic state of animals with the ability to visualize output reports are presented. The form and content of the output reports correspond to technological regulations of veterinary reporting, and prostate of the user interface allows manipulating data in a wide range for comprehensive study of the object in question. The results can be used by both analysts-researchers and specialists of real production, as well as developers of software products as methodological approach.

Keywords: Conceptual Model · Automated Information System · Business Process · Module · Database · Architecture · Visualization · Yandex.Maps · Epizootic State

1 Introduction

The achievement of modern society is the generation of huge amounts of information and their rational organization in order to be used with the help of the latest information technologies. Information technologies are a concentrated expression of scientific knowledge, information and practical experience, presented in a formalized form and allowing a rational organization of a certain information process, are aimed at solving

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management problems on the basis of software that uses a set of methods and means for implementing collection and registration operations, transmission, accumulation and processing of information.

Veterinary medicine, as one of the main areas of science and practice in agriculture, is aimed at studying, preventing, diagnosing and treating animal diseases, protecting the population from zooanthropoonous diseases, providing them with benign and safe products of animal origin. The development of a set of targeted programs for the prevention, prevention and elimination of infectious and mass non-infectious animal diseases on a national and regional scale (including private farms) contributes to a complete solution of the existing problems of the veterinary industry. In such conditions, there is objectively a need for high efficiency and flexibility when conducting applied and analytical research in order to substantiate and introduce innovative technologies into production. Increasing requirements for effective management in conditions of fierce competition in the commodity and raw materials markets necessitates an urgent need to obtain prompt and substantiated information. Therefore, the role of information and analytical support for the support of scientific decisions in the field of applied veterinary medicine has been sharply increasing in recent years. The volume of requirements for operational information is also increasing. The implementation of these requirements in practice is associated with the solution of a number of complex information-analytical and organizational-methodological problems [1–3].

The whole variety of existing "classical" approaches in solving control problems is based on the assumption that it is possible to obtain an analytically specified form of the functional dependence of the input and output signals of the control system, with the subsequent refinement of the values of the coefficients included in it. Nevertheless, with all the depth of elaboration of the existing formalization apparatus, the area of application of such control methods remains control objects with obvious properties, that is, well-formalized objects. In practice, however, control objects are typical, which are poorly formalized.

In connection with the above, scientific and design research aimed at creating software products for automated processing and visualization of the results of monitoring the epizootic state of animals using GIS technologies and PPP is of particular relevance.

The aim of this work is the development of scientific and methodological foundations of applied informatics, as well as the creation of an automated information system to support the visualization and analysis of the results of monitoring the epizootic welfare of animals using GIS technologies and an application package (APP).

2 Methodology and Materials

The theoretical and methodological basis of the research was made up of scientific works of domestic and foreign researchers and specialists in the field of system studies of complex systems and their objects, principles of designing databases, object-oriented and spatial (geographical) data of information systems. The study of the automation object and the substantiation of the tasks and functions of the AIS was carried out based on official statistical data, published results of the work of research institutions and information provided by periodical business and scientific publications, including the resources of the global information network Internet. The database design was carried out in cooperation with scientists in the field of applied veterinary medicine through mutual consultations, taking into account the requirements of information technology and software. At the same time, the results of scientific research in the field of veterinary reporting on infectious animal diseases of domestic and world research organizations were used.

3 Results and Discussion

According to the standards and protocols for creating automated information systems, the design of any automated information system (AIS) is based on the modeling of the subject area. In order to get an AIS project adequate to the subject area in the form of a system of correctly working programs, it is necessary to have an integral, systematic representation of the model, which reflects all aspects of the functioning of the future information system. The construction of such models is a laborious and knowledge-intensive process that requires a lot of effort from the participating specialists representing various industries and areas of knowledge.

One of the variants of the model of the process of forming a database of the subject area from the position of modeling the organizational structure of informatization subjects can be represented as an object with an ordered internal structure, where various connections (physical, technological, etc.) and human relations (Fig. 1).

According to the above scheme, the formation of a database is essentially an iterative process of sequential transformation of natural science models of the processes of achieving practically significant results into information models, the functioning of which is realized using modern hardware and software systems. The system-forming feature of such a system is the target setting to ensure mutual understanding between the participating specialists and the development of a unified view of the information models of the subject area and the hardware and software implementation of their representation in the database of the created AIS [15].

The starting point for starting work should be a conscious decision by a group of subject area specialists (subject specialists) that there is a need for the use of modern information and telecommunication technologies to solve practically significant problems within the studied subject area. The task of domain specialists includes defining the boundaries of the domain based on the nature of the problem being solved, as well as compiling a list of objects and their information models of real processes. In this case, a significant amount of information can be obtained, which is of a subjective nature. Its representation in natural language contains vagueness or ambiguity that have no analogues in the language of traditional mathematics [16].

System research specialists (analysts) play the most important role in the formation of the database. They practically accompany all stages of creating a database of a subject area; their main task is to extract knowledge from specialists in the subject area, which are formalized in models of knowledge representation [14]. At the stage of formation of a conceptual model of interaction of specialists, they are based on the principles of the systems approach and the methodology of systems analysis.

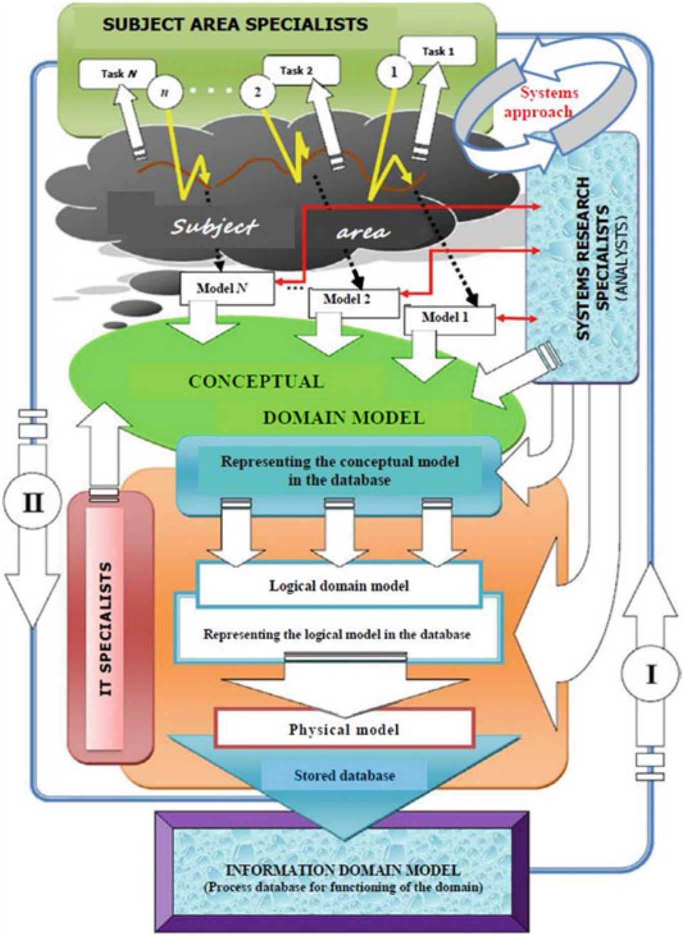


Fig. 1. Conceptual model of the database design process for representing the subject area in the AIS

The main task of IT-technology specialists includes step-by-step measures to justify the hardware and software of the designed information system, as well as the development of the architecture of the database of the subject area, in the structure of the AIS in agriculture.

Thus, the resulting database is tested for functional operability with the participation of end users from among specialists in the subject area, forming a feedback line (line I). After clarification and adjustment, all stages of database creation (line II) are repeated to maintain the quality of the database and AIS as a whole.

The proposed methodological guideline was implemented when creating a database to represent information models of the processes of engineering and technological support of various branches of agriculture [4, 5].

In relation to this work, based on the results of the analysis of the subject area, a diagram of the business logic of the “Monitoring of epizootic welfare of animals” process was presented in the IDEF0 notation, which is shown in Fig. 2, where automation nodes were predefined using modern software and hardware: data collection processes based on the results of animal examination and visualization of the results of monitoring and analysis of the epizootic situation in the Republic of Kazakhstan using GIS technologies (Yandex.Maps).

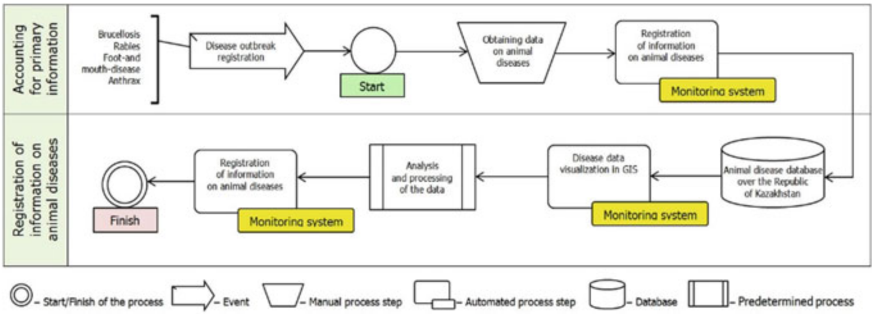


Fig. 2. Diagram of business logic for monitoring epizootic animal welfare

The structuring of primary data in order to form relational tables of the database was carried out according to a special methodology and technology for its implementation for the automated generation of output statistical indicators for various requests (filters) of decision makers and the tasks of presenting monitoring results for taking preventive and organizational and technical veterinary measures. At the same time, Visual Basic for Applications (VBA, Visual Basic for Applications) was used-a simplified implementation of the Visual Basic programming language, built into the Microsoft Office product line [6].

The database (DB) of the subject area, which is taken as the information processes for monitoring the epizootic welfare of animals in the regions of Kazakhstan and visualization of the results of its analysis, includes the following main modules (Fig. 3):

- DB “Administrative divisions”;
- DB “Animal species”;
- GID DB.

In which abstracts of the main objects of monitoring processes and analysis of its results will be presented for making decisions on improving the epizootic state of animals through preventive measures for the prevention of infectious diseases in the regions of Kazakhstan.

Screen forms of the main AIS DB modules for monitoring the epizootic welfare of animals are shown in Fig. 3.

The Service Oriented System (SOA) template was chosen as the architectural template for the system being developed. SOA is based on a modular approach to software

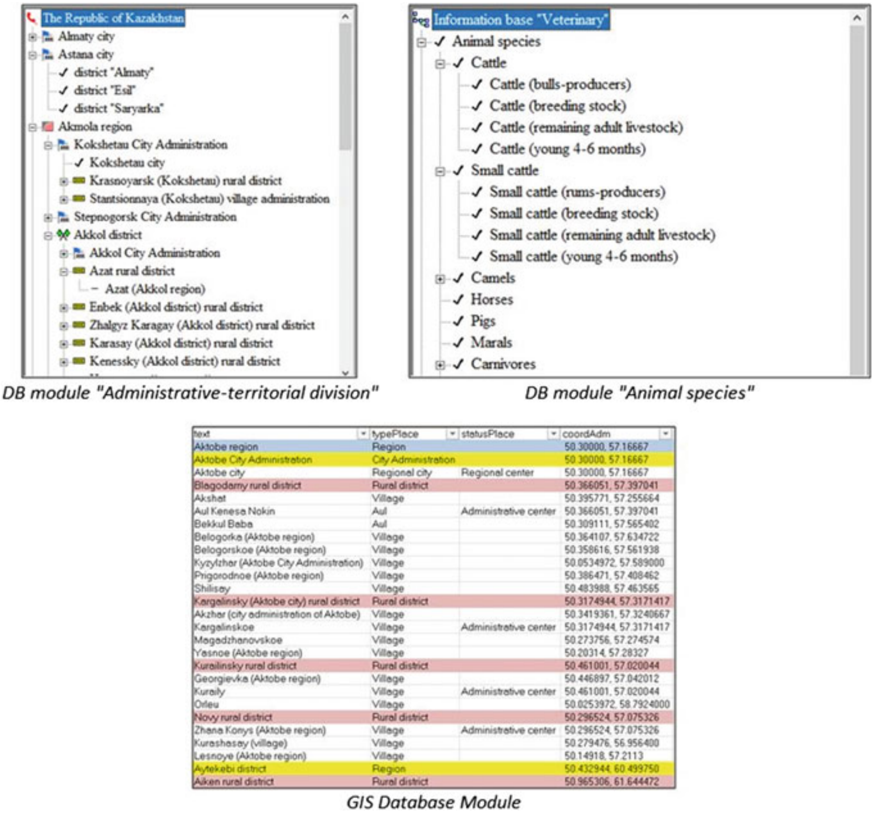


Fig. 3. Screen forms of the AIS database modules for monitoring the epizootic animals' welfare

development based on the use of services with standard interfaces. System components can be distributed over different network nodes, are loosely coupled or independent, interchangeable. Each component of the system encapsulates the details of its implementation, providing only a unified interface for interacting with other components [7].

As a result of a comparative analysis of more than ten software solutions, including both platforms for developing web systems and off-the-shelf products, the content management system (CMS) Drupal was chosen. It is freely distributed under the GNU GPL license, and is built on a service-oriented architecture pattern. PHP platform implementation language. MySql or Postgresql can be used as a DBMS for Drupal version 6. Starting with Drupal version 7, any DBMS can be used. A simplified diagram of the general architecture of the information system is shown in Fig. 4 [13]. The system consists of 3 main modules:

- administration (users, roles);
- data entry and reading (data entry, reference books);
- GIS (display, display customization).

The system user interacts with the modules at the presentation level based on the web interface. The business logic (core) is built according to the MVC (Model-View-Controller) concept, in which the scheme for dividing application data, user interface and control logic into three separate components: model, view and controller is applied-in such a way that modification of each component can be carried out independently. Representation and business logic form a layer that is responsible for providing a service for monitoring epizootic animal welfare [8].

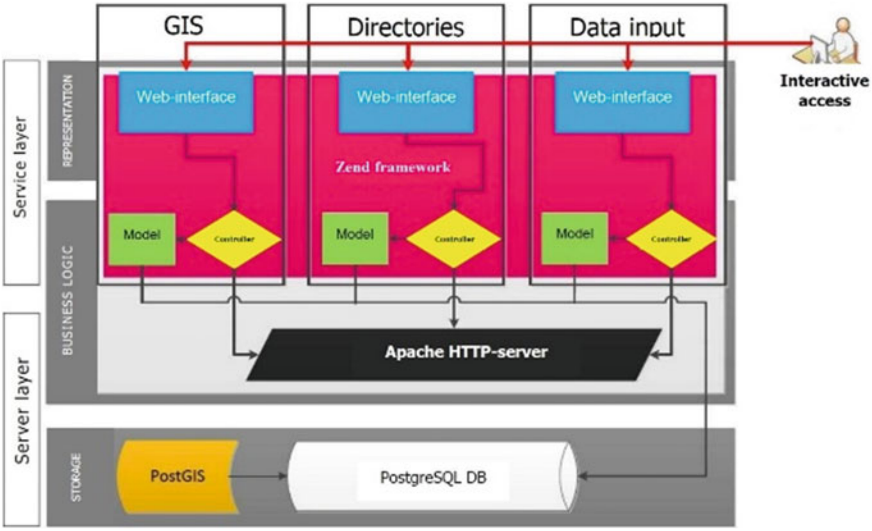
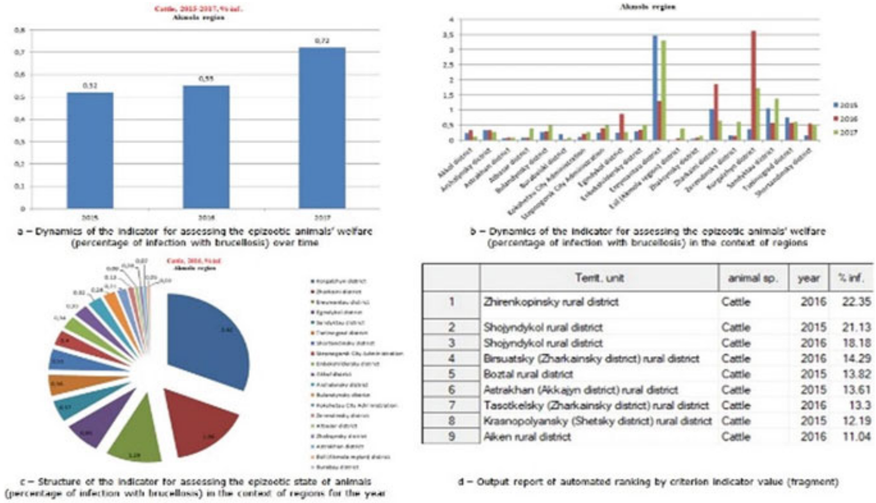


Fig. 4. Block diagram of the information system architecture

The Apache web server and PostgeSQL database form the back-end layer for storing and modifying data. Templates, design elements, any files are stored on the file system [9]. All text information is stored in the DBMS in a structured way. The PostGIS extension adds support for geographic features to the PostgreSQL relational database to implement fully the functionality of the GIS module. Data exchange is carried out using the standard HTTP protocol (between the presentation layer and the business logic layer) and the SQL query language (between the business logic layer and the data layer) [10].

Figure 5 shows the fragments of the output report using Excel, where the automated presentation of the results of data processing by various filters and features at the user's request is implemented: a-dynamics of the indicator for assessing the epizootic state of animals (percentage of brucellosis infection) over time; b-dynamics of the indicator for assessing the epizootic state of animals (percentage of infection with brucellosis) in the context of districts; c-the structure of the indicator for assessing the epizootic state of animals (percentage of infection with brucellosis) in the context of regions for the year; d-output report of the automated ranking by the value of the criterion indicator [12].



	Terrt. unit	animal sp.	year	% inf.
1	Zhirenkopinsky rural district	Cattle	2016	22.35
2	Shojyndykol rural district	Cattle	2015	21.13
3	Shojyndykol rural district	Cattle	2016	18.18
4	Birsuatsky (Zharkainsky district) rural district	Cattle	2016	14.29
5	Boztal rural district	Cattle	2015	13.82
6	Astrakhan (Akkajyn district) rural district	Cattle	2015	13.61
7	Tasotkelsky (Zharkainsky district) rural district	Cattle	2016	13.3
8	Krasnopolyansky (Shetsky district) rural district	Cattle	2015	12.19
9	Aiken rural district	Cattle	2016	11.04

Fig. 5. Fragments of the AIS output reports

Fragments of software implementation of visualization of monitoring results using Yandex technologies are shown in Fig. 6 (for example, FMD) [11]. The colors and sizes of the icons reflect the level of the epizootic state of animals and the actual value of the assessment indicator. If necessary, you can visualize the quantitative parameters of a specific object in the form of numbers, text.

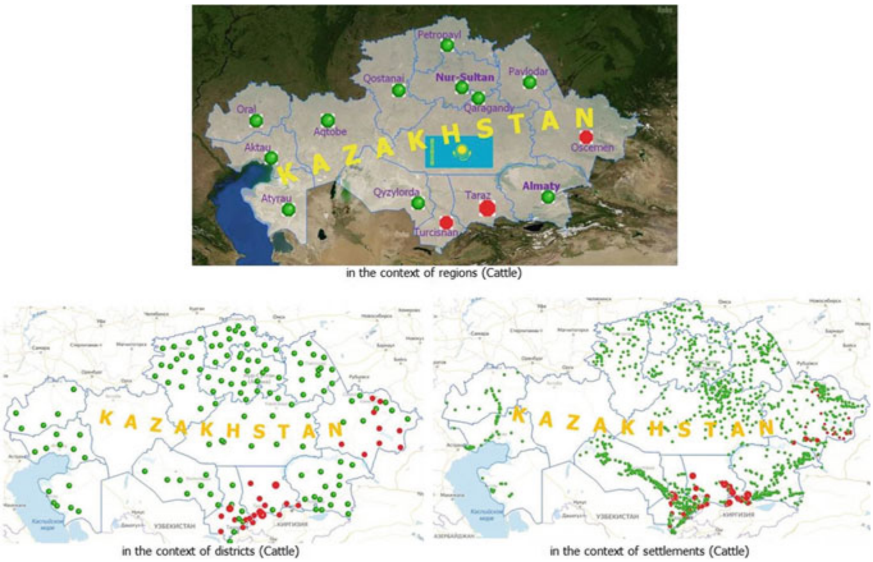


Fig. 6. Visualization of foot-and-mouth disease topology on Kazakhstan territory

Figure 7 shows fragments of detailing, where you can see the quantitative values of the statistical characteristics of the assessment (for example, the number of animals studied; the number of positively reacting animals; % of infection, etc.) indicating the zone and periods of the survey, as well as the level of the epizootic state of animals (color scheme).

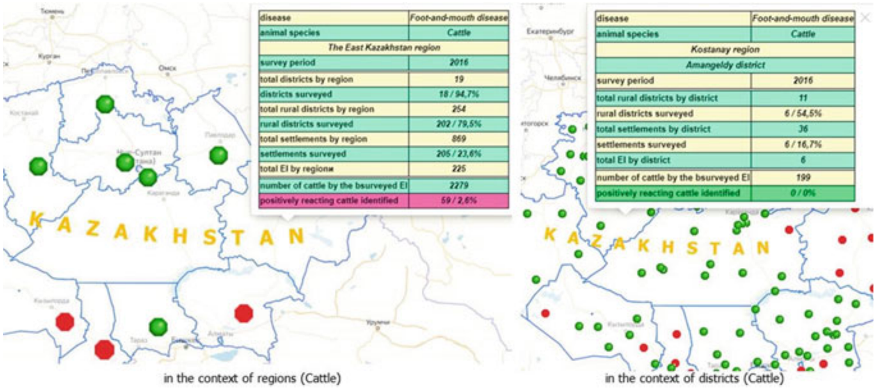


Fig. 7. Examples of specification

It should be noted that the primary data used to design the physical model of the database were presented by subject specialists in the field of applied veterinary medicine, the reliability of which is not considered within the framework of this work.

4 Output

Software products implement the following main functionalities:

1. automated issuance of calculation results in tabular form by indicators:

   - number of animals surveyed;
   - number of positively reacting animals;
   - % of contamination.

   in the context of rural districts, districts, regions and in Kazakhstan as a whole;
2. automatic ranking of the criterion indicator of the analysis by: ascending, descending value of the indicator, in alphabetical order of the location of the administrative-territorial unit;
3. automated visualization of the output results and processing to study the dynamics of the selected indicator: by years; by the structures of the region and districts, etc.;
4. procedure for visualizing the output results of automated processing on Yandex.Maps for assessing the topology of the state of infected and non-infected animals for all species;

Based on the results of operational and technological testing, it was found that:

1. the system promptly provides the end user with reliable information;
2. the system allows you to quickly detect gross errors when entering the initial data into the database;
3. methods and means of information support and its visualization satisfies the technological regulations of veterinary reporting for monitoring the epizootic welfare of animals.

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Hydrodynamic Aspects of Drying Brewer's Grains in a Suspended Bed

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Abstract. At present, in Russia, brewer's grain is used for the needs of animal husbandry in its raw form, which creates a number of difficulties that reduce the efficiency of using this valuable feed. This is due, firstly, to the fact that raw grains deteriorate during storage and become unsuitable for feeding, secondly—transportation of raw grains is difficult due to the high content of water in it and transportation costs greatly increase the cost of grains. The need to preserve raw brewer's grains by drying is dictated by the fact that dry grains are capable of long-term storage and good transportation, which ensures the rational use of this valuable feed. Having good transportability, dry grains, when used for the production of compound feed, can greatly contribute to the rational regulation of feed balances in animal husbandry in certain economic regions of Russia. In industrial practice, drying processes are widespread, in which the material is processed in a suspended layer, which is one of the most effective means of intensifying production. Due to the use of a suspended layer, it is possible to reduce the processing time of certain materials by using higher speeds of material flows.

Keywords: Drying · Suspended layer · Brewer's grain · Vortex chamber · Fluidization

1 Introduction

Currently, in the food industry, to obtain dry dispersed products, they mainly use convective drying in a suspended state, when the gas is not only a heat carrier, but also a transporting agent. Dryers with a suspended layer of dispersed material make up a significant part of the apparatus used in food technology. These include fluidized bed dryers, pneumatic dryers, spray dryers, aerofoil dryers, vortex dryers, etc. For hard-to-dry materials, devices with a fixed layer are used, such as belt and shaft dryers, as well as dryers with a semi-weighed layer of material—drum dryers.

The use of swirling streams in the drying area has begun relatively recently. Based on the analysis of domestic and foreign data, this principle is widely used both in "pure" form and in combination with other aerodynamic modes. In view of the variety of design

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solutions of such devices, we will consider only the most characteristic of them. The use of a swirling flow in order to intensify convective heat transfer under the conditions of an internal problem has been confirmed by a number of studies [1–17].

In this case, the nature of interphase heat transfer in vortex chambers is similar to heat transfer in dispersed flows created in other devices, in particular in pneumatic tubes. The given data [18–22] show that a significant intensification of heat transfer can be achieved by using only highly swirling flows. However, it should be taken into account that with a significant increase in the entry speed, the effect of intensification decreases. It is shown that the tangential air supply, which creates strongly swirling flows, makes it possible to increase the heat transfer by 60–70% in comparison with the results obtained for a pipe with a direct flow at the same power consumption and temperature conditions. Research results [23, 24] showed that at the same power consumption and temperature conditions, a single-phase flow compared to a non-swirled flow increases heat transfer by 2 … 2.5 times, and a two-phase swirling compared to a swirling single-phase flow additionally provides an increase in the heat transfer coefficient from 3 to 20 times, depending on heat flux and Re number. At the same Re numbers for the case of a swirling flow, the mass transfer increases by almost 4 times. This indicates a high degree of heat transfer intensification when using swirling flows. The main feature of devices with a swirling coolant flow is a sufficiently high concentration of dispersed material at high gas flow rates [25]. Thus, the intensification of the process in them is achieved both by increasing the surface of the phase contact and by increasing the exchange coefficient with an increase in the relative velocities of the phases in the flow. The speed of material movement in devices with spiral motion of suspension is usually much lower than in a direct flow due to friction and impact of material particles on the wall. The true concentration of material in pneumatic tubes with screw inserts can be 3 to 4 times higher than the concentration of particles in straight pneumatic tubes under all conditions being equal. Even higher values of material concentrations can be obtained in vortex and cyclone chambers.

2 Experimental Part

The study of the hydrodynamics and kinetics of brewing grain drying was carried out on an experimental setup shown in Fig. 1. Beer grains were dried in a conical-cylindrical chamber in the lower part, at the lower base of which a cylindrical ring was made, to which a branch pipe was connected tangentially for supplying a swirling flow of a drying agent. Chamber dimensions: inner diameter of the lower base of the cone—60 mm, inner diameter of the cylindrical part—200 mm, height of the cylindrical part—220 mm, height of the conical part varied from 220 to 535 mm, cone angle 15, 25, 35°, inner diameter of tangential branch pipe—25 mm.

The study of the hydrodynamics of a suspended swirling layer of beer grains was carried out in conical—cylindrical chambers with an angle at the apex of the cone 15, 25 and 35°. The picture of the movement of the product in the apparatus under the influence of the axial flow of air having a temperature of 293 K was studied in the range of air velocities from 4 to 14 m/s. Observations of the nature of the movement of bulk material in a conical-cylindrical chamber make it possible to note a number of specific features inherent in wet polydisperse mixtures liquefied in a flow of a gaseous agent.

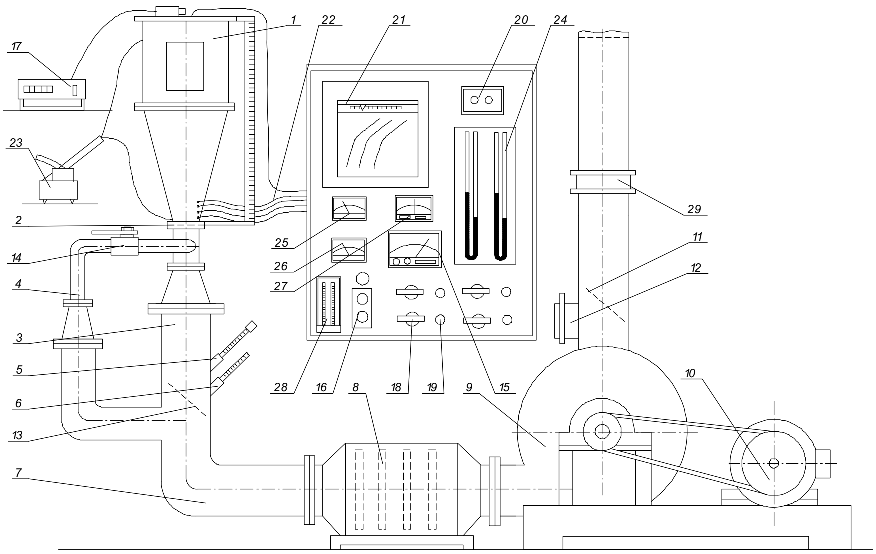

Fig. 1. Experimental setup diagram: 1—drying chamber; 2—gas distribution grid; 3; 4—branch pipe; 5—thermometer electrocontact mercury; 6—mercury thermometer; 7—drying agent preparation line; 8—sectional heater; 9—centrifugal fan; 10—drive unit; 11; 12; 13—gate damper; 14—ball damper; 15—thermoanemometer; 16—electromagnetic starter; 17—hygrometer; 18—batch switch; 19—signal lamps; 20—relay universal; 21—potentiometer; 22—Chromel-Copel thermocouple; 23—micromanometer; U—shaped micromanometer; 25—ammeter; 26—voltmeter; 27—wattmeter; 28—psychrometer; 29—chamber diaphragm.

In Fig. 2. Curves of fluidization by axial air flow in chambers with different angles at the apex of the cone for a layer of brewer's grains with a moisture content of W = 150% and a height of $H_0 = 120$ mm are presented. На рис. 3–6 the curves of fluidization by axial air flow in chambers with different angles are presented at the top of the cone for a layer of brewer's grains with a specific load on the gas distribution grid G_{sp} and humidity W = 150%.

In a chamber with an angle at the apex of the cone $\alpha = 15°$, After the explosive destruction of the layer, a channel appears, the walls of which are continuously collapsing and recovering, the movement of the layer was uneven, aggregation of particles, pistons were noted, and individual pulsations of the layer reached a rather high height. In a chamber with an angle $\alpha = 25°$, a fluidization of a layer of brewer grains in the diluted phase was observed, heavy and large particles form the walls of the channel, and an insignificant part of small particles carried away from the walls of the channel hover in the core, are thrown to the periphery and slide to the top of the conical part. Heavy particles falling from the walls of the channel and carried out from the layer adjacent to the gas distribution grid move along the walls of the channel and, as they exit from it, are thrown by the air flow to the periphery of the apparatus. In a chamber with an angle $\alpha = 35°$, the breakthrough of the material layer was accompanied by the formation of a channel located on the axis of symmetry of the conical part. In this case, the edges of the channel are uneven, there was no "boiling" and mixing of the material.

It is noted that for a layer of brewer's grains, an increase in the axial air flow does not contribute to the development of a uniform fluidized state, but leads to the formation of a channel located on the axis of symmetry of the conical part. The obvious tendency to the formation of a through channel in the layer of brewer's grains is due to a number of factors: high humidity, a significant difference in the geometric sizes of particles, a tendency to agglomeration, as well as the presence of perforations in the gas distribution grid, which affects the true distribution of air velocities above it. In the mode of fluidization in a layer of beer grains with moisture $\ll$ 150% a typical fluidized core with a diameter smaller than that of the apparatus is observed (Figs. 3, 4, 5 and 6).

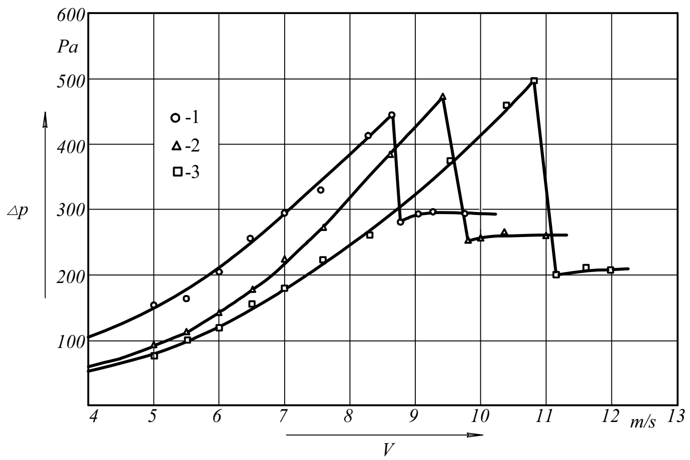

Fig. 2. Curves of fluidization in chambers with different angles at the top of the cone and H_0 = 120 mm: 1–15°; 2–25°; 3–35°.

As the moisture content of the product decreases, the structure and shape of the specified fluidization core acquire an increasingly distinct shape.

Thus, when only the axial flow acts on the layer of brewer's grains, no gas suspension is formed at the mouth of the cone, and the product, in turn, moves in a sliding flow. The observed phenomenon during fluidization does not allow providing the conditions for the development of intensive directed circulation of the product in the conical-cylindrical chamber with smooth walls at the air velocities noted above.

3 Conclusions

The results of experiments on drying various materials in devices with a swirling flow indicate a fairly high efficiency of this method. The residence time of the particles of the material to be dried in such devices can be adjusted from 5 to 15 s by changing the angle of inclination of the tangential nozzles. The results of operation of spiral dryers with contact heat supply to the gas suspension show that the volume of removed moisture in such devices can reach 500 kg/(m^3·h) or 30 kg with 1 m^2 of heat-dissipating surface. The

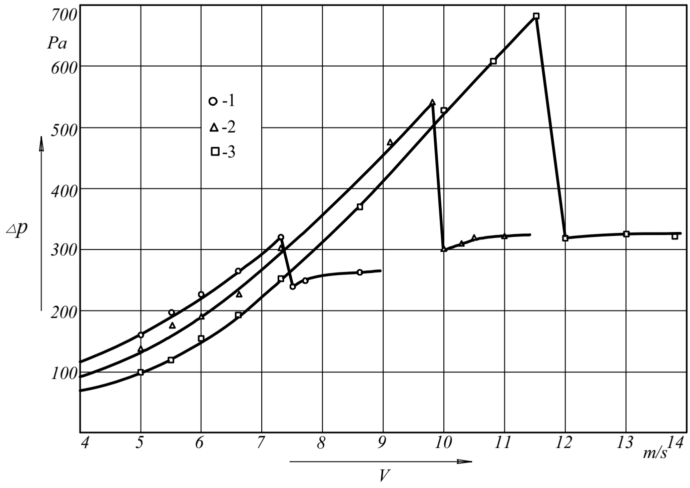

Fig. 3. Curves of fluidization in a chamber with an angle at the apex of the cone 15°: 1–35,4 kg/m^2; 2–70,77 kg/m^2; 3–106,15 kg/m^2.

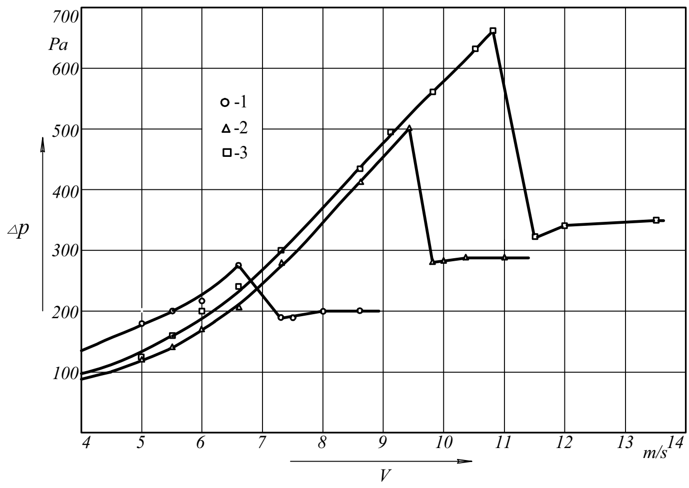

Fig. 4. Curves of fluidization in a chamber with an angle at the apex of the cone 25°: 1–35,4 kg/m^2; 2–70,77 kg/m^2; 3–106,15 kg/m^2

final moisture content of materials does not exceed 1%. From the analysis of modern methods of drying brewer's grains, it follows that mainly belt and drum convective dryers are used, which have a number of significant disadvantages; large dimensions and metal consumption, difficulty in maintenance and repair; charring of fine fractions of the dried material, high heat and power costs.

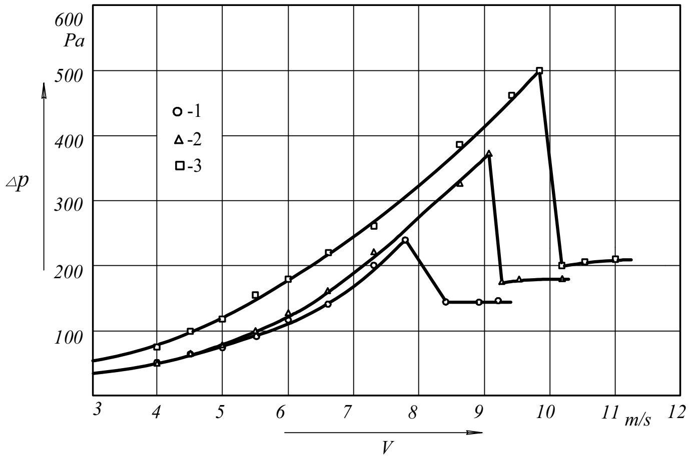

Fig. 5 Curves of fluidization in the chamber with an angle at the apex of the cone 35º: 1–35,4 kg/m^2; 2–70,77 kg/m^2; 3–106,15 kg/m^2.

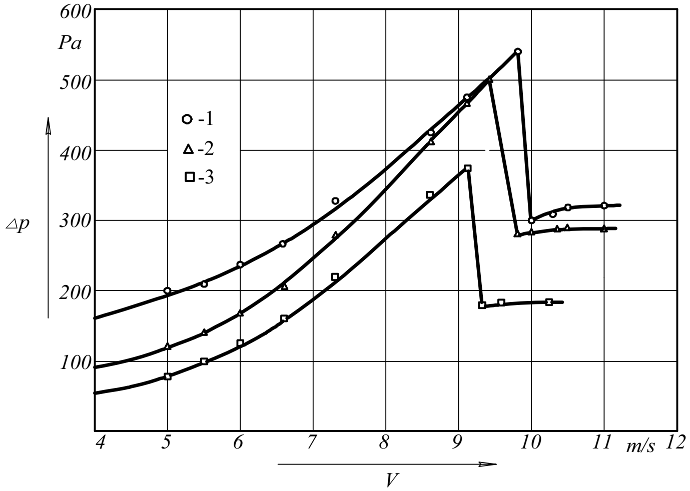

Fig. 6. Curves of fluidization in chambers with different angles at the top of the cone and G_{sp} = 70,77 kg/m^2: 1–15°; 2–25°; 3–35°.

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Results of a Study of the Efficiency of Dividing the Hermetia Illucens Larva into Fractions by Amino Acid Composition

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Abstract. Experimental studies were carried out in 2020 in the Rostov region. The problem of the shortage of high-quality high-protein feed was considered, in particular, the problem of the shortage of the main source of protein in feed - fishmeal on the world market, its causes and possible solutions. Due the research, the technologies for obtaining the protein concentrate were analyzed and the most effective was determined. The paper presents the results of the study of the efficiency of dividing the larva of a fly Hermetia Illucens into fractions: chitin, protein and fat according to the yield of protein concentrate and amino acid composition. The results of the analysis of the amino acid composition of the cuticle and muscle mass showed that a large proportion of amino acids remain in the cuticle. This may be due to the fact that the bulk of fat passes into the viscera and, thereby, the proportion of protein (amino acids) decreases. In addition, the loss of amino acids during the separation into fractions is 2.9%.

Keywords: Feed · Fish Meal · Hermetia illucens · Amino Acids · Protein

1 Introduction

Over the past 10 years, there has been a significant increase in global aquaculture production. This is due to a decrease in the volume of traditional fishing due to the loss of biological productivity of the World Ocean [1]. In addition, an increase in the population and the share of sales of agricultural products in the world market requires an increase in the food base, including fish production. All of the above inevitably generates a high demand and limited supply for fishmeal and fat—the main components for the production of feed. According to the FAO [13], the world consumption of fishmeal by 2022 is projected to be 7–7.75 million tons, however, the world stocks of fishmeal and fish oil

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sources can no longer meet the demand. Thus, there is an urgent need to find alternative sources of protein and fat for feed production and aquaculture development in general.

Analysis of the aquaculture market over the past year has shown an increase in the cost of cultivation and artificial breeding of salmon and Pacific salmon (Table 1).

Table 1. Percentage change in value (price is in dollars per kilogram)

Month	Price, $	Growth ↑/ fall ↓, %
August 2020	5.67	–
September 2020	5.42	↓4.41
October 2020	5.23	↓3.51
November 2020	5.25	↑0.38
December 2020	5.55	↑5.71
January 2021	5.74	↑3.42
February 2021	6.04	↑5.23

The decline in the cost of fish products was caused by a decrease in its consumption due to restrictive measures caused by the COVID-19 pandemic. The pandemic has shown that fish and seafood are among the most vulnerable group of goods, which consumers, if they cut costs, are the first to refuse. However, we see that starting from the end of December 2020, the indicators begin to return to their previous level and will continue to grow.

The main limiting factor in the development of production of feed for aquaculture is the shortage, high cost, low environmental friendliness of traditional raw materials—fishmeal [1]. In addition, due to the high variability in the content of nutrients, pathogens and biogenic amines, its quality varies greatly (Fig. 1).

Figure 2 shows the 25 world leaders in fishmeal production. Latin America is the main center for the production of fishmeal, which is geographically located far from the Chinese and European centers of consumption. This significantly affects its cost, which increases due to the cost of its transportation.

Over the past few decades, there has been an increase in demand for chicken meat, since it is significantly cheaper than beef, pork and fish. And since fishmeal is produced from fish processing waste, there is a shortage of raw materials for its manufacture. Figure 3 shows a graph of changes in fishmeal production in Russia from 1987 to 2020. There has been a significant decline since 1996 and weak growth to 2020.

2015—45 thousand tons, 0.00%; 2016—145 thousand tons, 0.00%; 2017—150 thousand tons, 3.45%; 2018—153 thousand tons, 2.00%; 2019—160 thousand tons, 4.58%; 2020—160 thousand tons, 0.00%.

Thus, there is an obvious need to find alternative sources of protein and fat for compound feed production, which in their composition would not be inferior to fishmeal.

Research and innovation centers for fish feed (Research Center Biomar, Coppens, AllerAqua, Skretting, Feed Research Center Nofima) promising research directions for

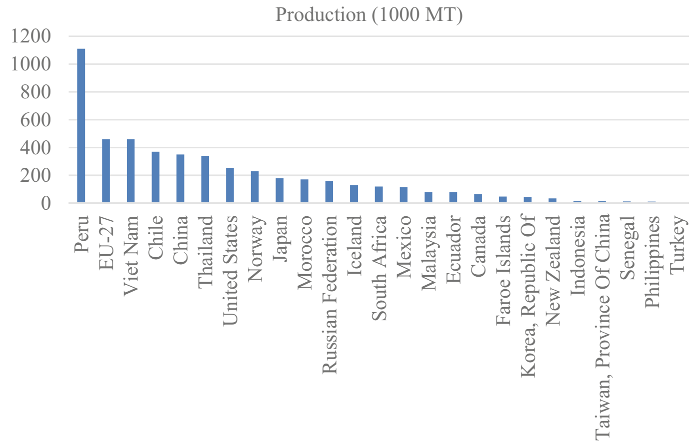

Fig. 1. World leaders in the production of fishmeal: https://www.indexmundi.com/agriculture/.

Fig. 2. Fishmeal production in the Russian Federation by years: https://www.in-dexmundi.com/agriculture/.

the development of this industry were developed, which can be reduced to the following groups [2]:

1. development of new and improvement of existing products: reducing the feed ratio, keeping the feed and reducing the cost of the product;
2. search for alternative sources of protein and fat for the production of feed and development of technologies for their production in order to replace fishmeal and fat;
3. development of new ingredients;
4. development of feed additives;
5. studies of digestive functions and energy metabolism of fish;
6. development of optimal feeding rates;

7. feeding requirements for different types of fish [2].

Insects are of increasing interest as alternative sources of protein and fat. They represent a largely untapped source of protein, fat, vitamins and minerals. Insects can be reproduced using less water and land than livestock, and less greenhouse gases are generated.

There are 1900 species of edible insects in the world. Among the most promising species for industrial feed production—Hermetia illucens, Muca Domestica, Anaphe panda and Tenebrio molitor. Oxya fuscovittata, Acrida exaltata, Hieroglyphus banian and Trinervitermes are also used, but to a lesser extent [13]. In works of Newton G. L., Moghadasian M. H., Ramos E. et al. show the results of studies on the successful replacement of fish and soy flour with flour from silkworms, flour beetles and grasshoppers are presented. Research has shown that they have a higher protein content compared to traditional soy and fish meal (Table 1). Hermetia illucens larvae have shown good results in feeding chickens, pigs, rainbow trout, channel catfish and blue tilapia. In the case of rainbow trout, larvae can replace 25% fishmeal and 38% fish oil.

Thus, the considered insects have a similar amino acid composition and can serve as alternative sources of protein and fat in compound feed production.

Hermetia illucens is the most promising of the above insects for the following reasons:

- Hermetia illucens is not a disease vector by biological characteristics, like other flies, including Musca Domestica;
- in comparison with the flour beetle and silkworm, it grows faster: the flour beetle grows in 1.5–2 months (depending on growing conditions), Hermetia illucens—1 months, Anaphe panda caterpillar develops over 26–32 days. The release of butterflies from their cocoons usually occurs on 15–18 days. Hermetia illucens has 10 eggs per day;
- the basis of the diet of flour beetle, silkworm, grasshoppers, locusts is dry plant products—grains, flour, compound feed, dried fruits, etc. While the Hermetia illucens larva can process any organic waste (including manure).
- when growing biomass of insects in Hermetia illucens there are also the following advantages: it is slower and calmer than other insects and is easier to care for. Moreover, Hermetia illucens do not bite, since they have a poorly developed jaw apparatus.

Hermetia Illucens larvae have a rich amino acid composition similar to that of meat. Fat content ranges from 23 to 35% depending on growing conditions.

Thus, the Hermetia illucens larva can become a worthy alternative source of protein and fat in feed production. The main components of the larva are protein, fat and chitin. Chitin has beneficial properties: lowers cholesterol, increases bone strength and improves digestive function. But with a high content of it in feed, it can lead to negative consequences: reduces the absorption of vitamin E due to a decrease in the absorption of fats in the intestine, leads to a decrease in the weight of animals due to the high content of solid indigestible substances. In addition, chitin is widely used in the food, feed, and pharmaceutical industries; therefore, it is advisable to isolate it as a separate component for further use. In addition, in order to obtain pure protein for feed, it must be separated from the fat.

2 Materials and Methods

The Hermetia Illucens larvae, grown within the framework of the initiative research work of the department “Technique and technology of food production” on a vegetable substrate, were used for the current experiment.

The laboratory experiment program consists of several exploratory studies, the purpose of which is to find the most productive way to carry out the considered basic process (cuticle removal, drying, protein concentration and fat extraction) and their combinations. Based on the results of the literature review, 4 exploratory studies were identified, presented in Table 2.

Table 2. Experimental studies of the fractionation process of the Hermetia Illucens larva

Exploratory research № 1	Exploratory research № 2	Exploratory research № 3	Exploratory research № 4
1. Deactivation; 2. Shredding with a knife auger grinder; 3. Separation of fractions in a screw press with a grain cylinder; 4. Drying; 5. Fat extraction	1. Deactivation; 2. Extrusion in a screw press with a grain cylinder; 3. Drying; 4. Fat extraction	1. Deactivation; 2. Extrusion in a screw press with a grain cylinder; 3. Centrifugation; 4. Protein isolation; 5. Drying; 6. Fat extraction	1. Deactivation; 2. Extrusion in a screw press with a grain cylinder; 3. Thermal coagulation; 4. Centrifugation; 5. Drying; 6. Fat extraction

Deactivation. Decontamination is carried out by lowering the body temperature of the insect to +4 °C in a household refrigerator for 4 h.

Shredding. The cooled mass is loaded into the receiving device of a knife auger grinder or a screw press with a grain cylinder, depending on the experimental plan given in Table 2.

Drying after separation the fractions are dried in an oven at 60–70 °C until the humidity of the object reaches no more than 14%. Then each of the fractions is squeezed out in a screw press, preheating the mass to 60 °C to reduce the viscosity of the fat [17].

Thermal coagulation. Coagulation, provided for in the plan of experiment No. 4, is carried out as follows: the selected and weighed muscle mass is placed in a heat-resistant glass, 750 ml of distilled water is added and placed on a quartz tile. The mixture is heated to 50 °C then maintain a constant temperature and hold the mixture on the tile until the end of coagulation, determined visually. The coagulum is separated from the rest of the mixture using a mesh filter, then placed in a centrifuge and centrifuged for 1 min at 5 thousand rpm. The aggregated protein mass is separated from the ichor and cell fluid using a sieve, weighed and dried.

The efficiency of separating the larva into fractions was determined by the yield of the protein concentrate. The research results showed that when using exploratory research № 1 the yield of the protein concentrate made up 13%, № 2—27%, № 3—21%, № 4—6% of the total mass of the larva.

The most effective technology for obtaining protein concentrate is the technology №2, consisting of the following technological operations: decontamination, squeezing in a screw press with a grain cylinder, drying, fat squeezing.

Also, to analyze the efficiency of mechanical separation of chitin (cuticle) from protein and fat (viscera), a sample obtained by technology № 2 was analyzed for amino acid content. Also, a whole larva was taken as a control sample to determine the efficiency of separating the larva into fractions. Determination of the amino acid composition was carried out in the laboratory "Biochemical and spectral analysis of food products" of the department "Technique and technology of food production" of the Don State Technical University by the method of capillary electrophoresis on the device "Kapel 104 T" company "Lumex", made in Russia.

The method is based on the decomposition of samples by acid or (only for tryptophan) alkaline hydrolysis with the conversion of amino acids into free forms, the preparation of phenylisothiocarbamyl derivatives (hereinafter referred to as FTC derivatives), their further separation and quantitative determination by capillary electrophoresis. Detection is carried out in the UV region of the spectrum at a wavelength of 254 nm. For the modifications of "Drops 104-T" it is possible to carry out a direct quantitative determination of tryptophan without obtaining the FTK-derivative, registering the absorption at a wavelength of 219 nm.

The prepared solutions are transferred into Eppendorf tubes, centrifuged for 5 min at a rotation speed of 5000 rpm.

For each prepared solution, at least two electrophoregrams are recorded. Upon completion of registration, check the correctness of the automatic marking of the peaks. Using the software, amino acids in the sample are identified by the coincidence of their migration times in the sample and in the control solution with an identification window width of no more than 5%.

If the analyzed amino acids are found, then their mass concentration is determined using a calibration characteristic [16].

3 Results

After detecting amino acids and marking peaks, the mass concentration of each amino acid was determined (Fig. 5).

Mass fraction of each amino acid (X, %) is calculated by the formula:

$$X = \frac{100 \cdot V_g \cdot V_k \cdot C_i}{1000 \cdot m \cdot V_{Al}} \tag{1}$$

where

X mass fraction of amino acid in the sample, %;

C_i measured value of the mass concentration of the amino acid in the prepared solution, mg/dm^3;

m sample weight, mg;
V_g total volume of hydrolyzate, cm^3;
V_k volume of the final (analyzed) solution, cm^3;
V_{Al} the volume of an aliquot portion of the hydrolyzate taken to obtain FTC—derivatives, cm^3;
100 multiplier for expressing results as a percentage;
1000 the coefficient of agreement of the dimension of the units of measurement of volume.

The results of calculating the mass fraction of amino acids are summarized in the Table 3.

Table 3. Mass fraction of amino acids in the sample

Mass fraction of amino acid, %				
Amino acid	Hermetia illucens	Hermetia illucens insides	Hermetia illucens cuticle	Losses when splitting into fractions
Arg	1.83	0.44	1.19	0.20
Lys	1.14	0.40	0.55	0.19
Tyr	1.27	0.36	0.87	0.04
Phe	0.44	0.17	0.25	0.02
His	0.66	0.18	0.25	0.23
Leu + Ile	0.94	0.33	0.55	0.06
Met	0.42	0.21	0.20	0.02
Val	1.00	0.24	0.75	0.01
Pro	1.69	0.46	1.20	0.03
Thr	0.76	0.26	0.48	0.02
Ser	1.02	0.22	0.75	0.05
Ala	1.61	0.30	1.29	0.02
Gly	1.41	0.42	0.88	0.11
Asp + Asn	13.53	5.20	8.23	0.10
Glu + Gln	10.41	3.96	6.42	0.03
Sum 16 AK	38.1	13.15	23.86	1.13
Substances	61.9	–	–	–
Ratio	100%	34.5%	62.6%	2.9%

Results of the analysis of electrophoregrams (Figs. 3, 4, 5)—show the correspondence of the amino acid composition of the larvae Hermetia illucens to the amino acid composition of fish meal.

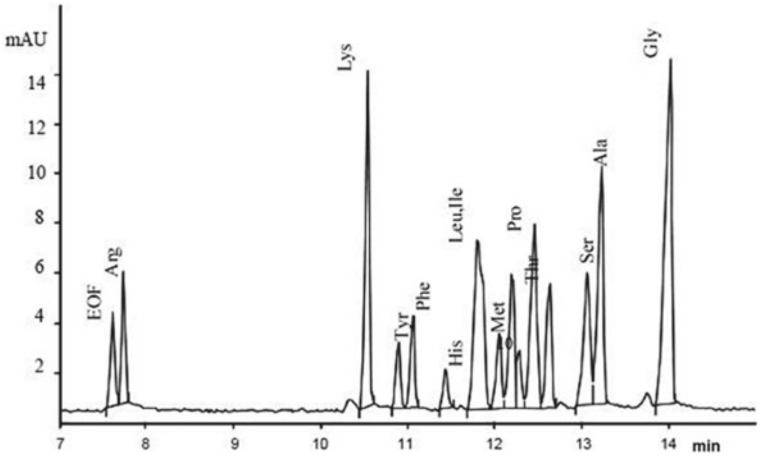

Fig. 3. Electropherogram of a fish meal sample

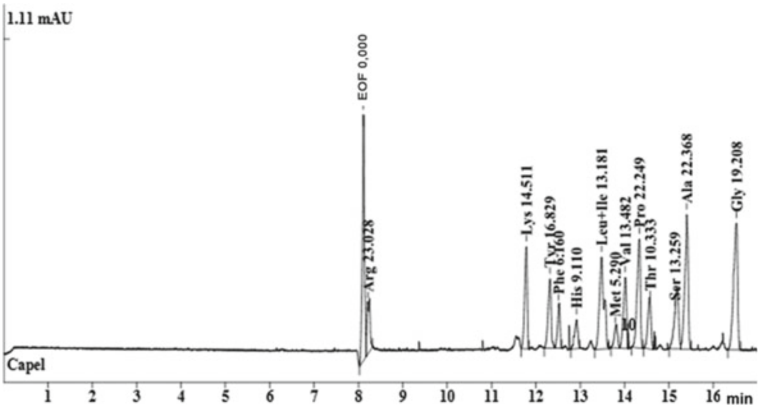

Fig. 4. Electropherogram of a larva sample Hermetia Illucens

The tyrosine and proline contents in Hermetia illucens and fishmeal differ by no more than 10%, while the amount of tyrosine in Tenebrio molitor is higher than in fishmeal. The content of phenylalanine and methionine in both insect species is significantly lower than in fishmeal. The content of arginine, lysine, threonine, serine and glycine differ with the content in fishmeal by about 50%. And the amounts of glutamine and asparagine in Tenebrio molitor and Hermetia illucens differ by more than 50% relative to fishmeal [17, 18].

As a result of fractionation of the larvae into the cuticle and viscera, the following fraction ratios were obtained in dry form (Fig. 6).

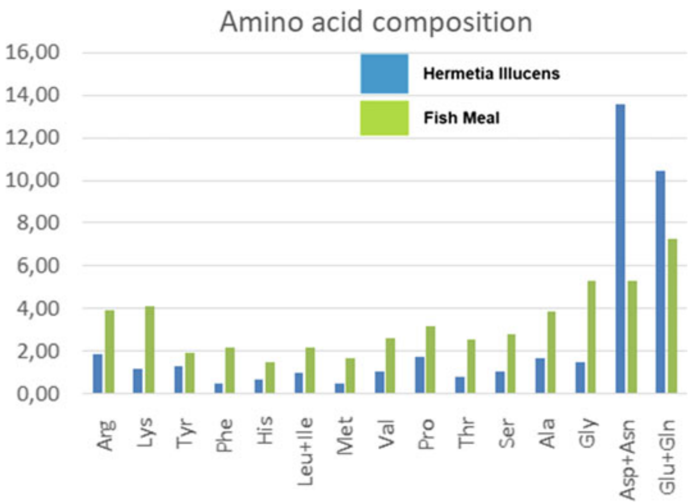

Fig. 5. Amino acid content histogram

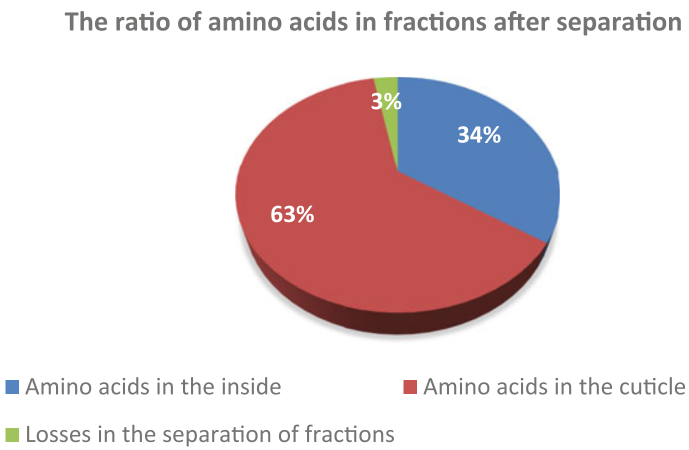

Fig. 6. Distribution of amino acids in *Hermetia Illucens* fractions after separation

4 Conclusions

Based on the data obtained, it follows that the most effective technology for separating the Hermetia Illucens larva into fractions is the technology № 2, consisting of the following technological operations: decontamination, squeezing out in a screw press with a grain cylinder, drying, fat squeezing. The results of the analysis of the amino acid composition of the cuticle and muscle mass showed that a large proportion of amino acids remain in the cuticle. This may be due to the fact that the bulk of fat passes into the viscera and, thereby, the proportion of protein (amino acids) decreases. In addition, the loss of amino acids in the process of separation into fractions is 2,9%. Thus, this technology shows its effectiveness and can be used to separate the Hermetia Illucens larva into fractions. To increase the efficiency of the technology, it is necessary to conduct additional research on the process of separating the cuticle and muscle mass, which will reduce the loss of the processed mass to a minimum.

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Linear Theory of Formation of Grinding Loads in Apparatus with a Magnetic Liquefied Layer

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Abstract. The issues of analysis and synthesis of the method of forming grinding loads in devices with a magnetically fluidized layer of ferrobodies are considered. Represented by the linear theory of the organization impact and abrasive loads with constant electromagnetic field. When developing a linear theory and physical and mathematical modeling of force and energy dispersion conditions, the basic theory of the method of mechanical activation in a magnetically fluidized layer of ferrobodies was used, based on the development of J. K. Maxwell's dipole model "on the interaction of ferroballs under the influence of forces and moments of a magnetic field." The research results are confirmed both by the visual method of high-speed cinematography (ultra-rapid), and by the methods of experimental and statistical studies of physical and mechanical processes on models, mock-ups and experimental samples of a standard series of electromagnetic devices with a magnetically fluidized layer of ferromagnetic elements. The research was carried out within the framework of the leading scientific school of prof. M. M. Bezzubtseva "Efficient use of energy, intensification of electrotechnological processes", registered in the register of scientific schools of St. Petersburg. The basic theoretical provisions and mathematical models formulated in the article are of great practical importance and allow designing energy-efficient electrotechnological devices for mechanical activation and grinding of materials for various purposes.

Keywords: Linear theory · Grinding loads · Magnetic liquefied layer · Mechanical activation

1 Introduction

The energy efficiency of the processes of grinding, crushing and mechanical activation of materials is determined by many factors, which, first of all, include the method of transformation supplied to the apparatus (disperser, mechanical activator, mill, etc.) into the energy of destruction of material particles [1–4]. Priority factors also include the mechanical and rheological properties of the processed products [5–7]. In these devices

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for the processing of products, various types of energy are used: mechanical energy from a drive electric motor, gas energy and electromagnetic energy in various forms of its manifestation. The final choice of the energy transformation method is determined by the grinding method (impact, abrasion, etc.), implemented in the process of forming force interactions in the contact systems of the working bodies of the apparatus with particles of the ground material. At the same time, first of all, when choosing the type of grinding equipment included in the apparatus and technological scheme of the enterprise, the determining factors are the properties of particles and the production requirements for the final quality of the processed products established by the standards. Attention is also paid to the degree of selectivity of grinding products, which is also regulated by standards in many technologies. In this regard, when choosing standard equipment and developing new types of dispersants, special attention is paid to the parameters of energy efficiency, the degree of selectivity of dispersed material particles, and the energy intensity of finished products. As practice has shown, the most effective in terms of the final parameters of the process being implemented are the devices based on the formation of grinding loads in the magnetically fluidized layer of ferromagnetic elements (grinding elements) in a mixture with the material being processed. Analysis of the results of theoretical and experimental studies of such devices as Direct Current electromagnetic grinders (DCEG), electromagnetic mechanical activators (EMMA), electromechanical dispersers (EMD) allows us to state that this type of equipment can be considered as a power amplifier, which a priori predetermines an increase in the energy efficiency of production [8].

In this regard, the purpose of the research is to identify the energy regularities of the formation of force contact interactions of grinding bodies in their magnetically fluidized layer during the implementation of the processes of mechanical activation of products for various purposes in devices of the type series DCEG, EMMA, EMD.

2 Materials and Methods

The method of forming grinding loads in the working volumes of devices of various design modifications (DCEG, EMMA, EMD) was investigated. An algorithm for calculating energy consumption for grinding products is presented. The study took into account that contact interactions are realized through an interlayer of the processed material. In the mathematical modeling of the force and energy conditions of dispersion, the basic theory of the method of mechanoactivation in a magnetically fluidized layer of a ferrobody, based on the development of J. K Maxwell's dipole model of the interaction of ferroballs under the action of forces and moments of a magnetic field, is used [9–11]. Theoretical studies, in particular the process of creating shock and abrasive grinding loads in a magnetically fluidized layer of ferromagnetic grinding bodies, are confirmed both visually using the method of high-speed fixation (ultra-rapid) and using experimental-static methods and methods of analysis and synthesis.

3 Results

A generalized cluster of physical and mechanical processes (using the example of a disk electromagnetic mechanoactivator—DEMM), which forms shock and abrasive loads in the magnetically fluidized layer of a ferrobody during the implementation of the mechanical activation process is shown in Fig. 1.

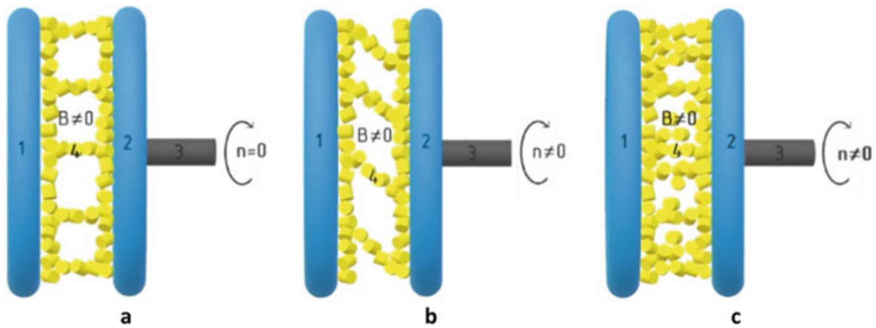

Fig. 1. Formation of impact and abrasion loads: a, **b**—intermediate stages of the formation of grinding loads; **c**—mechanical activation workflow: 1—stationary disk; 2—movable disk; 3—movable shaft (drive shaft); 4—structural groups of ferromagnetic grinding elements

Structural diagrams of devices based on the formation of contact interactions between the grinding elements of the magnetically fluidized layer and material particles are implemented in the equipment representing the subject of the invention. The intellectual property of the novelty of the development is confirmed by 27 patents for inventions of the Russian Federation. This is an unconventional type of energy-efficient devices for the implementation of the processes of mechanical activation of materials in feed production, cement, food and paint and varnish industries.

The highest priority was given to cylindrical devices. The structural schemes are shown in Figs. 2 and 3.

According to the established classification [8], the device (Fig. 2) is singlerotor, coaxial, unipolar, two-coil, single-chamber, with mechanical displacement energy, continuous operation, horizontal design and is used for fine milling of liquid and semi-liquid dispersed systems in the agricultural, food, paint and coatings industries.

The device (Fig. 3) is cylindrical, single-rotor, coaxial, multipolar, 4-coil, single-chamber, with mechanical displacement energy, pulsed, has vertical design, is equipped with an automatic product quality control system; the device is intended for the preparation of chocolate mass and fat glaze, processing of agricultural raw materials in food production.

At the same time, due to the synergy [12] of energy flows, minimization of power for managing the quality of finished products is achieved.

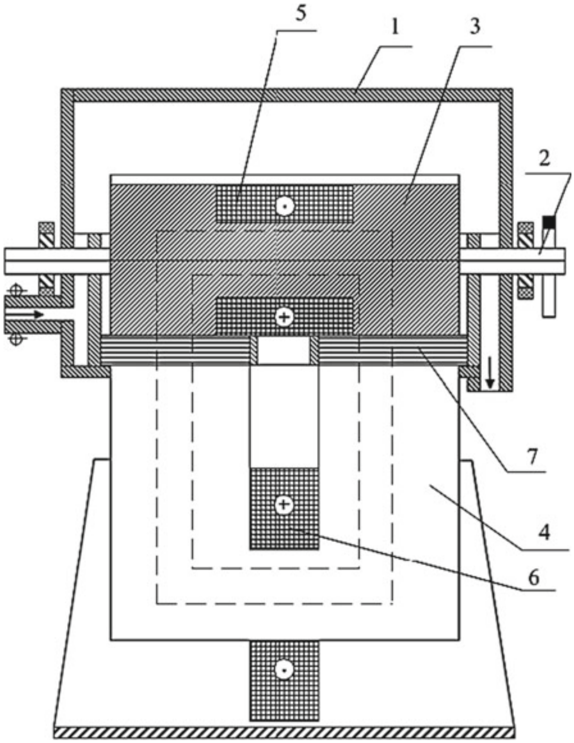

Fig. 2. Patent of the Russian Federation No. 1457881: 1—housing; 2—rotor; 3—cylinder; 4—external magnet core, 5, 6—control windings; 7—cylindrical grinding media

The number of chains of grinding ferrobodies (in this case N_b, balls with a diameter d) organized under the action of the forces of the electromagnetic field between the surfaces of the working volume of the apparatus located at a distance, moving with the difference in speed h_0, is determined by the expression:

$$n_{ch} = Entier\left(N_b \frac{d}{h_0}\right) \quad (1)$$

Modeling of power contacts was carried out under the condition that $d \ll h_0$ and $d \gg r_p$ (here r_p is the geometric averaged size of the initial particle).

From the dipole model of J. K. Maxwell it follows that the forces Fr and moments Mv acting on the elements of the magnetically fluidized layer (in this case, ferrous balls with a radius R_0) from the side of the magnetic field with strength H are equal:

$$Fr = \frac{1}{2}\frac{\mu - 1}{\mu + 2} R_0^3 \frac{\partial H^2}{\partial r}\Big| r = 2R + r_p \quad (2)$$

$$Mv = \frac{1}{2}\frac{\mu - 1}{\mu + 2} R_0^3 \frac{\partial H^2}{\partial v}\Big| r = 2R + r_p \quad (3)$$

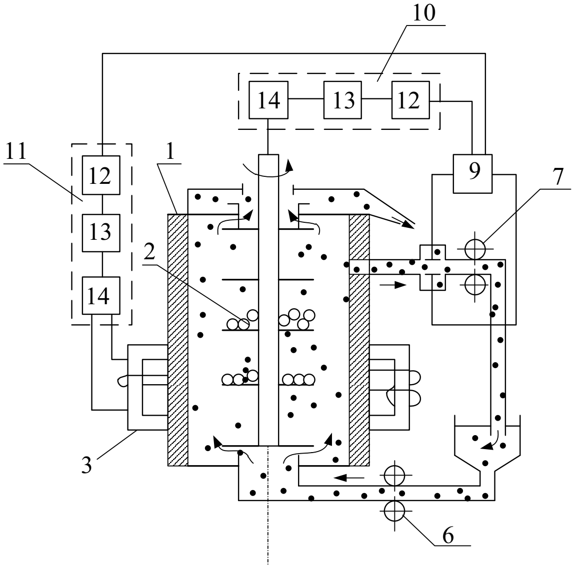

Fig. 3. Author's certificate No. 15460501: 1—bead mill, 2—ferromagnetic grinding balls; 3—DC electromagnets; 4—rotor; 5—diamagnetic disks; 6, 7—main and additional pumps; 8—dispersed product composition control unit; 9—comparison unit; 10—automatic rotor speed control system; 11—automatic electromagnets control system; 12—signal amplifier; 13—phase discriminator; 14—control unit

After numerical integration, we get:

$$M_\nu = \frac{3}{128} H_0^2 R_0^3 \frac{(\mu-1)^2}{(\mu+2)^3} sin(2\nu)[-(31+17\mu) + \frac{r_p}{R_0}(5+3\mu)]. \quad (4)$$

The angle of inclination of the chains of grinding bodies determines the sign of the acting force—attraction or repulsion (formation of chains or their destruction).

In this case, the angle of inclination in the process of forming a force effect on the product is of critical importance

$$\nu_{cp} = \frac{1}{2} arccos \frac{11+13\mu}{9(5+3\mu)} \approx \frac{1}{2} arccos \frac{13}{27} \approx \frac{\pi}{6} \quad (5)$$

At $\nu_{cp}= 0$ the force is maximum

$$F_r \frac{3}{23} H^2_0 R^2_0 \frac{(\mu-1)^2}{(\mu+2)^2}[-(5\mu+7) + \frac{r_p}{2R_0}(23\mu+25)] \quad (6)$$

This value corresponds to the compressive force acting on the segments CA, VD, EG, etc. (Fig. 4).

The work done by this power is defined by the expression

$$A_1 = \frac{N_b}{2} \int_{r_{p2}}^{r_{p1}} \left| Fr_p \right| dr_{p_{\max}} \right| \quad (7)$$

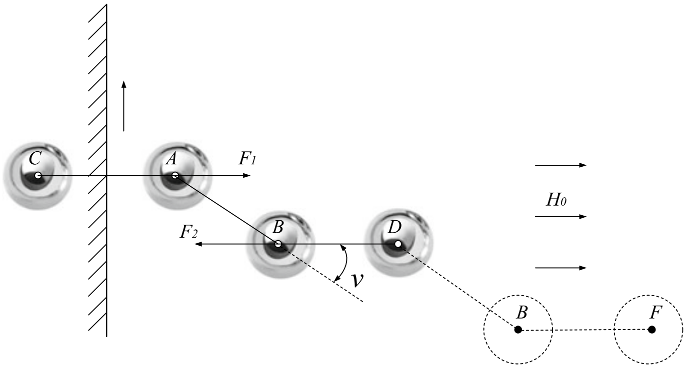

Fig. 4. Non-equilibrium chain of grinding ferrous balls

As a result of integration, we obtain the calculation formula

$$A_1 = \frac{3}{64} H_0^2 R_0^2 \frac{(\mu - 2)^2}{(\mu + 2)^3} \frac{N_b}{2} [(5\mu + 7)(r_{b1} - r_{b2}) - \frac{(23\mu + 25)}{4R_0}(r_{b1}^2 - r_{b2}^2)] \quad (8)$$

Figure 5 shows a non-equilibrium chain of ferro balls.

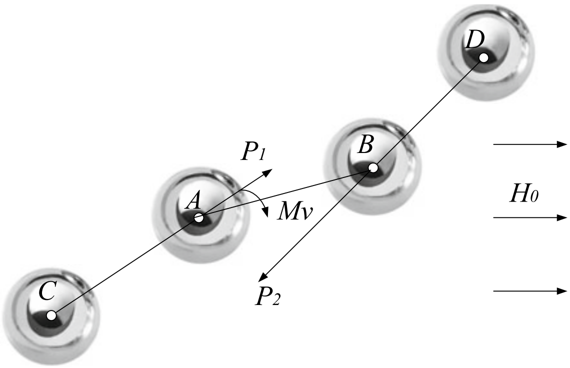

Fig. 5. Equilibrium chain of grinding ferro balls

As follows from Fig. 3, segments AB, DE, etc. are characterized by a change in the magnitude of the force of attraction of ferro balls, since the value of the angle changes in the range from 0 to ν_{cp}.

With values, the calculation formulas for calculating the average forces and moments are converted to the form

$$F_r = H_0^2 R_0^2 \frac{(\mu - 1)^2}{(\mu + 2)^3} \left[-0,43(\mu + 1,37) + \frac{r_p}{R_0}(\mu + 1) \right]. \quad (9)$$

$$A_2 = H_0^2 R_0^2 \frac{(\mu - 1)^2}{(\mu + 2)^3} \frac{N_p}{2} [0,43(\mu + 1,37)(r_{p1} - r_{p2}) - \frac{1}{2R_0}(\mu + 1)(r_{p1}^2 - r_{p2}^2)]. \quad (10)$$

According to the physical interpretation of the process of the formation of grinding loads in the form of abrasive effects from the grinding bodies, the total work for the destruction of the product particle from r_{p1} to r_{p2} calculated by the formula $A_{com} = A_1 + A_{2.}$

Impact fracture [13] is due to the breaking of the chains when the inclination angle is equal to the critical value ν_{cp}. At the same time, it is reliable to assume that all the energy expended in this case (energy for changing the angle of inclination) is converted into kinetic energy and is transformed into the energy of impact destruction of material particles. According to Fig. 3 to sections AB, DE, etc. chain the moment is applied $M\,\nu$. Taking into account that the particle size is much smaller than the size of the grinding element, formula 4 can be converted to the form.

$$M(\nu) = F(\nu)2R_0 \sin\nu - M_\nu(\nu) \tag{11}$$

The rotation of $Nvol/2$ of the sections under consideration in the working volumes of the apparatus at an angle from 0 to $\pi/6$ requires work.

$$A = \frac{N_{vol}}{2}\int\limits_0^{\pi/6} |M(\nu)| d\nu$$

Then the formula for calculating the work on impact destruction of product particles has the form.

$$A = N_{vol} H_0^2 R_0^3 \frac{(\mu - 1)^2 (0,002\mu - 0,02)}{(\mu + 2)^3} \tag{12}$$

4 Conclusion

The presented linear theory of the method of forming power contacts in a magnetically fluidized layer of a ferrobody when creating a force field of shock and abrasive loads in the working volumes of devices such as DCEG, EMMA, EMD is included in the design calculation when creating new structural forms of grinders. Practice has shown that the maximum relative error of calculated and experimental data is no more than 7%. Thus, it can be argued that the presented linear theory contributes to the development of grinding technology in the priority direction—increasing production efficiency [14–16].

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Polyketides Are Agents for Probiotics Antagonizing Pathogenic Microbiota

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Abstract. Probiotics are actively studied and used to improve the health of animals and humans. One of the essential properties of many probiotics is their antagonism to various pathogens, realized in a wide range of ways. These ways include producing antibiotic substances (antimicrobial and antifungal) capable of suppressing pathogenic microorganisms' vital activity and not harming the host organism. In this review, we focus on analyzing the role of polyketides in producer organisms' vital activity, their antibiotic ability against pathogens in animals and humans, and their contribution to probiotics' antagonism with pathogens.

Keywords: Polyketides · Probiotics · Antagonism · Antibiotics · Animal pathogens

1 Introduction

Today, human infectious diseases are growing due to the ever-increasing spectrum of antibiotic-resistant bacteria and pathogenic fungi. Despite attempts to strictly control antibiotic substances in the agricultural industry, many industries misuse them. As a result, antibiotic resistance spreads and more and more diseases do not respond to adequate treatment [1]. For several other diseases caused, for example, not by bacterial or fungal pathogens but by protists, there are still no full-fledged approaches.

The worldwide spread of antibiotic-resistant strains leads to a high degree of severity and even mortality from those infectious diseases that were considered mild yesterday [2]. Pan-resistance is an even more severe problem due to the exceptional mortality from pan-resistant infectious agents [3]. The situation with fungal pathogens is complicated by the small number of major classes of antimycotics. Although the number of antibiotics classes exceeds a dozen and a half, there are only four main classes of antimycotics:

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echinocandins, azoles, polyenes and antibiotic analogues [4]. The development of resistance to one of the compounds from a particular class often decreases the efficiency compared to other similar compounds, and the development of total resistance to the entire class is greatly accelerated. Moreover, protozoan diseases, for example, usually have a more severe course and worse mortality prognosis than bacterial and fungal infections, but the list of approaches to their treatment is even more limited [5]. This problem is especially acute in the field of animal husbandry, as some protozoa can cause infection of the fetus and further miscarriages in dairy cattle [6].

These problems pose significant challenges in livestock production, the consequences of considerable economic losses and obstacles to global growth in many production sectors, such as aquaculture [7]. Furthermore, control over this area is traditionally lower than that of medicine. Thus, it is believed that more than half of all antimicrobial drugs produced in the world are used specifically for the needs of livestock [8]. Moreover, the spread of resistant strains in animals raises concerns about the likelihood of new zoonotic infections and the spread of resistance among pre-existing human pathogens. Therefore, the development of new approaches to the treatment of animal infections is a global problem. In this regard, the use of probiotics seems to be a possible solution to the problem.

2 Use of Probiotics to Increase the Initial Resistance of Animals to Pathogens

Probiotics are live microorganisms that, when administered in adequate amounts, confer a health benefit on the host [9]. Researchers focus on overcoming antibiotic resistance in a variety of ways. On the one hand, the search and synthesis of new antibiotic substances. On the other hand, it is a revision of approaches to the treatment of infectious diseases.

The use of various probiotic compositions with antagonistic activity against pathogenic microorganisms could be part of such revision. It is well known that the gastrointestinal microbiota plays a crucial role in human and animal health [10], and the use of probiotics is a great way to improve gut microbial balance and host health [11, 12].

The beneficial effects on the health of the host organism can be achieved in various ways. First of all, it could be an increase in resistance to diseases.

Probiotics have several ways of improving the host's resistance:

- immunomodulation [13];
- adhesion to the epithelium of the mucous membranes, which helps to resist pathogens [14];
- improving feed absorption by increasing the level of certain digestive enzymes, which has a positive effect on the health of the host organism [15];
- synthesis of bioactive substances such as vitamins, organic acids, fatty acids, as well as antibiotics that act directly against pathogens [16].

Bacillus spp. are producers of an extensive range of secondary metabolites that have different functional features. One of the largest groups of such metabolites is antimicrobial substances—a chemically heterogeneous group. It includes non-ribosomally synthesized peptides (surfactin, iturin, bacitrocin and others), ribosomally synthesized proteins (bacteriocins), including enzymes (quorum quenching enzymes such as AHL lactonase), polyketides (macrolides, polyenes, polyethers and others), NRPS/PKS hybrids (like amicoumacin A), and others [16, 17].

Due to the ability to produce a wide range of antimicrobial (and not only) compounds, Bacillus spp. are a promising group for searching and creating probiotic strains [18].

Thus, in work [19], it was shown that Bacillus sp. isolated from the fish intestines have antagonistic activity against a number of pathogens of intestinal infections of fish, such as Vibrio vulnificus, Photobacterium damselae subsp. damselae., Photobacterium damselae subsp. piscicida, Staphylococcus aureus, Edwarsiella tarda, etc.

Another study examined the Bacillus subtilis BSXE-1601 strain's antimicrobial activity and the mechanisms of its effect on pathogens in shrimp aquaculture. B. subtilis BSXE1601 metabolites were able to suppress the activity of various pathogenic strains, including Vibrio alginolyticus AR-1, Vibrio harveyi SRTT9, V. vulnificus S01P2., Pseudoalteromonas sp. LPE40 and Staphylococcus marisflavi AP629 [20].

Bacillus velezensis V4 probiotic supplements increased the initial resistance of salmonids to Aeromonas salmonicida furunculosis. Moreover, it had a positive effect on weight gain [21].

The following species are actively studied and used as probiotics: Bacillus subtilis, Bacillus cereus, Bacillus coagulans, Bacillus clausii, Bacillus megaterium, Bacillus licheniformis, Bacillus circans, Bacillus pumilus, Bacillus velezensis и Paenibacillus polymyxa [22].

3 Implementation of Probiotic Properties Via Polyketides

Polyketides (PK) are bioactive compounds produced by various microorganisms, including Bacillus spp. [19]. These substances have antibacterial, immunosuppressive, antitumor, and many other antagonistic properties. Their synthesis is realized through mechanisms using a cluster of polyketide synthase genes (multienzyme system PKS). They are synthesized from acyl-CoA precursors such as malonate and methylmalonate. The molecular structures of some polykitides are shown in Fig. 1.

Polyketide synthases (PKS) are classified into three types based on their functional domains' structural organization. Type I PKS contains large multifunctional enzymes. The domains strung on top of each other, held together by short peptide fragments [23]. Type I PKS are processive and iterative. In prokaryotes, the most common type I is iterative PKS [24].

PKS type II are enzyme complexes consisting of single monofunctional enzymes. They catalyze the formation of compounds requiring aromatization and cyclization but not extensive reduction or reduction/dehydration cycles. They are similar to fatty acid synthases (FAS) [25].

Type III PKS are most studied and represented in plants. However, they are found in both prokaryotic and other eukaryotic cells [26]. Type III bacterial PKS are classified

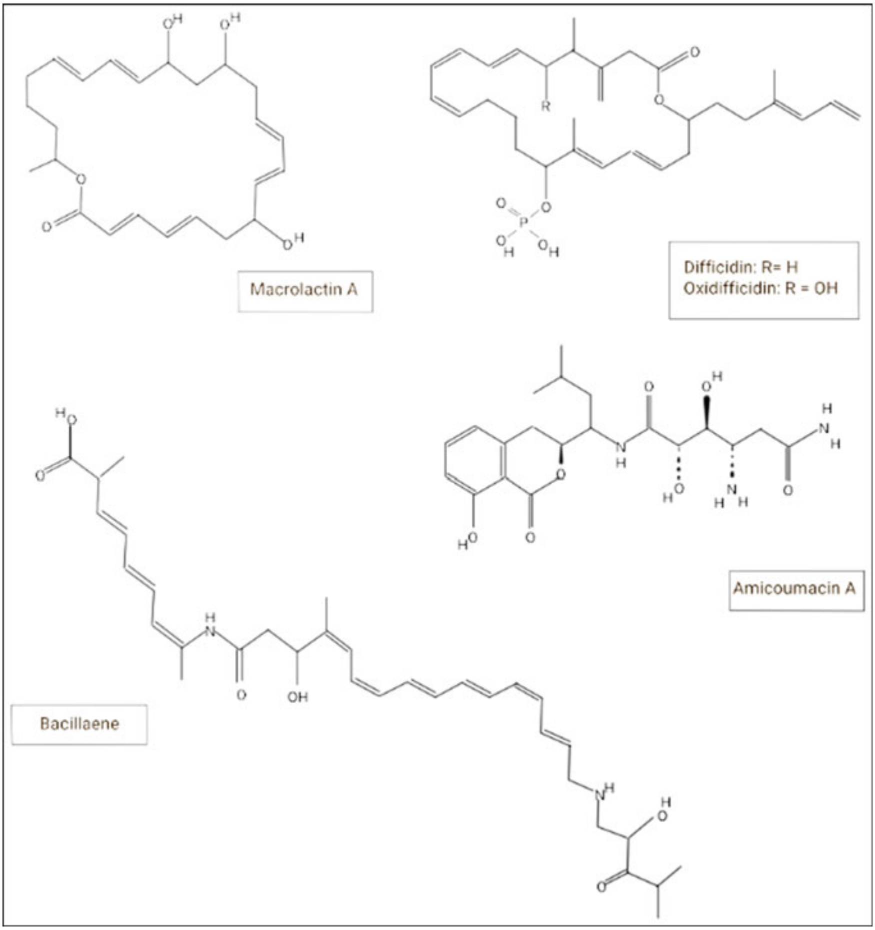

Fig. 1. Molecular structures of Macrolactin A, Difficidin, Oxidiffidicin, Bacillaene and Amicoumacin A.

into five groups [27]. They are small proteins with a single polypeptide chain, similar to plant chalcone synthase [27]. They act directly on thioesters without any ACP (acyl carrier protein) domain [28].

Due to the variety of PKS, there are many exceptions and transitions between the three main types. In addition to hybrids of one type of PKS with another type of PKS, they can be combined with fatty acid synthases (PKS-FAS) and non-ribosomal peptide synthases (PKS-NRPS) to form products such as amicumacin A and bacillaene [20, 29].

Among the whole variety of probiotic strains, Bacillus spp. can synthesize a wide range of bioactive substances, including polyketides and their hybrids with NRPS and FAS. Accordingly, we are focusing on polyketides that are produced by Bacillus spp. This review focuses on analyzing 4 common PKS products and PKS/NRPS hybrids found in Bacillus spp., which can act as probiotic strains.

3.1 Bacillaene

Bacillaene was first isolated from the Bacillus subtilis strain [30]. To date, it has been revealed that it is produced by a relatively wide range of species of the genus Bacillus and Paenibacillus [31]. Bacillaene is a polyene polyketide obtained by hybrid synthesis with PKS type I and the NRPS bae operon (baeJ, baeL, baeM, baeN and baeR). Bacillaene is a linear molecule composed of a highly conjugated hexaene linked to an alpha hydroxycarboxylic acid and a conjugated triene with two amide bonds [32].

The mechanism of realization of bacillaene's antimicrobial activity is still unclear. It is known to be associated with impaired translation in prokaryotes. It is known to exhibit no activity against Candida albicans and Saccharomyces cerevisiae [30]. Nonejuie P. et al., using bacterial cytological profiling (BCR) analysis, concluded that bacillaene are more likely to cause translation arrest than inappropriate translation behaviour (eg, translation lengthening) [33].

In a recent study [34], it was found that bacillaene can stimulate biofilm formation in the producer strain at low concentrations (1.0 and 0.1 μg/ml), inhibit growth at a concentration of 100 μg/ml, and not affect at a concentration of10 μg/ml.

It is also interesting that bacillaene production promotes the survival of Bacillus against the predatory bacterium Myxococcus xanthus [30].

There is evidence that bacillaene shows good antimicrobial activity against a wide range of bacteria. According to [30], a zone of growth inhibition under the influence of bacillaene was observed in such strains as Klebsiella pneumoniae SC 1 0440, Proteus vulgaris SC94 1 6, Serratia marcescens SC9783, Bacillus thuringiensis SC2928, Staphylococcus aureus SC240. However, it was absent in such bacteria as Staphylococcus epidermidis SC9087, Pseudomonas aeruginosa SC8723. It should be noted that there are very few studies of the antimicrobial activity of bacillaene to date. Most often, the structural features of the molecule, synthase and its genes, and the details of the synthesis are analyzed [32, 33, 35]. Also, information about certain strains and their metabolites' antagonistic abilities could often be found, but identification of particular metabolites is a rare event [22].

Thus, bacillaene is not only an antagonistic agent for various pathogens; it also regulates some physiological aspects of Bacillus activity, such as biofilm formation.

3.2 Macrolactins

Macrolactins are a huge group of lactone macrolides, consisting of a 22–25 membered lactone ring with three diene moieties in the carbon chain. They are produced by a wide range of bacteria, including Bacillus spp. Macrolactins and their 7-O-succinyl- or 7-O-malonyl derivatives are synthesized by PKS type I. They are already used in medicine because of their diverse activity. It is known that they have antibacterial and antifungal activity, and there are also data on the effect on the vital activity of eukaryotic cells. In particular, it has been shown that macrolactins can inhibit the proliferation of mouse melanoma cancer cells and disrupt the replication of the herpes simplex virus in cell culture [36].

24-membered macrolactins include macrolactin A, F, G, I, K, J, L, N, S and others; to 22-membered—macrolactin H; to 25-membered—macrolactin M.

Most macrolactins are composed of a 24-membered lactone ring. Moreover, they can all have different biological activity and show antagonism to different groups of microorganisms.

So, macrolactins A, B, F and W inhibit the growth of mainly plant pathogens such as Botrytis cinerea, Colletotrichum acutatum, etc. However, there is evidence that they have antifungal activity against Candida albicans, the causative agent of human opportunistic infections [37].

The 24-membered macrolactin N has antibacterial activity against S. aureus. The target for macrolactin N is the bacterial peptide deformylase (PDF) enzyme required for the growth of bacterial cells [36]. Macrolactin S selectively inhibits FabG genes of S. aureus and exhibits antibacterial activity against E. coli, S. aureus, B. subtilis [36].

The macrolactin A derivative 7-O-succinyl macrolactin A inhibited the growth of methicillin-sensitive S. aureus and vancomycin-resistant enterococci [39].

It is interesting to note that many macrolactins at certain concentrations are capable of inhibiting the growth of Bacillus subtilis, including their producers. However, in vivo, this process is strictly regulated by the producing cells. As was noted above, bacillaene is also active against Bacillus spp. at a concentration of 100 μg/ml. However, at the same time, it accelerates the synthesis of biofilms at relatively low concentrations, which only stabilize the culture. It is possible that some complex regulatory mechanisms, which are still poorly understood, play a role here.

It is also important to note that all of these macrolactins were isolated from Bacillus spp., which originate mainly from the seas. This fact suggests that marine Bacillus are promising to search for useful secondary metabolites and probiotic strains. However, Bacillus from other habitats (e.g. soil) also produces a wide variety of antimicrobial metabolites.

3.3 Difficidin and Oxydifficidin

Difficidin and its oxidized form oxydifficidin are polyenes that contain a highly unsaturated macrocyclic polyene containing a 22-membered carbon skeleton with a phosphate group [40]. Dificidin is a type I PKS product.

Unfortunately, there are not many studies devoted to the action of difficidin alone on animal and human pathogens. A study Gao et al. (2017) [21] showed that the probiotic strain Bacillus velezensis V4 could inhibit the growth and development of Aeromonas salmonicida, the causative agent of furunculosis in fish from the salmon family. This disease is characterized by high mortality rates among infected fish and severely damages the salmon industry. Bacillus velezensis V4 is a producer of several secondary metabolites, including macrolactins, iturin, and oxydicidin. It is assumed that such metabolites provide an integrated approach to fight against the pathogen. It is important to note that the addition of a probiotic to the fish diet led to a decrease in the mortality of fish infected with furunculosis (from 9.65% to 3.51%) and an increase in the final body weight (from 231.6 g to 250.57% g).

Bacillus velezensis 157, isolated from Eucommia ulmoides, has antimicrobial activity against a wide range of animal pathogens such as Salmonella typhimurium ATCC25241, Proteus hauseri, Clostridium perfringens, etc. Full genome sequencing has shown that the strain produces a wide range of metabolites—macrolactins, bacillin, dificidin and other secondary metabolites [41].

Additional data is needed to get a complete picture of the mechanism of action and activity of difficidin and its derivatives. At the moment, it could only be stated that effective antagonists of pathogens (for example, Bacillus velezensis 157, Bacillus velezensis V4, etc.) produce difficidin and oxydifficidin, among other metabolites.

3.4 Amicoumacin

Amicoumacin belongs to the class of natural dihydroisocoumarins. Amicoumacin A is synthesized by the PKS-NRPS hybrid, which is encoded by a cluster of 17 genes. In a study [20], it has been shown that amicoumacin A inhibits the growth and development of gram-negative pathogens in shrimp aquaculture: V. alginolyticus AR-1, V. harveyi SRTT9, V. vulnificus S01P2, Pseudoalteromona ssp. LPE40 and S. marisflavi AP629. Lama et al. [42] suggest that this compound's mechanism of action is based on inhibition of murein hydrolase, which plays a crucial role in regulating cell wall processes. In a later study [43] it is hypothesized to be the inhibition of protein synthesis by blocking mRNA in the mRNA-binding channel of the 30S subunit. Amicoumacin A is also known to be effective against methicillin-susceptible S. aureus [42].

4 Summary

Nowadays, our understanding of probiotics, their functional role and capabilities are continually expanding. The selection criteria for probiotic strains are also expanding and refining. Bacillus spp., which are already actively researched or used as probiotics, mainly in animal husbandry, are some of the most promising representatives for research and use in the field of medicine and veterinary medicine. They are potential producers of various natural biologically active substances. Among these secondary metabolites, some perform a wide range of functions: regulatory, communicative, antibiotic, etc. For example, polyketides are synthesized by special multienzyme complexes of polyketide synthases and hybrids of PKS with synthases of other types (NRPS, FAS), including a huge group of substances, often have pronounced antibacterial and antifungal activity, which can be realized through various mechanisms. For example, by inhibiting protein synthesis (such as bacillin) or inhibiting certain enzymes necessary for the growth and development of microorganisms (such as macrolactins). Thus, polyketides act as one of the agents for antagonizing probiotics with pathogenic microbiota, along with non-ribosomal synthesized peptides.

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The Use of Catalysts in the Production of Fuel for Agricultural Machinery

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Abstract. Fischer–Tropsch synthesis is the main process for obtaining synthetic hydrocarbons from a mixture of CO and H_2, called synthesis gas. The process is carried out using catalysts based on cobalt or iron, supported on carriers of various nature. The composition of the resulting product depends on the process conditions and the catalyst used [1]. The authors obtained a cobalt-magnesium-zirconium catalyst of the following composition: Co—100; MgO—6,5; ZrO2—9,8; carrier—200. Diatomite from the Malchevskoye deposit of the Rostov region was chosen as a carrier. The mechanical strength, chemical composition, degree of reduction of catalysts, as well as their activity and selectivity with respect to the target fraction have been investigated. 225–335 °C. Catalytic tests were carried out in a laboratory unit under conditions close to industrial technological parameters. Based on the study, the data obtained on the activity and selectivity of the catalyst in the process of obtaining synthetic hydrocarbon fuel by the Fischer–Tropsch method allow us to speak about its operating parameters and evaluate them as satisfactory in comparison with similar catalytic systems.

Keywords: Fischer–Tropsch synthesis · Diatomite · Called synthesis gas · Cobalt-Magnesium-Zirconium catalyst · Diesel fuel · Catalyst · Estimation of greenhouse gas emissions

1 Introduction

Industrial demand for hydrocarbon fuels is increasing every year and, according to BP Global energy forecasts, by 2040, electricity and hydrocarbon fuels will account for about two-thirds of the energy used in industry. At the same time, the cost of fuel is increasing, as well as the natural reserves of oil and gas are rapidly decreasing. Consequently, technologies are needed to synthesize fuel from alternative sources of oil. Reference [2] Solid fossil fuels, household waste and other hydrocarbon-containing raw materials are processed in various ways into synthesis gas (a mixture of CO and H2), from which components of motor fuel and raw materials for petrochemical processes are obtained using the Fischer–Tropsch technology.

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Currently, experts from all over the world note an increase in emissions into the atmosphere of exhaust gases containing oxides of nitrogen, carbon, sulfur, as well as benzopyrene and other substances, therefore, countries have regulations that strictly determine the quality of fuels in terms of permissible emissions of harmful substances during fuel combustion in engine. The fuel obtained by the Fischer–Tropsch method practically does not contain compounds of sulfur, nitrogen and aromatic substances, therefore, the emissions of fuel combustion products into the atmosphere are significantly reduced. In addition, researchers note a decrease in emissions of hydrocarbons, polyaromatic hydrocarbons and particulate matter during the combustion of fuel fractions of the Fischer–Tropsch synthesis in comparison with diesel fuel obtained directly from oil [3–7].

The Fischer–Tropsch synthesis is a promising technological process that makes it possible to obtain high-quality fuel fractions for internal combustion engines of agricultural machinery [8]. The main advantages of the process [9, 10] are:

- economic efficiency of the technology as a result of the development of catalysts with high selectivity for fuel fractions;
- use of synthesis gas, which can be obtained from any hydrocarbon feedstock, including household waste;
- low costs of transportation of liquid products compared to gaseous;
- high cetane number of the resulting diesel fuel, which is due to the low content of aromatic hydrocarbons;
- process flexibility provided by the ability to use various hydrocarbon feedstocks and at the same time obtain a wide range of products for various industrial sectors;
- the possibility of compounding the resulting fuel fractions with various mixtures of hydrocarbons, including using fractions of organic origin (seed oil).

The composition and yield of synthesis products depend on the ratio $CO:H_2$ in synthesis gas, technological parameters of the process, as well as the catalyst used [11].

Basically, works devoted to the study of catalysts for the synthesis of motor fuels were carried out in order to determine the effect of the nature of the catalyst carrier, the type and amount of additives to the active component on the activity and selectivity of catalysts, depending on the process conditions.

The activity of catalytic systems in the Fischer–Tropsch synthesis and their selectivity with respect to the formation of liquid hydrocarbons of fuel fractions substantially depends on the carrier used [12, 13].

The study of catalysts is of a comprehensive nature, ensuring the identification of their main consumer characteristics. These include, first, activity, mechanical strength and stability in work [14].

The choice of catalytic systems depends on the required composition of the synthesis products. At the same time, changes in catalyst preparation technologies, the use of synthetic carriers, and the delivery of diatomite from abroad require significant costs. The work is devoted to the study of the activity and physicochemical properties of cobalt catalysts, as well as the influence of the carrier and the conditions of the process of synthesis of hydrocarbons from synthesis gas on the composition and yield of products.

The use of diatomites of the Malchevskoye field as carriers of catalysts for the synthesis of diesel fuel by the Fischer–Tropsch method has been investigated. Studies of the chemical composition of diatomites are presented in Table 1.

Table 1. Chemical composition of diatomites

Diatomite	Oxide content, %							
	SiO_2	Al_2O_3 + TiO_2	Fe_2O_3 + FeO	K_2O	Na_2O	CaO	MgO	SO_3
Kisatibsky	85.0–96.8	0.9–6.2	0.36–3.2	0.5	0.6	0.19	0.06	–
Malchevsky	66.0–72.0	12.0–16.0	3.6–7.2	–	–	0.9–3.0	0.3–1.3	0.01–0.8

In its natural form, in addition to minerals, diatomites contain a large amount of ballast inclusions, which are firmly bonded with the minerals that make up the structure of diatomite, therefore, it is necessary to separate pollutants from the natural material.

2 Methodology

2.1 Preparation of the Catalyst

For thyye research, the catalyst was prepared with the composition: Co—100; MgO—6,5; ZrO_2—9,8; carrier—200.

In a special container, the coprecipitation of metals and the carrier was carried out at a temperature 95 °C. The resulting mass was filtered, the precipitate was washed with hot distilled water to pH 7.5–8 in washing waters, and the catalyst was molded by extrusion into particles with a diameter of 3–4 mm. The resulting catalyst was dried at a temperature 120–130 °C, crushed and sieved. The catalyst grains with a size of 1.0–5.0 mm were reduced in the reactor until 60% of cobalt was transformed into a metallic state at a volumetric velocity of hydrogen 3000 h–1 and temperature 400 °C. After the completion of the reduction, the catalyst was cooled in a weak flow of carbon dioxide.

2.2 Determination of the Catalysts' Chemical Composition

The chemical composition of the obtained catalysts was determined by the method of trilonometric titration: cobalt—in acetone and ammonium thiocyanate, zirconium—in xylene orange, and magnesium—in the environment of eriochrome black.

2.3 Determination of the Catalysts' Mechanical Strength

Strength tests were carried out in the following way: a weighed portion of the catalyst (100 g) and a metal ball with a diameter of 8 mm were placed in a drum rotating at a speed of 1200 rpm. For 15, abrasion was carried out, then particles less than 2 mm in size were sifted out and the sample was weighed.

$$Y = \frac{m_0 - m}{m_0} \tag{1}$$

where

Y abrasion, %;
m_0 sample weight before abrasion, g;
m sample weight after abrasion, g.

2.4 Determination of the Degree of Catalyst Reduction

The degree of cobalt reduction in the catalyst was determined by trilonometric titration in acetone with ammonium thiocyanate taking into account the dilution of solutions.

2.5 Study of Catalytic Properties

The rate of reaction in the presence of a catalyst can serve as a measure of catalytic activity. When assessing the activity of contact masses under production conditions, the reaction rate is usually calculated with respect to a unit volume of catalyst per unit time [12, 15].

There are many methods for determining the kinetic characteristics of catalysts, which can be divided into two main groups:

- static, carried out in closed systems;
- dynamic—in open systems.

2.6 Static Method

The reaction is carried out in a closed volume until thermodynamic equilibrium is established or until one of the starting reagents is completely converted. The concentration of the reagents changes from the initial to the equilibrium one, and accordingly the reaction rate changes according to the law of effective masses.

Static methods can only be used to study stationary catalysts in relation to reaction mixtures.

2.7 Dynamic (Flow) Methods

The most common are flow-through methods for measuring catalytic activity. In flow-through installations, a stream of reagents is passed at a certain rate through the reaction volume containing the catalyst, and the process parameters are measured, compositional analyzes are performed at the inlet and outlet of the reactor and, if possible, at various points in this volume. Flow-through methods make it possible to carry out kinetic studies under steady-state conditions, i.e. at constant initial concentrations, temperatures, pressure, degree of mixing and other parameters in each individual experiment. During the transition from one experiment to another, certain process parameters are changed by a predetermined value.

The flow method is integral and continuous. It allows you to carry out the process for as long as you like at given concentrations, temperatures, pressures, linear and volumetric velocities of the gas flow at the inlet to the reactor. Naturally, the concentrations of reactants and other parameters change along the height of the reactor as a result of chemical transformation. The hardware design of such installations is simpler, and the sensitivity is lower than that of static ones.

The main advantage of the flow-through method is the ability to determine the catalytic activity at a steady state of the catalyst. Significant disadvantage—the impossibility of direct measurement of the reaction rate and the difficulty of realizing the ideal displacement regime in real conditions.

The essence of the method lies in the fact that a flow of synthesis gas at a certain rate was passed through a fixed catalyst bed, while simultaneously fixing the process parameters and analyzing the composition of the initial gas and reaction products. The use of this method is based on simplified assumptions about the ideal displacement mode at a steady state of the catalyst and a quasistationary state of the system; deviations from such modes are caused by the presence of certain gradients—concentration, temperature, etc., arising in the system under consideration.

2.8 Determination of the Activity and Selectivity of Catalysts

The tests of the activity and selectivity of the catalysts were carried out in continuous operation, changing the temperature of the process, maintaining the contraction K = 50–60%. Preliminarily at atmospheric pressure and synthesis gas space velocity equal to 50–80 h^{-1} catalyst was developed in a flow of synthesis gas, then the temperature was raised to 100 °C, from 100 to 160 °C the rise in temperature was carried out at a speed 3–5 °C, from 160 °C every 8 h the temperature was raised by 2 °C to contraction equal 45%. The contract is determined by the formula:

$$K = \frac{C_{out} - C_{in}}{C_{in}} \cdot 100\% \tag{2}$$

where

K contraction;
C_{out} tail gas concentration of carbon dioxide;
C_{in} concentration of carbon dioxide at the inlet to the installation.

2.9 Determination of Synthesis Products' Composition

The component composition of the hydrocarbons obtained during the Fischer–Tropsch synthesis was determined by gas chromatography. The essence of the method lies in the separation of hydrocarbon mixtures introduced into a chromatograph equipped with a capillary column with methylsiloxane as a stationary phase.

2.9.1 Characterization of Substances—Ecological and Safety Aspects

Carbon monoxide—flammable gas, explosive, poisonous, colorless and odorless, lighter than air, non-irritating.

MPC—0,02 mg/l, explosion limit of carbon monoxide—12,5–75,0%.

Hydrogen—odorless, colorless, tasteless, non-toxic gas. Explosive, flammable, lighter than air. Explosive limits—4,1–75%.

Paraffinic hydrocarbons—mixture of gaseous, liquid and solid substances. The mixture is flammable, explosive. MPC = 300 mg/m^3. Fire and explosive properties of hydrocarbons (for gasoline):

flash point—(–20 °C);

autoignition temperature—234 °C;

ignition area—1,2–7,5%;

2.9.2 Estimation of Greenhouse Gas Emissions

It is planned to carry out calculations to estimate the annual emissions of combustion products of the resulting diesel fuel into the atmosphere. Reduction of greenhouse gas emissions [16, 17] from the combustion of the resulting synthetic fuel is calculated according to the formula presented in Directive 2009/28/EU of the European Parliament and of the Council of April 23, 2009:

$$E(E_F - E_B)/E_F \tag{3}$$

where

E	total emissions from fuel use;
E_B	total emissions from Fischer–Tropsch fuels;
E_F	total emissions from equivalent fossil fuels.

Carbon dioxide emissions from fuel combustion in internal combustion engines are estimated by the expression:

$$E = M \cdot K_1 \cdot TH_3 \cdot K_2 \cdot 44/12 \tag{4}$$

where

E	total annual emission CO_2;
M	actual fuel consumption per year;
K_1	fuel carbon oxidation ratio (fraction of carbon burned);
TH_3	net calorific value;
K_2	carbon emission factor;
44/12	factor for conversion of carbon emissions C into carbon dioxide CO_2.

For diesel fuel, net calorific value $TH_3 = 43{,}02$ TJ/thousand tons; fuel carbon oxidation ratio $K_1 = 0{,}995$; carbon emission factor $K_2 = 19{,}98$ tC/TJ. The conversion factor for CO2 emissions from fossil fuel combustion for diesel is 3,15 t CO_2/t or 2,6–2,8 kg CO_2/l depending on the temperature of the fuel and its brand.

3 Results

Diatomite is used in industry as the main carrier for precipitated catalysts for the Fischer–Tropsch synthesis. The results of the study of the chemical composition, strength and degree of reduction of the obtained catalysts are presented in Table 2.

Table 2. Chemical composition and physicochemical properties of catalysts (Co content 100 parts by weight)

Catalyst	Chemical composition, %			Abrasion, %	Cobalt recovery time, min	Recovery rates, %
	Co	MgO	ZrO_2			
1	22.1	1.3	2.3	8.1	20	60
2	22.3	1.3	2.1	8.0	25	59
3	22.5	1.2	2.1	7.9	20	58
4	24.2	1.5	2.5	7.2	20	58

The data obtained allow us to say that the studied catalysts contain approximately the same amount of active components, and the degree of reduction of cobalt to the metallic state, as well as the recovery time of the catalyst, practically do not depend on its composition.

The advantages of cobalt catalysts include the fact that they start to work at low pressure, and sometimes at atmospheric pressure.

Catalyst activity and selectivity tests were carried out under pressure 0,7–1,0 MPa on synthesis gas of composition, volume percent %: $H_2 = 58–61$; $CO = 26–31$; $CO_2 = 6–13$; $CH_4 = 1–3$; $N_2 = 2–3$. The volumetric flow rate of synthesis gas during activity tests was varied within 100 h^{-1}, syngas processing 52–58 volume percent % (Table 3).

Studies have shown that the developed catalysts have shown their activity in the process of obtaining hydrocarbons of the fraction C5 and higher. So, at a synthesis temperature equal to 173° C and volumetric velocity 94–98 h–1 there was received 146–150 g/nm3 of hydrocarbons composition C5 + , and with an increase in temperature to 176° C, degree of processing 97–99 h-1 the yield of the target fraction was 151–158 g/nm3.

One of the most important characteristics of catalysts, in addition to their activity, is their selectivity, which in this case was evaluated by the composition of the obtained hydrocarbons. Fractional composition data are presented in Table 4.

The products obtained were represented by a wide range of hydrocarbons with different boiling points. To determine the groups of hydrocarbons, we carried out fractionation of the obtained fractions. The yield of hydrocarbons in the temperature range 170–225° C was 15–25%, the yield of the target fraction 225–335° C was 32–41%, the fraction 335–450° C was 19–28%. The yield of ceresins with a boiling point above 450° C varied from 7 to 20%.

Table 3. Catalyst activity

Catalyst	Synthesis temperature, °C	Syngas volumetric velocity, h^{-1}	Syngas processing rate, %	Hydrocarbon yield C_{5+}, g/nm^3
1	173	94	52	146
	176	99	54	151
2	173	98	56	150
	176	97	55	156
3	173	95	54	145
	176	98	57	152
4	173	96	53	146
	176	99	50	158

Table 4. Fractional hydrocarbon composition of the resulting product

Catalyst component	Composition of hydrocarbons, % in the boiling range, °C					The dropping point of hydrocarbons with a boiling point above 450 °C
	To 170	170–225	225–335	335–450	Higher than 450	
1	6	15	32	28	19	102
2	6	16	31	27	20	102
3	4	17	37	26	16	102
4	6	25	41	19	7	102

The cost of the produced synthetic fuel [10] is determined by the formula:

$$\mathrm{LevelizedCost}_{\mathrm{FTDiesel}} = \frac{C_{\mathrm{ICP}} + C_{\mathrm{O\&M}} + C_{\mathrm{EI}} + C_{\mathrm{Feedstock}} + C_{\mathrm{U}} - C_{\mathrm{income}}}{\mathrm{AnnualFTDieselProduction} \times \mathrm{CapacityFactor}}. \quad (5)$$

where

C_{ICP} the cost of installation, operation of the installation and its maintenance,
$C_{\mathrm{O\&M}}$ utility costs,
$C_{\mathrm{El.}}$ electricity cost,
$C_{\mathrm{Feedstock}}$ raw material,
C_{U} by-products,
C_{income} income from the sale of manufactured products.

4 Conclusion

In the course of research, the chemical and mineralogical composition of diatomite was established. The precipitation method was used to prepare samples of a cobalt-magnesium-zirconium mechanically strong catalyst for the synthesis of hydrocarbons from synthesis gas by the Fischer–Tropsch method. The relationship between the catalytic properties and the chemical and mineralogical composition of the carrier and its physicochemical properties has been established. Catalysts were tested under conditions close to industrial ones.

Based on the results obtained, it can be said that the use of diatomite as a carrier of a cobalt-magnesium-zirconium catalyst is very promising, since it allows one to reduce production costs and at the same time achieve an increase in the yield of the target fraction; therefore, the catalysts have good activity and selectivity.

The activity of the catalyst is due to the developed porous structure of the catalyst formed as a result of the deposition of active components and is determined by the structure of diatomite.

The studies carried out show the relevance of the development of new catalytic systems that can be used in various areas of the chemical and petrochemical industries, as well as the need to improve the technological processes themselves by changing the design of the devices used in technologies.

Instrumental methods of obtaining data are of great importance. The use of new devices for research and monitoring of ongoing reactions will allow reaching a new level of obtaining new catalysts and optimizing technological processes.

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Operational Management of Reliability of Technical Systems in the Agro-Industrial Complex

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Abstract. A generalized analysis of the ways to improve the operational reliability and efficiency of the use of MES in the implementation of technological processes in the agro-industrial complex is presented. On the basis of the conducted analysis, methods of operational reliability management based on functional operational diagnostics of mobile power facilities and their structural elements are developed. The models of increasing the interval operational reliability of mobile power facilities and their structural elements in the implementation of various technical service strategies are substantiated.

Keywords: Reliability · Mobile power plant · Technical service · Functional operational diagnostics · Strategies and service trajectories

1 Introduction

Improving reliability, as well as maintaining it at high level throughout the entire period of exploitation is largely determined by the perfection of the system and methods of reliability management. The process of reliability management, depending on the stages of the life cycle of mobile energy vehicles (MEV), can be conditionally divided into strategic reliability management, implemented at the design and production stages, as well as operational reliability management, implemented at the operational stage.

The greatest interest in the working environment of agro-industrial enterprises is attracted operational reliability management, which consists in the implementing set of measures determined on the basis of operational (continuous or periodic) control and analysis of the technical condition of mobile energy vehicles (MEV), as well as their structural elements to ensure high level interval operational reliability with minimal

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material costs and labor intensity. The main function of operational reliability management under conditions of physically and morally obsolete fleet of mobile energy vehicles (MEV) is the rational use of limited resources in order to ensure and maintain the required level of operational reliability.

Managing the reliability of mobile energy vehicles (MEV) during their exploitation is impossible without taking into account the peculiarities of production operation, since it is the types of agricultural work, the timing of their implementation, the brand and quantitative composition of machines, the degree of their load, load fluctuations, etc. ultimately determine the use of certain repair and maintenance actions to increase their reliability. However, in accordance with the tasks of research, the issues of improving the organization of technical operation are of greatest interest [1–10].

2 Materials and Methods

Ensuring the equality of fail-free and actual execution time of the corresponding operation, expressed in the striving of the interval readiness factor to the absolute value, is consequence of the improving the organization of technical service of mobile energy vehicles, and is achieved on the basis of the resource-saving direction proposed by Professor A. T. Lebedev. This is achieved by the implementation of measures to restore the operability of mobile energy vehicles (MEV) in the intervals between technological operations, when its work is not required, due to the correct selection of cultivated crops, high level of technical and technological maintenance of agricultural equipment [11].

One of the methods for increasing the operational reliability of technical systems and their elements is the method of reservation, which consists in increasing the reliability of the object by introducing redundancy. Redundancy should be understood as additional funds and (or) measures that are extremely necessary for the object to perform the specified functions. To ensure high reliability of mobile power vehicles (MEV), functional reservation is of greatest interest, in which given function can be performed in various ways and technical means. The required function is to provide absolute interval reliability.

Another reserve for increasing the operational reliability of mobile energy vehicles (MEV) can be operational diagnostics—real-time determination of the parameters and features of technical systems, as well as their components for operational assessment of their state at the given stage of operation.

Along with standard diagnostics, the general diagnostics system includes operational diagnostics. The operational diagnostics complexes put into operation when it is necessary to ensure high level of reliability of technical systems are mainly mobile. Operational diagnostics can be carried out continuously or discretely in accordance with previously designed program, inextricably coordinated with the use of standard instrument-measuring diagnostic complex.

Based on the foregoing, in order to ensure high level of interval operational reliability of mobile power facilities, functional reservation of mobile power facilities and their structural elements is proposed by operational diagnostics—“Functional operational diagnostics” (FOD).

Functional operational diagnostics (FOD) is a new tool for functional reservation of the properties of technical system and (or) its subsystems through operational diagnostics in order to increase its operational reliability [12–14].

With regard to the agro-industrial complex, functional operational diagnostics (FOD) is understood as a list of measures aimed at ensuring the absolute interval reliability of mobile energy vehicles (MEV) and their structural elements through methods and means of operational diagnostics. From the point of view of classical domestic strategies for maintenance and repair, which at this stage of development of the agro-industrial complex have lost their relevance, these techniques and methods of maintenance can be considered to be redundant.

Distinctive feature of functional operational diagnostics (FOD) in relation to the crop production industry is that set of redundant measures must be performed in the intervals between technological operations, but without damage to the crop production technology used in terms of the quality of operations and compliance with agrotechnical terms.

According to the method of switching on the functional operational diagnostics, it can be continuous and periodic.

As an example of continuous functional operational diagnostics (FOD), standard systems of operational control and diagnostics of the technical condition of mobile energy vehicles (MEV) and their structural elements (engine, transmission, etc.) can serve [15–18].

Periodic functional operational diagnosis (FOD) can be planned and unscheduled.

Functional operational diagnostics (FOD) as backup element can be applied both to the mobile energy vehicle (MEV) as a whole, and to its individual elements or to their groups. In the first case, functional operational diagnosis (FOD) is called general, in the second it is element-by-element. The combination of the first and second methods in the same system is called mixed.

Functional operational diagnostics acts as backup element for the activities of the S1 strategy “On demand after failure” or the S2 strategy “Regulated”, depending on the specific conditions of agro-industrial enterprises, which requires improvement of the existing system of maintenance and repair.

Taking into account the foregoing, there is proposed new integrated strategy “Operational reliability management”, which consists in the development and implementation of measures aimed at ensuring absolute interval reliability of machines, taking into account their condition and available resources with minimal labor costs and funds for their service.

The proposed integrated strategy (Fig. 1) provides for the improvement of the technical service program by creating set of flexible universal trajectories of functional reservation by functional operational diagnostics (FOD) of the basic strategies S1 and S2.

Taking into account the different trajectories of service (Figs. 1 and 2), models for increasing the operational reliability of mobile energy vehicles (MEV) and their structural elements are proposed.

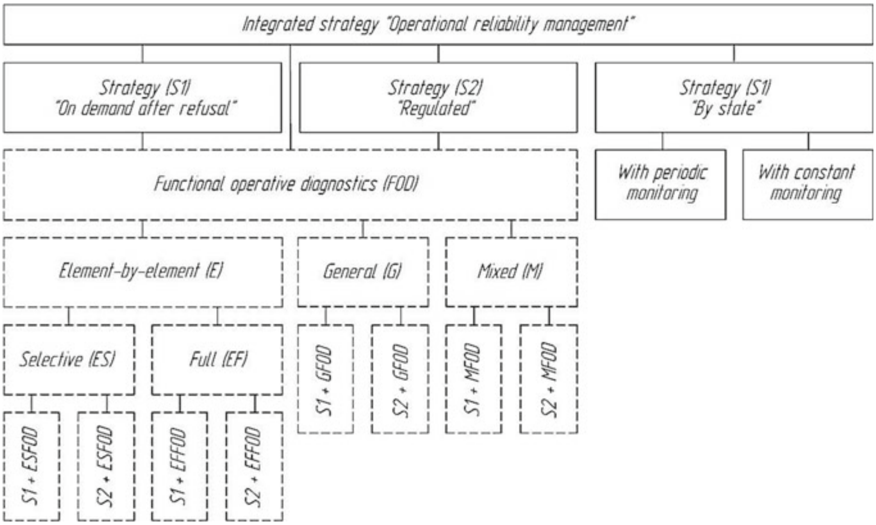

Fig. 1. Block diagram of the integrated strategy «Operational reliability management»

The probability of failure-free operation (PFFO) of the system with series connection of elements is determined by the formula.

$$P(t) = 1 - \prod_{i=1}^{n} P_i(t). \tag{1}$$

When reserving system elements (parallel connection), the probability of failure-free operation is determined by the formula:

$$P(t) = 1 - \prod_{i=1}^{n} (1 - P_i(t)), \tag{2}$$

where $P_i(t)$—probability of failure-free operation of the *i*-th element of the system during exploitation t; n—number of elements (subsystems) of the system.

The probability of failure-free operation (PFFO) of mobile energy vehicles (MEV) served by strategy S1 (Fig. 1a) is determined by the formula:

$$P_{MEV}^{S_1} = P_e \cdot P_t \cdot P_{rg} \cdot P_{es} \cdot P_{hs} \cdot P_{os} \tag{3}$$

where P_e, P_t, $P_{r,g}$, $P_{e,s}$, $P_{h,s}$, $P_{o,s}$,—accordingly, the probability of failure-free operation (PFFO) of the engine, transmission, running gear, electrical system, hydraulic system, other systems.

It is accepted: $P_e = 0{,}9$; $P_t = P_{r,g} = P_{e,s} = P_{h,s} = P_{o,s} = 0{,}95$.

The probability of failure-free operation (PFFO) of mobile energy vehicle (MEV) served along the trajectory S1 + ESFOD (Fig. 1b) is determined by the formula:

$$P_{\mathrm{MEV}}^{\mathrm{S1+ESFOD}} = [1 - (1 - P_e) \times (1 - P_{\mathrm{FOD}})] \times P_t P_{rg} P_{e,s} P_{o,s} \tag{4}$$

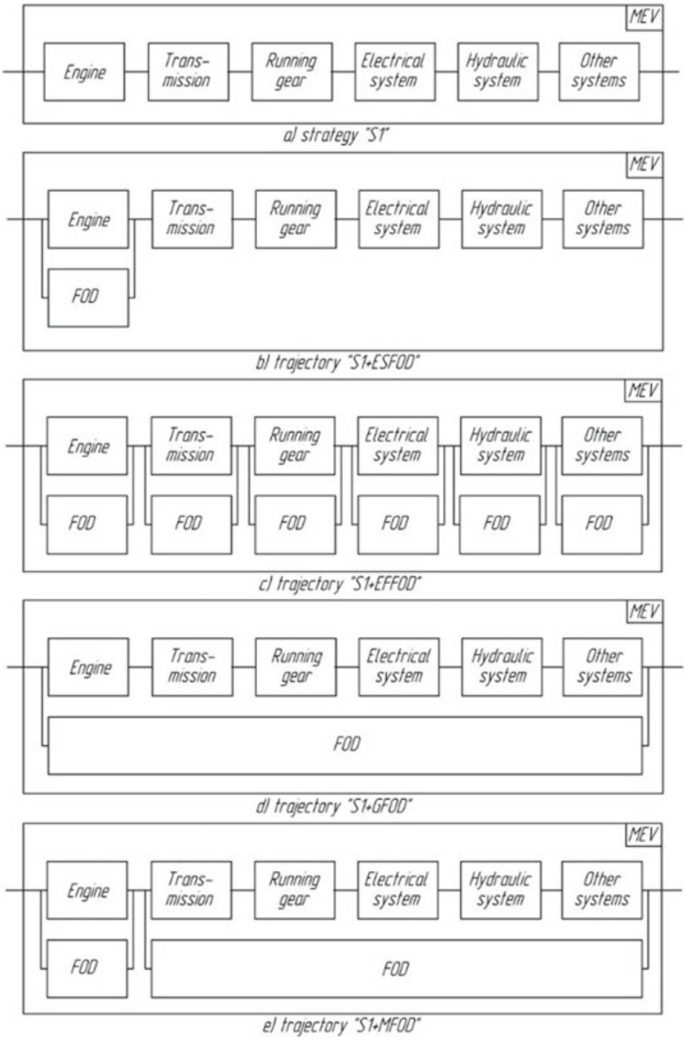

Fig. 2. Block diagrams of mobile energy vehicles served by different trajectories of the strategy S1

The probability of failure-free operation (PFFO) of mobile energy vehicle (MEV) served along the trajectory S_1 + EFFOD path (Fig. 1c) will be:

$$\begin{aligned} P_{MEV}^{S1+ESFOD} &= [1 + (1 - P_e) \times (1 - P_{FOD})] \times [1 - (1 - P_t) \times (1 - P_{FOD})] \\ &\times \left[1 - \left(1 - \mathrm{P}_{r,g}\right) \times (1 - P_{FOD})\right] \times \left[1 - \left(1 - P_{e,s}\right) \times (1 - P_{FOD})\right] \\ &\times \left[1 - \left(1 - P_{h,s}\right) \times (1 - P_{FOD})\right] \times \left[1 - \left(1 - P_{o,s}\right) \times (1 - P_{FOD})\right] \quad (5) \end{aligned}$$

and the probability of failure-free operation (PFFO) of the mobile energy vehicle (MEV), served along the trajectory S1 + GFOD (Fig. 1d):

$$P_{MEV}^{S_1+MFOD} = [1 + (1 - P_e) \times (1 - P_{FOD})] \\ \times \left[1 - \left(1 - P_t \times P_{r,g} \times P_{e,s} \times P_{h,s} \times P_{o,s}\right) \times (1 - P_{FOD})\right]. \quad (6)$$

The probability of failure-free operation (PFFO) of mobile energy vehicle (MEV) served along the trajectory S1 + MFOD (Fig. 1e) is determined by the formula:

$$P_{MEV}^{S_1+MFOD} = [1 - (1 - P_e) \times (1 - P_{FOD})] \\ \times [1 - (1 - P_t \times P_{r.g} \times P_{e,s} \times P_{h,s} \times P_{o,s}) \times (1 - P_{FOD})] \quad (7)$$

The results of determining the values of the probability of failure-free operation (PFFO) of mobile energy vehicle (MEV) served along different trajectories of strategy S1 are presented in Table 1.

Table 1. Results of determining the values of the probability of failure-free operation of mobile power facilities serviced by various strategies and trajectories

Service strategies (trajectories)	Symbol name	Meaning
Strategy «S1»	$P_{\text{MEV}}^{S_1}$	0.7
Trajectory «S1 + ESFOD»	$P_{\text{MEV}}^{S_1+\text{ESFOD}}$	0.766
Trajectory «S1 + EFFOD»	$P_{\text{MEV}}^{S_1+\text{EFFOD}}$	0.978
Trajectory «S1 + GFOD»	$P_{MEV}^{S_1+\text{GFOD}}$	0.91
Trajectory «S1 + MSFOD»	$P_{MEV}^{S_1+\text{MSFOD}}$	0.939
Strategy «S2»	$P_{\text{MEV}}^{S_2}$	0.910
Trajectory «S2 + ESFOD»	$P_{\text{MEV}}^{S_2+\text{ESFOD}}$	0.945
Trajectory «S2 + EFFOD»	$P_{\text{MEV}}^{S_2+\text{EFFOD}}$	0.9995
Trajectory «S2 + GFOD»	$P_{MEV}^{S_2+\text{GFOD}}$	0.972
Trajectory «S2 + MSFOD»	$P_{\text{MEV}}^{S_2+\text{MSFOD}}$	0.996

Figure 3 presents the structural diagrams of mobile energy vehicles (MEV), served along different trajectories of the S2 strategy, which differs from the S1 strategy by the presence of scheduled technical maintenance (TM), presented in the diagram as additional element of functional reservation.

The probability of failure-free operation (PFFO) of mobile energy vehicle (MEV) served by S2 strategy (Fig. 2a) is determined by the formula:

$$P_{MEV}^{S_2} = 1 - (1 - P_e P_t P_{r,g} P_{e,s} P_{h,s} P_{o,s}) \times (1 - P_{TM}). \quad (8)$$

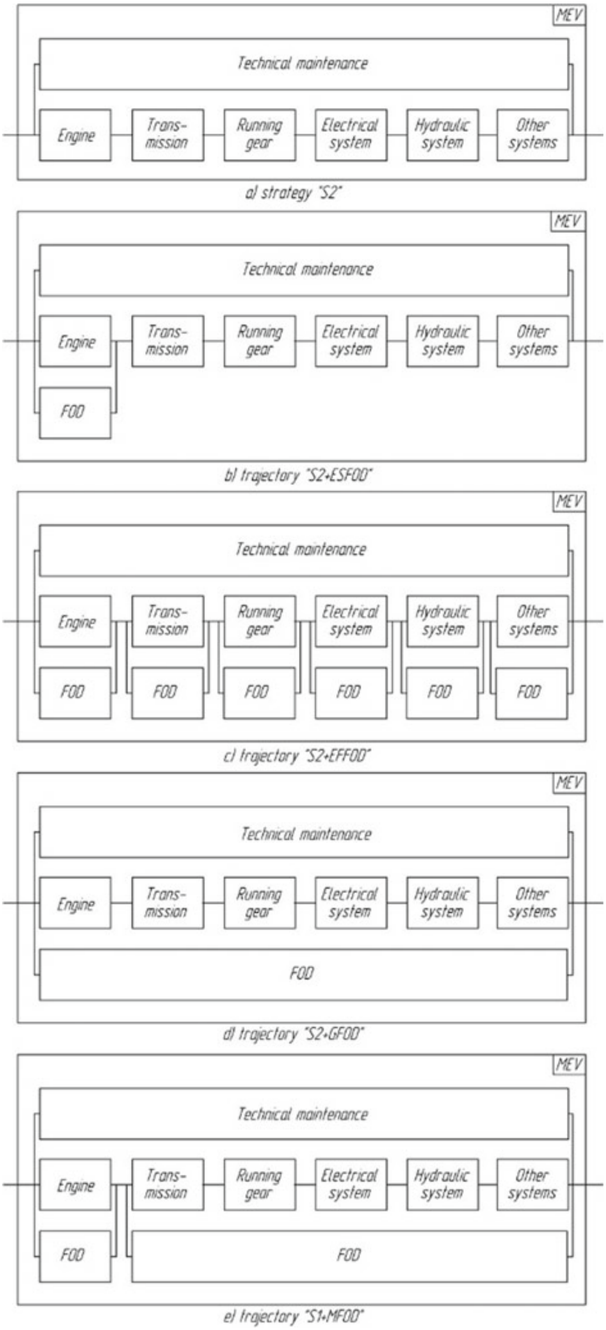

Fig. 3. Block diagrams of mobile energy vehicles served by different trajectories of the strategy S2

The values of the probability of failure-free operation (PFFO) of mobile energy vehicles (MEV), served along different trajectories of the S2 strategy are detected similarly (Fig. 2) (Table 1).

3 Conclusion

According to the criterion evaluating the ratio of the service time to the probability of failure-free operation (PFFO) of the test object, the optimal service trajectories of the mobile energy vehicles (MEV) are "S1 + GFOD" and "S2 + GFOD". If the service along these trajectories is not sufficient to achieve the required level of operational reliability, which is usually typical for outdated mobile energy vehicle (MEV) fleet, then, depending on the adopted strategy, it is recommended to use the "S1 + MSFOD" or "S1 + MSFOD" trajectories.

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Evaluation of Technical Characteristics and Agrotechnical Performance Indicators of Seeders of Various Assembling

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Abstract. The efficiency of grain crops production largely depends on the technical and technological level of agricultural machinery used by enterprises of the agro-industrial complex, among which seeders are among the most demanded and structurally complex. Grain seeders are available in two basic configurations—monoblock (classic seeders) and single-unit seeders, which are now commonly called seeding complexes. The machines of these two groups differ significantly from each other not only structurally, but also in terms of operation and functional indicators. Therefore, in terms of optimizing the design, production and operation of seeders, it is important to have an objective comparative assessment of their technical characteristics and performance indicators. The study was carried out by statistical processing and analysis of data from 70 test reports of seeders that passed certification at mechanical test stations of the Russian Federation in the 21st centure, the analysis of which showed that, in terms of agrotechnical and operational indicators, the seeding complexes are somewhat inferior to "classic" grain seeders, but at the same time they allow the implementation of rowless method of sowing grain on an unprepared stubble background, which are the most promising from the point of view of modern production experience.

Keywords: Agrotechnical indicators · Seeders of various assemblies · Production efficiency · Grain crops

1 Introduction

The efficiency of agricultural production largely depends on the technical and technological level of the technical means used by enterprises of the agro-industrial complex, among which sowing machines, primarily grain seeders, are one of the most demanded and structurally complex ones [1–3]. Sowing machines can be subdivided according to

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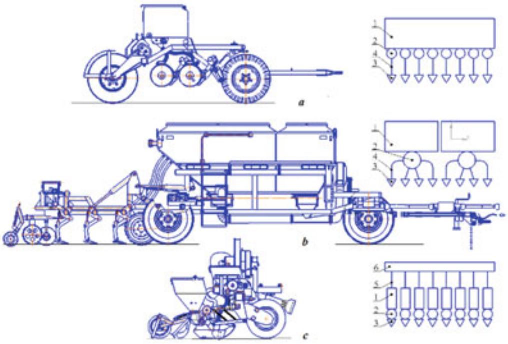
the purpose (sown crops or the method of sowing), the method of aggregation with a tractor, the type of used sowing unit, the type of used ploughshare, etc. Their layout is an important classification feature of all seeding machines [4–7]. On this basis, all seeding machines by modern agroengineering science are divided into three groups (Fig. 1): monoblock, separate-aggregate and sectional machines.



a - monoblock; *b* - separate-aggregate machine; *c* - sectional machine;
1 - bunker; 2 - sowing unit; 3 - ploughshare; 4 - seed line (pneumatic seed line); 5 - suspension mechanism; 6 - shassis

Fig. 1. Configuration diagrams of sowing machines

Units of monoblock planters (Fig. 1a), including the bunker (bunkers) 1, are mounted on a single rigid shassis. Characteristic feature of such seeders is that each seeding unit 2 serves its own "personal" ploughshare 3, into which the seeds are fed through the seed line 4. As a rule, such seeders are equipped with a mechanical dosing system for seeds and mineral fertilizers. Due to historical traditions, this scheme can be considered to be a classic one.

Separate-modular planters (Fig. 1b), contain two blocks (units): a mounted or trailed hopper of increased capacity with mounted seeding units 2 of group planting and distribution system, and tillage tool with ploughshares 3. As a rule, such seeders are equipped with pneumo-mechanical dosing and distribution system for feeding seeds and fertilizers into the ploughshare.

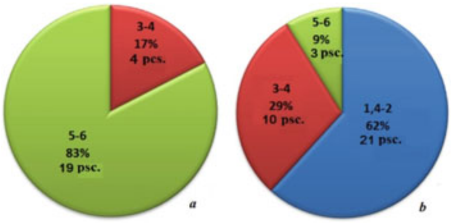
Sectional planters (Fig. 1c) consist of separate seeding sections (each of which can be considered as a single-row seeder) attached to the shassis 6 by special suspension mechanisms 5. This arrangement is widely used in the design of row-crop seeders. Cereals (close-growing crops) are usually not sown with such machines.

Thus, grain seeders are produced in two main versions - monoblock ("classic" seeders) and separate-aggregate mashines [8, 9], which are now commonly called seeding complexes. "Classic" seeders and seeding complexes differ significantly from each other not only structurally, but also in terms of operation and functional indicators. Therefore, from the point of view of optimizing the design, production and operation of grain seeders, it is important to have objective comparative assessment of their technical characteristics and performance indicators.

The purpose of the presented research is comparative assessment of the technical and technological level of modern grain seeders and seeding complexes.

2 Methods and Materials

The study was carried out by means of statistical processing [10] and data analysis of the test reports of planters [11–15], which were certified at machine testing stations of the Russian Federation in the twenty-first century. At the same time, 70 test reports were considered. Taking into account the passage of repeated and periodic tests, the number of brands of considered machines was 57 pieces. Among the considered machines there were 21 planters for tractors of 1.4 and 2 pulling class; 14-for tractors of 3 and 4 classes; 22-for tractors of 5 and 6 classes (Fig. 2).



a - separately modular planters (sowing complexes); b - monoblock planters (classic)

Fig. 2. Distribution of seeding machines that were considered in the study in terms of pulling classes of tractors with which they are aggregated

Some statistical data obtained as a result of the study are presented in Tables 1, 2, 3, 4 and 5. The following designations of indicators are adopted in the Tables: X_{AV}-average value of the analyzed indicator; σ_{XAV}—standard deviation of the indicator; $X_{\max}$—maximum value of the analyzed indicator; $X_{\min}$—minimal value of the analyzed indicator; $q_{\min}$—minimum sowing norm of seeds (for wheat), kg/ha; $q_{\max}$—maximum sowing norm of seeds (for wheat), kg/ha; $q_{\min\ spec}$—minimum dose of fertilization, kg / ha; $q_{\max\ spec}$—maximum dose of fertilization, kg/ha; $a_{\max}$—maximum seed planting depth, mm; $a_{\min}$—minimum seed planting depth, mm; a—seed planting depth during testing, mm; s—average deviation from the specified seeding depth, mm; PD—plant density (according to test results), pcs/m^2; DAR—deviation of the actual seeding rate from the set one, %; SD—seed damage level, %; U—unevenness seed feed through the ploughshare, %; SC—seed content in a given soil layer, %; V_{o}—operating speed of seeding unit, km/h; B_{o}—seeder working width, m; N_r—number of rows, pcs.; V_{H}—hopper volume, m^3; W_b—seeding unit productivity per one hour of basic time, ha/h; $W_{\text{э}}$—seeding unit productivity per one hour of operating time, ha/h; N—power spent on aggregation of the unit, kW; N_{PTO}—power spent on the PTO drive, kW; $q_{spec.}$—specific fuel consumption, kg/ha; SM—labor intensity of shift maintenance, person-h; m—seeder weight, kg; P—seeder price, thousand rubles[19].

3 Research Results and Discussion

The primary analysis of test reports' data made it possible to conclude that the industry does not produce seeding complexes for tractors of pulling 1.4 and 2 classes (they were not submitted for testing). Monoblock seeders for tractors of the fifth and sixth class are produced in very limited quantities. In addition, none of the machines presented for testing was intended for aggregation with tractors of the eighth class.

Table 1 shows the generalized values of some technical, operational and economic characteristics of the studied seeding machines. [16, 17]

Analysis of the data in Table 1 allows to conclude that, regardless of the configuration diagram, the average values f the movement speed of the units in the field are approximately equal: it is about 11.6 km/h. The maximum range of speed variation (from 6.9 to 14.2 km/h) is typical for sowing complexes. This can be explained by the fact that in their design, in addition to the ploughshares, groups of specialized ploughshares or additional tillage working bodies can be used. So, for example, only two planters among considered seeding complexes, were equipped with double-disc single-row ploughshares, eight machines were equipped with double-disc ploughshares in combination with disc tillage working bodies and rolling system (i.e., in fact, these are combined tillage and sowing machines), and all the other seeding complexes were equipped with powerful cultivator teeth, designed, in the overwhelming majority, for working on stubble backgrounds (in combination with rolling working body). At the same time, among the considered "classic" grain seeders, only nine were of stubble type (SFS type), and all the rest were equipped with various options for double-disc single-row ploughshares and were intended to work on a previously prepared background [18].

On average, the width of the seeding complexes presented for testing was 1.7 times greater than the working width of the "classic" grain seeders. This is caused by the fact that the overwhelming majority of the considered monoblock seeders were aggregated with tractors of classes, and the majority of seeding complexes are aggregated with tractors of 5 or 6 classes. This is also associated with the ratio of the number of ploughshares (sown rows (strips)), hopper volumes, productivity, power consumption for aggregation, masses, cost indicators, etc. It follows from this that in order to increase the reliability of the obtained analisis results, it is necessary to carry out not only a general comparison of the characteristics and performance of seeders, but also the collection and analysis of these indicators in the context of the class of tractors with which they are aggregated (Tables 2 and 3).

Analysis of the data in Tables 2 and 3 allows to conclude that, regardless of the type of seeders and the class of tractors with which they are aggregated, the average speeds of the units across the field vary from 10 to 11.3 km/h.

It is obvious that the working width of seeders is directly related to the class (power) of the tractors with which they are operated. Moreover, if for tractors of the third-fourth class, the working width of classic seeders (or aggregates composed of them) is approximately equal to the width of similar seeding complexes, then for seeders for tractors of 5 and 6 classes, the width of classic seeders, on average, turned out to be greater than the width of the corresponding seeding complexes. This can be explained both by the need for additional significant power consumption for the pneumatic system fan actuator, which ensures the operation of pneumatic transport of seeds from the dosing

Table 1. Technical, operational and economic characteristics of monoblock (classic) and separate-aggregate grain seeders

	Indicator	V_o, km/h	B_o, m	N_r, pcs	V_H, m^3	W_b, ha/h	W_o, ha/h	N, kW	N_{PTO}, kW	$q_{spec.}$, kg/ha	SM, person-h	m, kg	P, th.rub
SC[a]	X_{AV}	10.7	8.7	42	6.05	9.11	7.11	168.3	63.5	5.50	0.24	8631	3275.8
	σ_{XAV}	1.5	1.8	11	2.07	2.33	2.83	62.8	35.5	1.28	0.06	3004	1467.4
	X_{max}	14.2	12.0	64	12.60	13.00	66.12	380.00	98.9	9.19	0.40	14,590	6500.0
	X_{min}	6.9	3.0	16	0.75	3.65	2.72	80.1	28.0	2.70	0.12	2072	900.0
CGS[b]	X_{AV}	10.6	5.1	34	1.54	5.50	3.69	47.4	0	3.15	0.20	2768	1363.3
	σ_{XAV}	1.3	1.7	15	0.71	2.14	1.27	24.1	0	1.13	0.04	1200	1086.7
	X_{max}	13.9	15.0	100	5.24	15.30	8.60	93.0	0	7.80	0.31	14,000	5423.7
	X_{min}	7.8	1.5	11	0.16	1.23	0.83	19.3	0	1.10	0.13	540	280.0

[a]Sowing complexes
[b]"Classic" grain seeders

Table 2. Technical, operational and economic characteristics of monoblock (classic) grain seeders

Tractor class	Indicator	V_o, km/h	B_o, m	N_r, pcs	V_H, m^3	W_b, ha/h	W_o, ha/h	N, kW	N_{PTO}, kW	$q_{spec.}$, kg/ha	SM, person-h	m, kg	P, th.rub
1.4–2	X_{AV}	10.6	4.4	28	1.19	4.54	3.01	28.0	0	2.50	0.18	2171	671.6
	σ_{XAV}	1.3	1.1	9	0.35	1.17	0.90	6.5	0	0.58	0.03	778	274.3
	X_{max}	12.8	7.2	48	2.12	8.50	5.23	43.3	0	4.02	0.21	3145	1815.0
	X_{min}	7.8	1.5	11	0.16	1.23	0.83	19.3	0	1.10	0.13	540	280.0
3–4	X_{AV}	11.3	6.5	41	2.3	7.46	5.25	66.9	–	3.85	0.20	3207	2252.3
	σ_{XAV}	1.2	1.5	9	1.2	2.21	1.24	20.2	–	1.38	0.06	992	878.2
	X_{max}	13.9	10.8	48	4.0	12.95	8.15	93.0	–	6.50	0.31	5090	3525.3
	X_{min}	8.2	3.4	27	1.3	3.70	3.08	24.0	–	2.00	0.14	990	935.0
5–6	X_{AV}	10.0	12.2	77	5.24	13.09	8.05	–	–	3.56	0.26	11,697	3161.8
	σ_{XAV}	0.2	1.9	23	–	2.21	0.55	–	–	0.88	0.00	3271	2261.8
	X_{max}	10.2	15.0	100	–	15.30	8.60	–	–	4.42	0.26	14,300	5423.7
	X_{min}	9.8	10.5	54	–	10.88	7.50	–	–	2.24	0.26	6790	900.0

Table 3. Technical, operational and economic characteristics of separate-aggregate grain seeders (seeding complexes)

Tractor class	Indicator	V_o, km/h	B_o, m	N_r, pcs	V_H, m^3	W_b, ha/h	W_o, ha/h	N, kW	N_{PTO}, kW	$q_{spec.}$, kg/ha	SM, person-h	m, kg	P, th.rub
3–4	X_{AV}	10.7	6.4	32.0	3.7	6.20	3.89	95.8	28.0	4.97	0.27	3499	955.5
	σ_{XAV}	1.7	2.0	16.0	1.8	1.45	0.60	18.8	–	1.63	0.07	1618	94.5
	X_{max}	14.2	9.0	48.0	6.8	8.10	4.62	124.0	–	7.00	0.33	6735	1050.0
	X_{min}	9.0	3.0	16.0	0.8	4.16	2.78	80.1	–	2.70	0.20	2072	861.0
5–6	X_{AV}	10.7	8.9	42	6.5	9.56	7.71	192.5	98.9	5.72	0.24	9358	3735.9
	σ_{XAV}	1.5	1.7	10	1.9	2.17	3.04	55.5	–	1.24	0.06	2582	1238.7
	X_{max}	14.2	12.0	64	12.6	13.00	66.12	380.0	–	9.19	0.40	14,590	6500.0
	X_{min}	6.9	4.0	16	2.0	3.65	2.72	87.8	–	3.20	0.12	2360	9988

system to the ploughshares, and the difference in the seed planting systems (ploughshares and additional tillage working tools) of the seeders, as mentioned above [20].

Decrease in the working width of the aggregates and the differences in the ranges of change in operating speeds explain the fact that the productivity of the aggregates with seeding complexes is almost 40% lower than the productivity of aggregates with classical grain seeders. The increase in the productivity of the seeding complexes was not even facilitated by the fact that the volume of their hoppers is 1.24–1.60 times larger than the volume of hoppers of classic grain seeders.

Also, the differences in the designs of the seed planting systems of the studied machines can be explained by the fact that the specific fuel consumption during the operation of the seeding complexes is 1.28–1.61 times higher than when using "classical" grain seeders. Moreover, according to the data in Table 2, it can be assumed that with growth in the width of the seeding machines, the specific fuel consumption per unit of work performed increases. If to compare the values of the specific fuel consumption characteristic of units with seeding complexes (5.0–5.7 kg/ha) with the similar indicator of the six considered "classic" stubble seeders (5.2 kg/ha), it can be concluded that they are close. This suggests that the previously observed difference in the values of this indicator is indeed caused by differences in the designs of the seed planting working bodies [21].

Also, with the growth in the working width of seeders, the labor intensity of their daily maintenance increases, which is logical and does not need additional justification.

The mass of "classic" grain seeders and seeding complexes for tractors of 3–4 classes are close to each other (the difference in average values does not exceed 10%), at the same time, monoblock seeders for powerful tractors (5 and 6 classes) are almost a quarter heavier than seeding complexes to similar tractors. Obviously, this is reflected in the cost of the analyzed machines, but this indicator is characterized by extremely low objectivity. So, for example, if the average value of the price of "classic" seeders and seeding complexes for tractors of the third and fourth classes are analyzed, it is obvious that they differ by almost 2.5 times. Moreover, seeding complexes are cheaper than "classic" seeders, although the opposite situation is observed for tractors of the fifth and sixth class. It can be explained by the fact that in the short test reports of monoblock seeders for tractors of 3 and 4 classes, data were provided mainly on foreign machines, and in the test reports of single-unit seeders there are presented mainly the prices of Russian machines.

Separately, it should be noted a wide range of variation in the masses of both "classic" seeders and seed complexes. Even in the same group of pullinf classes of tractors, the mass of seeders aggregated with them can differ by six or more times. And this, in turn, speaks of a wide variety of designs of individual machines of the same class (differences in the shassis structure, the absence or presence of fertilizer dispensing system; different volumes of hoppers; the presence of trailed or mounted system; the type of used ploughshares; the presence and type of furrow-closing and soil compacting working bodies, etc.) and the used materials.

Assessment of the specific (relative) characteristics of grain seeders presented in Table 4 will contribute to an increase in the objectivity of the analysis.

Analysis of the data in Table 4 leads to the following conclusions:

Table 4. Specific (relative) characteristics of studied grain seeders

Indicator		m/B_o	τ	Δq	Δq_{spec}	$\Delta q_{spec.}/\Delta q$	$b = B_o/N_r$	P/B_o	P/m	m/B_o	V_H/B_o
Planter type	Units	kg/m	–	kg/ha	kg/ha	–	m	rub./m	rub./kg	kg/m^3	m^2
CGS	X_{AV}	553	0.66	377	180	0.50	0.15	200,238	390.1	2017	0.28
	σ_{XAV}	133	0.05	67	53	0.15	0.02	89,980	187.8	635	0.06
	X_{max}	933	0.78	560	350	0.94	0.23	382,768	1067.6	3550	0.42
	X_{min}	165	0.51	191	90	0.26	0.13	100,357	156.3	576	0.11
SC	X_{AV}	1031	0.66	390	363	0.98	0.22	433,623	409.8	1505	0.71
	σ_{XAV}	229	0.03	100	100	0.08	0.05	201,474	47.0	581	0.19
	X_{max}	1603	0.76	657	563	1.20	0.33	1,322,250	511.8	3720	1.13
	X_{min}	288	0.54	259	269	0.86	0.13	81,227	334.7	560	0.25

- the specific gravity (weight per one meter of the working width) of "classic" grain seeders is almost two times less than the same indicator typical for sowing complexes;
- despite the significantly large volumes of hoppers of seeding complexes, the coefficient of use of the work shift time (τ) of units with them does not differ from the coefficient of time use of the work shift of units with monoblock seeders;
- on average, the change ranges in the seeding norm of seeds for wheat (Δq) for "classic" seeders and sowing complexes are approximately equal and equals to about 380 kg/ha, although for individual machines the seeding norm of seeds by "classic" seeders varies from about 190 to 560 kg/ha, and for sowing complexes it equals from 260 to 660 kg / ha;
- on average, the range of variation of the pre-sowing dose of mineral fertilizers for "classical" seeders is about 180 kg/ha, and for sowing complexes is almost twice as much;
- the average row spacing of "classic" grain seeders is about 15 cm (varies from 13 to 23 cm), of sowing complexes it is 22 cm (varies from 13 to 33 cm), which once again emphasizes the difference in the used ploughshare groups of the studied sowing machines;
- the cost of one meter of working width of seeding complexes is almost twice as high as for monoblock seeders, however, it should be noted once again the extremely low objectivity of this indicator (as well as of the specific price of one kilogram of machine weight as indicator);
- the ratio of the mass of the planter and the volume of the hopper for both studied groups is close, however, the volume of the hopper per meter of the working width of the seeder for "classic" seeders ($V_H/B_o = 0.28$ m^2) is almost 2.5 times less than the same indicator for sowing complexes (0.71 m^2).

Table 5 presents the generalized agrotechnical indicators of the considered sowing machines.

Analysis of the data in Table 4 leads to the following conclusions:

Table 5. Agrotechnical indicators of seeding machines

	Indicator	q_{min}, kg/ha	q_{min}, kg/ha	$q_{min\ spec.}$, kg/ha	$q_{max\ spec.}$, kg/ha	amax, mm	amin, mm	a, mm	s,m	RD, pcs./m^2	DAR, %	SD, %	U, %	SC, %
SC	X_{AV}	30	372	42	334	93	29	56	7	407.33	4.39	0.28	6.67	88.3
	σ_{XAV}	34	82	20	81	12	11	7	2	110.90	2.47	0.26	3.14	6.9
	X_{max}	240	660	79	568	120	50	73	11	620.00	11.10	1.09	14.09	100.0
	X_{min}	1	240	5	65	62	5	30	5	122.00	0.67	0.01	0.56	68.9
CGS	X_{AV}	26	404	58	239	84	26	47	9	382.40	1.44	0.18	3.65	86.3
	σ_{XAV}	22	60	42	72	7	7	12	4	97.91	0.99	0.08	2.43	6.4
	X_{max}	90	650	298	441	120	48	77	19	515.90	5.00	0.30	13.70	100.0
	X_{min}	2	205	25	125	60	10	3	3	104.00	0.10	0.00	0.30	62.6

- seeding systems of both monoblock and separate-aggregate planters provide, on average, approximately the same ranges of change in the seeding norm (q) of seeds (from 26 … 30 to 370 … 400 kg/ha);
- the average range of fertilization ($q_{spec.}$) by "classic" grain seeders (58 … 239 kg/ha) is almost 30% lower than the corresponding indicator for sowing complexes;
- the limiting values of the seed planting depth (a) of seeds by both groups of planters are approximately the same - from 5 … 10 mm to 120 mm, with an average range of 26 … 29 - 84 … 93 mm. At the same time, the quality of seed planting in the soil for sowing complexes is slightly higher than that of "classic" grain seeders: for the first ones, the deviation from the specified depth (s) of seed planting is 12.5%, for the second ones it is about 19% (with limited agricultural requirements of ± 15%). At the same time, the share of seeds embedded in given soil layer (SC) with ploughshares of sowing complexes was about 88%, and with ploughsharesof "classic" grain seeders it is about 86%;
- the quality of dosing seeds is higher in "classic" grain seeders, for which the deviation of the actual seeding norm from the specified one (DAR) is on average about 1.4% (with an admission of agricultural requirements of 3%). For sowing complexes, the average value of DAR is about 4.4%. The uniformity of the delivery of seeds into the furrows by "classical" seeders is also higher (the index of seeding unevenness is 3.7% for classic seeders and 6.7% for seeding complexes);
- damage (crushing) of seeds (SD) in sowing complexes (0.28%) is slightly higher than in "classic" grain seeders (0.18%) on average, with the limit value of 0.2% set by agricultural requirements.

4 Conclusion

In general, the conducted research allows to conclude that grain seeders for tractors of the eighth class, as well as seeding complexes for tractors of 1.4 and 2 pulling classes are practically not produced by the Russian industry. Also, monoblock seeders for tractors of the fifth and sixth classes are produced in limited quantities. The average values of the working speeds of movement of the compared groups of seeding units are approximately equal and it is about 11.6 km/h. The working width of the seeders is directly related to the class (power) of the tractors with which they are operated, on average, with equal pulling classes of the aggregating tractors, the working width of the seeding complexes is somewhat (up to 40%) less than the width of the "classic" grain seeders. This iis caused by the additional power consumption for the pneumatic system fan drive unit, as well as the fact that the ploughshare groups of seeding complexes in the overwhelming majority of the considered cases are designed (and were used during testing) to work on stubble backgrounds, while most of the "classic" monoblock seeders worked on pre-prepared backgrounds. Decrease in the working width of the seeding complexes led to proportional decrease in the productivity of the corresponding units. Moreover, the increase in the hopper volume of the seeding complexes by 1.24–1.60 times in comparison with the hopper volumes of the "classic" seeders did not lead to the growth in the productivity of the first ones: for both groups of machines the average coefficient of use of the shift time is approximately the same and equals about 0.66. Differences in the designs of the seed planting systems of the studied machines led to the fact that the specific fuel consumption during the operation of seeding complexes is 1.28–1.61 times higher than when using “classical” grain seeders, however, if to compare the values of the specific fuel consumption characteristic of units with seeding complexes (5.0–5.7 kg/ha) with the similar indicator of “classic” stubble seeders (5.2 kg/ha), it can be concluded that they are close. The specific gravity (weight per one meter of the working width) of “classical” grain seeders is almost two times less than that of the sowing complexes. Seeding systems of both monoblock and separate-aggregate planters provide, on average, approximately the same ranges of change in the seeding rate (from 26 … 30 to 370 … 400 kg/ha), while the average range of fertilization by “classical” grain seeders (58 … 239 kg/ha) is almost 30% lower than the corresponding indicator for sowing complexes. The average row spacing for “classic” grain seeders is about 15 cm, for sowing complexes it is about 22 cm, which indicates the implementation of various sowing methods (ordinary row and rowless) by the studied groups of machines. The ratio of the hopper volume to the working width of the “classic” seeders (VH/Bo = 0.28 m2) is almost 2.5 times less than the same indicator for the seeding complexes (0.71 m2). The limiting values of the depth of seed planting by both groups of planters are approximately the same (from 5 … 10 to 120 mm), with the average range from 26 … 29 to 84 … 93 mm. At the same time, the quality of planting seeds in the soil of the sowing complexes is somewhat higher than that of the “classic” grain seeders: for the first ones, the deviation from the specified depth of planting seeds was about 12.5%, for the second ones it is about 19% (with the limitation of agricultural requirements of ± 15%).

The quality of dosing seeds is higher in “classic” grain seeders, for which the deviation of the actual seeding norm from the specified one is on average about 1.4% (with the tolerance of agricultural requirements of 3%). For seeding complexes, the average value of this indicator is close to 4.4%. The uniformity of the seed supply to the furrows by “classic” seeders is also higher (the index of unevenness seeding is 3.7% for classic seeders and 6.7% for seeding complexes). Damage (crushing) of seeds in sowing complexes (0.28%) is slightly higher than in “classic” grain seeders (0.18%) on average, with the limit value of 0.2% set by agricultural requirements.

In general, in terms of agrotechnical and operational indicators, the sowing complexes are slightly inferior to the “classical” grain seeders, but at the same time they allow implementing row-free method of sowing cereals on unprepared stubble backgrounds, which is the most promising from the point of view of modern production experience [16].

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Models for Studying the Effects of Probiotics Based on *Caenorhabditis Elegans*

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Abstract. Probiotics are of great practical importance in animal husbandry and veterinary medicine. However, at times, putting them into operation is fraught with difficulties caused by unexpected side effects. This is often due to the selection of an inappropriate model organism when testing probiotics. The model organism must meet a number of requirements, and at the same time be convenient for use. One of the models widely used at the moment is based on nematodes. *Caenorhabditis elegans* is currently being used as a model organism to study host-bacteria interactions in the gut and the general effect of probiotics on the host organism. On nematodes, one-time studies of a particular group of potentially suitable probiotics can be carried out. And nematodes can also be considered quite convenient organisms to be used as test systems for a wide range of probiotics. Nematodes have a number of advantages over other model organisms, however, they are also limited in use, so they have not yet ousted their competitors. Here, we will show the features and consider the pros and cons of this model host for probiotic studies.

Keywords: Nematodes · Probiotics · Test system · Model organism · Screening

1 Introduction

Evaluation of probiotic properties requires, along with molecular techniques, suitable in vivo models. *Caenorhabditis elegans* are a relatively simple model for studying conservative aspects of biological signalling pathways in the intestinal environment [1]. In addition, recently, an approach to modeling the gastrointestinal tract of living organisms has become widespread. A model of the gastrointestinal tract has been successfully created using organoids engineered with cellular and microbiota niches [2]. Various models of the intestinal tract of humans [3, 4] and farm animals [5, 6] have been constructed. With the help of these models, the selection of new strains of probiotics is successfully carried out. In world practice, the models of the gastrointestinal tract "TIM-2 in vitro gastrointestinal model" [7] and SHIME [8] are used and have proven themselves well—complex systems that simulate the processes of interaction of enzymes, acids and microbiota. When implementing this approach, a significant number of problems are

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successfully solved, such as the problems of ethical conduct of experiments on living animals and the problems of limited resources, reproducibility of experiments and control of their conditions. A large number of model animals are known to be used to study the gastrointestinal tract [9, 10]. However, the search for new model organisms is still underway, since some familiar models are outdated or become inconvenient to use.

The aim of this review is to consider the currently available approaches to the study of probiotics on *Caenorhabditis elegans*, as well as the possibility of using such a model organism for screening probiotics.

The nematode *Caenorhabditis elegans* represents a valuable tool to test the effects of ingested bacteria on host physiology [11]. *C. elegans* is a differentiated multicellular organism with a nervous system, reproductive organs, and digestive apparatus, which, in contrast to simpler model organisms, makes it possible to predict with great confidence a similar or such effect on target organisms, such as, for example, farm animals. The life cycle of less than three days allows multiple series of tests to be carried out within a short time, which significantly speeds up the experimental part of the research. Dietary sources, such as bacteria, play an important role in controlling *C. elegans* lifespan, which makes it possible to notice the effect of certain tested probiotics before additional molecular or biochemical analyses. But it should be borne in mind that the trophic relationship between nematodes and bacteria is different from the synergistic relationship between mammals and the gut microbiota. However, the C. elegans model's bacterial component can represent both direct and indirect aspects of a diet because live bacteria can influence the nematode physiology through their metabolites [12].

2 Probiotics in Animal Husbandry

To treat and prevent various infections, the use (and misuse) of antibiotics has been widespread in clinical and veterinary medicine during recent decades [13]. Thus, residual antibiotics may accumulate in the meat and milk from treated animals. The presence of residual antibiotics in milk is not only undesirable from a public health perspective. Therefore, many methods have been developed to identify new natural antibacterial substances, such as probiotics.

Probiotics are defined as "live microorganisms which, when administered in adequate amounts confer a health benefit on the host" [14], for example, intestinal microbiota normalization, immunomodulation, and prolongation life span [15].

Probiotic microorganisms must fit the following criteria:

1. the ability to attach to intestinal cells and colonize the intestinal tract [15]
2. must be isolated and characterized;
3. should be presented scientific proof for their health benefit on the host [16].

Probiotics have been emerging as a safe and viable alternative to antibiotics for increasing performance in livestock. In-feed probiotics have been shown to be able to reduce the number of pathogens in the gastrointestinal tract, improve immunomodulation and nutrient absorption. But every novel probiotic strain cannot be assumed to share historical safety with conventional strains [17]. Several species belonging to the genera of *Lactobacillus, Streptococcus, Lactococcus* and *Bifidobacterium* remain the most popular probiotic agents to date [18]. In addition to the above criteria, each new probiotic candidate must be suitable for a specific target animal, taking into account its physiological characteristics. In such a case, it would seem that there is no more suitable model organism for screening probiotics than a particular animal itself. But the research data is too expensive and time consuming, and some new probiotics may be universal for different animals. Therefore, it is worth considering a simpler model organism for the screening system.

3 Studying the Effects of Probiotics

3.1 In Vitro

In vitro research usually means using cell cultures. For example, probiotics isolated from humans are often researched [19]. These have an undeniable advantage: strict control of the experimental conditions (e.g., nature of the culture media, quantity of microorganisms, temperature, pH, etc.) as well as interactions between a limited number of microorganisms, most often using binary models. However, the experimental conditions are particularly distant from the complex conditions found in a host [20]. In addition, at the moment the regulations for pharmaceutical laboratories do not allow the production of probiotics based only on in vitro research [21].

3.2 In Vivo

Tests on target organisms. One of the approaches to studying the effects of probiotics is to conduct experiments on a specific organism of interest. As a rule, with this approach, a sample of target organisms is fed with food supplemented with various probiotics, and then the effectiveness of this feed is observed when considering the functioning of the gastrointestinal tract and the general condition of test animals. So, for example, studies were carried out in a similar way on broiler chickens [22, 23]. Also, studies on lactating dairy cows have been carried out in a similar manner [24]. The approach of in vivo studies on target organisms is good in that the effect of probiotics on test organisms and on target organisms does not differ. However, with this technique, research is time-consuming, expensive, and does not allow for the identification of universal probiotics.

Tests on standard model organisms. Among the standard model organisms used to study probiotics are *Mus musculus, Rattus norvegicus, Danio rerio, Drosophila melanogaster* and *Galleria mellonella* and *Caenorhabditis elegans* [23].

The laboratory mouse *M. musculus* is a powerful model for the evaluation of host-microbiota interactions. Many genetic tools are available to the scientific community: many strains inbred or not, a collection of mutants and the possibility of carrying out RNA interference in vivo. However, experimental limitations exist. The skin, fur, and oropharyngeal structures, compartmentalization of the digestive tract and behavior are different from those of some farm animals and can have a great influence on microbial communities and therefore their impact on the host. The rats is used to study the impact of bacteria with probiotic potential on the intestinal level, in the case of inflammatory syndromes, in particular in connection with obesity [25]. However, the development of the rat model has until recently been slowed down by the lack of available mutants, the first of which were only generated by genome editing tools in 2010 [26]. Its rapid development, its small size, its high degree of homology with mammals make the zebrafish a tool interesting for mechanistic studies, not only in the adaptive immune system (TLR and NOD receptors), but also in the digestive system [27]. Limitations of the zebrafish model in microbiota research include differences in environmental conditions compared to farm animals [28]. Despite the greater taxonomic and structural similarity of vertebrate model animals, they should not be considered ideal test organisms. They have two significant drawbacks: firstly, their cost is relatively higher than that of invertebrate models, and secondly, their growth and reproduction rate is rather low.

D. melanogaster can allow reliable validation of probiotic effects on a living organism: high throughput screening capabilities, inexpensive and rapid reproduction, and microbiome easy to handle [23]. However, there are difficulties in interpreting the results in mammals. Firstly, the microbiome of fruit flies is much poorer, and secondly, they have to be infected by direct injection, which differs from how probiotics will enter the target organism, which distorts the effect. The simplicity of handling and infection of the larvae of *G. mellonella* combined with their survival at 25 and 37∘C makes this animal a promising model [29]. Unfortunately, the use of this model in a wide range of studies is possible only in the future, since the complete genome sequence is unknown, there are no convenient mutant strains, and there is no standardization between different laboratories for this model organism [30]. The strength of *C. elegans* as a model organism for microbiome research is its ability to conduct high- throughput experiments with a gnotobiotic organism and to explore the complex cause and effect relationship between presence and absence of amicrobial species and a phenotype reflecting good or bad health [23]. The use of nematodes for the screening of probiotics is favored by the possibility of easily monitoring anti-aging markers, as well as the storage of body fat [31]. Important tool of *C. elegans* is the availability of transgenic animals. Many mutants, available in libraries, can help study the mechanism of action at the molecular level of a compound or pathways involved in the host-microorganism interaction. Also a collection of *E. coli* strains enabling RNAi feeding to be carried out in C. elegans is available. Despite the significant advantage in the studies of invertebrate model organisms, it is worth keeping in mind their large differences from the target organisms and taking this into account when interpreting the results.

4 *C. Elegans*: Model Possibilities

4.1 Effects of Probiotics on Lifespan

In general, nematodes are used as a model host for a fairly wide range of bacteria [32]. It has been repeatedly shown that a number of bacteria are capable of positively affecting *C. elegans*. Foodborne strains of *Weissella koreensis* and *Weissella cibaria* significantly extend the lifespan of these nematodes [33]. The influence is usually assessed by comparing the curves of lifespan of the experimental group and the control group (Fig. 1).

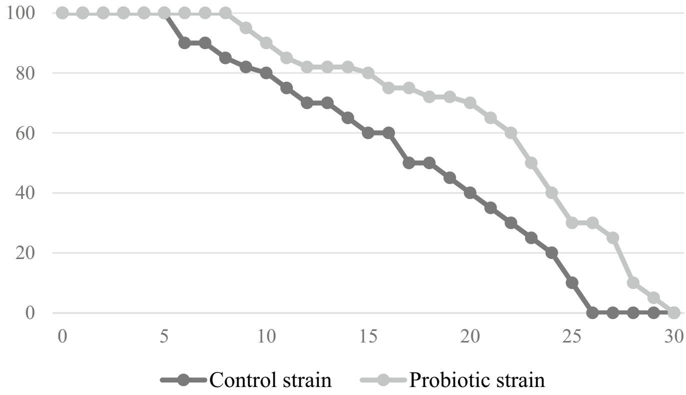

Fig. 1. Typical longevity curves

The interactions between *C. elegans* and bacteria with respect to aging and host longevity are complicated and multifactorial [26]. One of the known mediators of this interaction is serotonin. The unifying characteristic of *C. elegans* serotonergic responses is the coupling of food perception to various endocrine outputs. Serotonin and dopamine signaling pathways modulate food-related behaviors and physiology in mammals [34] and *C. elegans* [35]. That serotonin in particular plays a role in modulating behavior that has been established largely through the analysis of mutants forserotonin signaling including tph-1 (encodes tryptophan hydroxylase), bas-1 (encodes serotonin- and dopaminesynthetic aromatic amino acid decarboxylase), mod-1 (encodes serotonin-gated chloride channel), and ser-1 (encodes serotonin receptors). It has been established that the level of serotonin production decreases with age in nematodes. With a proper diet, this decrease can be stopped and thus the lifespan of nematodes can be increased. Emerging research suggests that bacteria in the gastrointestinal tract can communicate with the central nervous system, even in the absence of an immune response. TPH-1, BAS-1, MOD-1, and SER-1 signaling pathways are involved in antiaging and immune stimulation while probiotics stimulate the expression of tph-1, bas-1, mod-1, or ser-1 genes [32].

Anti-Inflammatory *Lactobacillus rhamnosus* strain protects against oxidative stress and increases lifespan in *C. elegans*. *Lactobacillus rhamnosus* CNCM I-3690, protected worms by increasing their viability by 30% and increased average worm lifespan by 20%. Moreover, transcriptomic analysis of C. elegans fed with this strain showed that increased lifespan is correlated with differential expression of the DAF-16/insulin-like pathway [36].

4.2 Effects of Probiotics on the Immune System

Lactic acid bacteria can exert protective functions on *C. elegans* by acting on intestinal permeability. The beneficial role of LAB against graphene oxide toxicity under different genetic backgrounds may be due to the combinational effects on intestinal permeability and defecation behavior. Moreover, the beneficial effects of LAB against GO toxicity was dependent on the function of ACS-22, homologous to mammalian FATP4 to mammalian FATP4 [37].

It was shown that several metabolic products/secondary metabolites produced by non-pathogenic bacteria are involved in protecting *C. elegans* from being infected by pathogenic bacteria. Microbe-mediated protection is an emerging trend on the topic of host-microbe interaction, which down-regulates the virulence factor of powerful pathogenic bacteria, thereby minimizing the infection of the host [38]. A probiotic *Enterococcus faecalis* Symbiofloar when fed along with *E. coli* O157: H7 resulted in the down-regulation of virulent genes such as locus for enterocyte effacement (LEE), flagellum and quorum sensing in E. coli O157: H7 pathogen thereby increasing the lifespan of *C. elegans* [39]. Colonization of mildly pathogenic *Enterococcus faecalis* to the worm intestine also provides protection against pathogenic bacteria such as Staphylococcus aureus by production of antimicrobial superoxide [40]. A recent report showed the ability of *Propionibacterium freudenreichii*, non-lactic acid probiotic bacteria, to extend the lifespan of *C. elegans* by the binding of a TGF-β-like ligand to TGF-β receptors and activation of PMK-1 and TGF-β target genes via p38 MAPK and TGF-β pathways involved in innate immunity [41].

The *Lactobacillus casei* have been shown to trigger the detoxification system in nematodes while protecting them from malathion-induced damage. Short-term exposure and food choice assay divulged that *L. casei* could serve as a better food to protect *C. elegans* from noxious environment. The expression analysis unveiled that *L. casei* gavage upregulated the phase-II detoxification enzymes coding genes metallothioneins (mtl-1 and mtl-2) and glutathione-S-transferase (gst-8) and thereby eliminated malathion from the host system. Furthermore, the upregulation of ace-3 along with down-regulation of cyp35a in the nematodes supplemented with *L. casei* could be attributed to attenuate the malathion-induced physiological defects in *C. elegans* [42].

In addition, some probiotics have been shown to induce resistance to *E. coli* infections [43]. The possibility of Bacillus subtilis protection from α-Synuclean aggregation has been proven [44].

4.3 Screening System

A growing body of literature demonstrated that the nematode could be successfully used to screen the probiotic features of several bacterial strains [11]. Thus, potential probiotic strains of Bacillus licheniformis isolated from traditional Korean food sources were analyzed [45]. Shown are the probiotic properties of *L. delbrueckii* subsp. *bulgaricus* [46]. A system for screening potential probiotics was developed [1]. Screening systems based on nematodes show the potential for finding a wide range of probiotics. Already existing screening systems show ease of use. In the future, it will probably be possible to create a screening system for probiotics applicable to a specific narrow range of important farm animals.

C. elegans: model limitations

This model organism has a number of disadvantages that limit its use in the study of probiotics for veterinary medicine and animal husbandry. Unlike in vitro experiments, it is rather difficult to control all conditions, it requires some training [47]. Some crucial experimental points can be quite tricky such as synchronization step or daily worms counting on solid medium spread with yeasts for example; in the absence of an automated system, its implementation is particularly timeconsuming. The cell number of the worm is limited and that questioning about the relevance of the phenotypes observed and their extrapolation to mammals which are composed of many different and complex tissues. It should be especially noted that the temperature of the nematodes is significantly lower than the average body temperature of mammals, which also complicates the extrapolation of the results. In addition, such a low temperature does not allow considering many types of probiotics, whose temperature of comfortable existence is about 37° C [48]. Although, in general, feeding the nematodes with potential probiotics is quite convenient, since the probiotics will be used as nutritional supplements on the target organisms, there is a risk of killing the beneficial bacteria by the digestive system of the nematodes.

5 Conclusion

Summarizing all the above, we can conclude that *C. elegans* are a very suitable model organism for screening probiotics. These model organisms are quite simple to work with, they are readily available, and relatively inexpensive to acquire and maintain. It is quite convenient to observe the effects of certain probiotics on nematodes. In addition, their genome is completely sequenced, and there are also many mutant strains for various types of research. An important advantage of using nematodes is the absence of ethical problems. But it should be borne in mind that these organisms are structurally and taxonomically far enough from the target organisms when extrapolating the results. It is also worth considering their physiological features and certain subtleties of work. In the future, it will probably be possible to create a screening system that minimizes the negative aspects of this model and maximizes the positive aspects of using *C. elegans.*

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Regulation of Nonribosomal Peptide Synthesis as a Mechanism of Antifungal Activity of Probiotics Based on the Bacteria Genera Bacillus and Paenibacillus

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Abstract. Recently, spore-forming bacteria have been frequently used to solve various problems of humanity. They are used in the creation of probiotic additives to improve the agricultural traits of animals (egg production in chickens, resistance to disease, the ability to better process feed, etc.), in the creation of probiotics for humans, as well as in the design of biological products to combat plant pests. All of the above properties are associated with secondary metabolites of different nature, of which a group of non-ribosomal-synthesized peptides stands out. This is related not only to their broad functional significance but also to their significant representation in spore-forming bacteria. The aim of this article is to demonstrate the regulation of the expression of genes responsible for the synthesis of NRPS (non-ribosomal peptide synthases) as a mechanism of antifungal activity of spore-forming bacteria.

Keywords: NRPS regulation · Bacillus · Paenibacillus · Probiotics · Antifungal activity · Fusarium

1 Introduction

Fungal diseases are a relatively rare group of animal diseases but often lead to a gradual deterioration in the general condition of the infected host and, in some cases, to death. Most fungi are destructors of various organic residues, living mainly on plant materials and other organic debris, but under certain conditions, they can infect living hosts. Most clinically essential fungi, in addition to yeasts, produce spores designed to spread.

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The most common diseases caused by fungal agents are candidiasis and aspergillosis. Among all fungal diseases, Candidiasis is the major fungal infection of the digestive tract and urinary tract in various animals, usually occurring when the normal microflora is disrupted or otherwise depleted by multiple internal factors. Candidiasis is a mycosis caused by infection with mycelial yeasts of the genus Candida, mainly C. albicans. Based on the literature, outbreaks of candidiasis in poultry farms can cause high losses of young birds (from 20 to 40% of all livestock) [1]. In addition to birds, this disease can cause severe damage to other animals, including pigs, cattle, horses and many others.

This spectrum of diseases poses a severe problem because of the gradual development of resistance in these pathogens to the drugs used in the treatment of candidiasis. For example, a recent review demonstrated that although azoles and echinocandins are effective against a large number of Candida species, some species have developed resistance even against these classes of agents [2].

Speaking about fungi that are often harmful to agriculture, it is impossible not to mention fungi of the genus Fusarium. Although direct pathogenic activity for these fungi is sporadic and is due to suppressed immunity in the patient [3], these fungi are capable of causing severe harm to the health of farm animals and even healthy people due to the production of a large spectrum of mycotoxins, of which the most toxic are Trichothecenes, Fumonisins and zearalenone [4]. This genus of fungi is also a big problem for crop production since plants affected by these fungi are not suitable for further use due to the accumulation of mycotoxins, and the range of affected plants is very large: from wheat, soybean, cabbage and up to bananas and watermelons [5].

That is why fungi of this genus cause significant economic losses in agriculture, which leads to the need to control this group of fungi, both in the environment and in farm animals.

Due to the growing number of poultry and livestock farms, one possible way to solve these problems is the use of probiotics and biological remedies to improve the overall resistance of farm animals and a preventive measure against pathogens in the environment.

2 Probiotics as a Way to Control Mycosis Pathogens

Probiotics are live microorganisms that, when administered in adequate amounts, confer a health benefit on the host. Their effects on intestinal flora have been widely and variedly studied. Probiotics can be based on a wide range of microorganisms and can include different species from the same genus as well as various species from different genera. The leading players in this field are representatives of the genera Lactobacillus [6], Bifidobacterium [7], Bacillus [8] and many others.

Probiotics are known for their ability to inhibit the growth of pathogenic microorganisms through competitive, antagonistic and immunological action and by enhancing host defense mechanisms by stimulating the reproduction of beneficial bacteria [9, 10].

Various compounds produced by probiotic bacteria play a huge role in the manifestation of these functions. In particular, these include siderophores [11], polyketides [12], non-ribosomally synthesizable peptides (NRSPs) [13–16], and various messengers of the quorum sensing system [17].

Recently, bacteria of the Bacillus genus have been increasingly considered as probiotic microorganisms [18], as well as microorganisms that form the basis of biofertilizers and antimicrobial preparations [19]. Since they can inhibit a wide range of pathogenic microflora by producing a wide range of different compounds, they are easy to cultivate due to their aerobic nature and the presence of a spore stage, which allows for long-term storage of obtained probiotics without losing their quality.

The most extensive class of compounds produced by bacteria of this type are peptides of non-ribosomal synthesis. Their functional significance is quite broad, although poorly understood. Since among the functions of these compounds, there is a strong antifungal activity, this work aimed to study the regulation of the expression of genes responsible for the synthesis of different NRPS fractions in the bacteria of the genus Bacill*us*.

3 Non-ribosomal Peptides and Their Regulation

3.1 Non-ribosomal Peptides

Surfactins. Bacterial cyclic lipopeptide, representative of the heptapeptide group, consisting of L-aspartic acid, two molecules of L-leucine, glutamic acid, L-valine, and two molecules of D-leucine. Surfactin synthesis is encoded by the srfA operon composed of 4 genes srfAA, srfAB, srfAC and srfAD.

In the course of various studies of its properties, it was found that surfactin exhibits antibacterial, antiviral, antifungal, antimycoplasmic and hemolytic activity and is also a strong biosurfactant [20, 21].

Fengicins. Bacterial cyclic lipopeptides of the decapeptide group consisting of 2 molecules of L-glutamic acid, D-ornithine, two molecules of D-tyrosine, D-alanine, L-proline, L-glutamine, L-tyrosine, and L-isoleucine. The peptide ring is formed through a lactone bond between the OH-group of tyrosine at position 3 and the COOH-group of isoleucine at position 10, with a β-hydroxy fatty acid attached to the N-end. Fengicin synthesis is encoded by the fen operon consisting of 5 genes: fenC, fenD, fenE, fenA, and fenB [22].

Fengicin has been reported to have intense antifungal activity, especially against filamentous fungi [23–25]. A possible mechanism of the antifungal activity of fengicins is that they interact with sterol and phospholipid molecules in the membranes and thus change the fungal cell membrane's structure and permeability [26].

Fusaricidins. Bacterial cyclic lipopeptides of the hexapeptide group consisting of 4 D-amino acids and 2 L-amino acids. They all carry an L-threonine linked to a unique side chain of 15-guanidino-3-hydroxypentadecanoic acid via the N-end. This specific ω-functionalized lipid side chain has a key role in antibiotic activity through its interaction with phospholipids of bacterial cell membranes [27].

All fusaricidins have 3 amino acids in common: L-Thr, D-allo-Thr, and D-Ala [28]. Fusaricidins have antimicrobial activity against Gram-positive bacteria as well as a wide range of fungi [29].

Iturins. Bacterial cyclic lipopeptides of the heptapeptide group, consisting of seven amino acid residues attached to a 14-carbon chain, indicating its amphiphilic nature. The amino acids involved in this structure are three D-amino acids (Tyr, Asn and Asn) and four L-amino acids (Pro, Ser, Asn and Gln). The synthesis of this polypeptide encodes an *itu* operon consisting of *ituD*, *ituA*, *ituB*, and *ituC* [30].

Polymyxins. Polymyxins are a group of polypeptide antibiotics that have been isolated from *Paenibacillus polymyxa.* A gene cluster covering a 40.6 kbp region is responsible for polymyxin synthesis. The cluster consists of five open reading frames designated *pmxA*, *pmxB*, *pmxC*, *pmxD*, and *pmxE*. The *pmxC* and *pmxD* genes correspond to genes encoding transport proteins, whereas *pmxA*, *pmxB*, and *pmxE* encode polymyxin sinthetases. Polymyxin B is an amphipathic cyclic decapeptide and a cationic detergent. It acts against Gram-negative bacteria [31]. Polymyxin B has also demonstrated fungicidal activity against numerous species of the genus *Fusarium* [32, 39].

3.2 NRPS Regulator Genes

degQ. DegQ is a 114 bp gene encoding for the fusion of the DegQ protein. DegQ is a small pleiotropic regulatory protein. It consists of 46 amino acids that control the expression of degrading enzymes, intracellular proteases, and several other secreted enzymes. DegQ indirectly regulates the expression of secondary metabolites via DegU [33]. DegU, in turn, regulates cell competence, cell motility, biofilm formation in colonies, regulates the maintenance of complex colony architecture, and is also responsible for the regulation of protease production [34].

abrB. The *abrB* gene, a repressor and activator of gene transcription, is expressed during the transition state between vegetative growth and the beginning of the stationary phase and sporulation. 39 operons have been identified which are influenced by *abrB*; it regulates the production of extracellular degrading enzymes and amino acid metabolism, membrane bioenergetics and cell wall functions, and biofilm formation [35, 36].

oppA. The *oppA* gene is responsible for proteins that bind and transport signal oligopeptides, which in turn affect factors regulating the transcription of the *srfA* gene. *oppA* mutations lead to changes in the spectrum of signal oligopeptides, such as CcpA, ComA and DegU, thereby indirectly regulating surfractin synthesis [37, 40].

ectB. The enzyme EctB is responsible for the synthesis of 2,4-diaminobutyrate aminotransferase. In the absence of EctA and EctC, 2,4-diaminobutyrate aminotransferase cannot be used for ectoin synthesis, so the 2,4-diaminobutyrate aminotransferase synthesized by EctB cannot be used as an intermediate for ectoin synthesis, resulting in an increase in its concentration in the cell. This condition is favorable for the cell in terms of polymyxin synthesis [36].

4 Materials and Methods

For the initial evaluation of expression in the antagonist strains, an experiment was carried out to co-cultivate the target strains with isolated fungi of the genus Fusarium, according to the following scheme:

The antagonist bacterial strains were reseeded 6 h before the experiment to obtain an active-growing spore-free culture.

Then, each strain was cultured on 2 different dishes, on a dish containing no phytopathogenic fungi (negative control) and on a dish with the fungus F. oxysporum strain Ras 6.1.

The co-culture was performed for 7 days at 25° C. Subsequently, total RNA was isolated from bacterial cultures.

For RNA isolation, ExtractRNA reagent (Evrogen) was used; MMLV RT kit (Evrogen) was used to generate complementary DNA on the isolated RNA matrix. The qPCRmix-HS SYBR kit (Evrogen) was used for the PCR reaction. The -2deltaCT method [38] and the deltaCT comparison method between control and experiment for regulator genes were used to assess the expression since, in most cases, their value.

Gene expression was studied using quantitative real-time PCR on a BioRad CFX 96 amplifier.

Amplification was performed according to the following program:

1. Pre-denaturation of DNA at 95° C for 5 min
2. Denaturation at 95° C for 30 s.
3. annealing of primers at 54 to 64° C for 30 s
4. Elongation at 70° C for 40 s
5. Steps 2 to 4 were repeated 45 times
6. Analysis of melting curves in the temperature range from 65 to 95° C with an increase in temperature by 0.5° C every 5 s.

5 Results and Discussion

The genes responsible for the synthesis of the 16 s subunit of the ribosome (a member of the housekeeping gene group) were used as references.

To study the regulation of NRP (non-ribosomal peptide) synthesis, we selected primers for the NRPS (non-ribosomal peptide synthetases) genes of interest. Thus, we studied the expression of the genes: fusA—responsible for the synthesis of fusaricidin synthetase subunit A, ituA—accountable for the synthesis of iturin synthetase subunit A, pmxE—responsible for the synthesis of polymyxin synthetase subunit E, fenC—accountable for the synthesis of fengicin synthetase subunit C, srfAA—responsible for the synthesis of the AA subunit of surfactin synthetase, degQ—responsible for the synthesis of phosphotransferase DegQ, abrB—responsible for the synthesis of the transcription regulator AbrB, oppA—responsible for the synthesis of oligopeptide-binding protein, OppA, ectB—responsible for the synthesis of 2,4-diaminobutyrate aminotransferase.

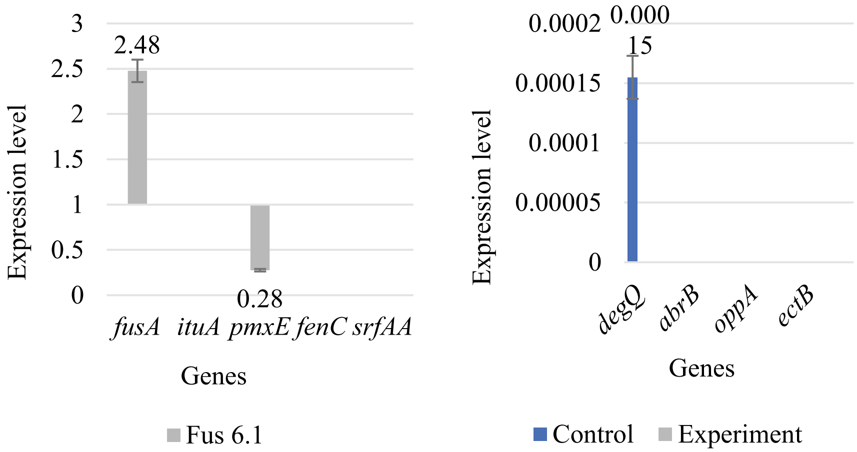

Fig. 1. Changes in the expression patterns of genes responsible for the synthesis (left) and regulation of NRPS (right) in strain F1 relative to the control level (the gene responsible for the synthesis of the 16 s ribosome subunit was used as a reference gene)

According to a similar scheme, was analyzed antifungal activity against fungi of the genus Fusarium in 4 strains of Bacillus and Paenibacillus, which could potentially form the basis of probiotic and antifungal drugs, namely: F1—Paenibacillus polymyxa, F2—Bacillus amyloliquefaciens, F3, F4- Paenibacillus peoriae (the internal laboratory nomenclature of strains is given).

For the convenience of display in the case of analysis of changes in the expression of genes responsible for NRPS synthesis, the control level was taken as 1 on the Y-axis, for a more precise display.

For example, changes in the expression of the fusA and pmxE genes were detected for strain F1 (Fig. 1).

In this case, we can observe on the graph that in the presence of fungi, fusaricidin expression increased up to 2.48-fold, and polymyxin expression decreased to 0.28-fold, respectively.

A completely different expression profile was detected in strain F2 (Fig. 2).

These graphs show that fusaricidin and fengicin expression was detected in this strain, with fusaricidin expression increasing up to 3.5-fold in the presence of fungi, while fengicin expression showed an inverse relationship.

Subsequently, a similar analysis was performed for strain F3 (Fig. 3).

This graph shows that in this strain expression was detected only for the gene responsible for fusaricidin synthesis. At the same time, the expression level of this gene was 1.4 times higher compared to the control level.

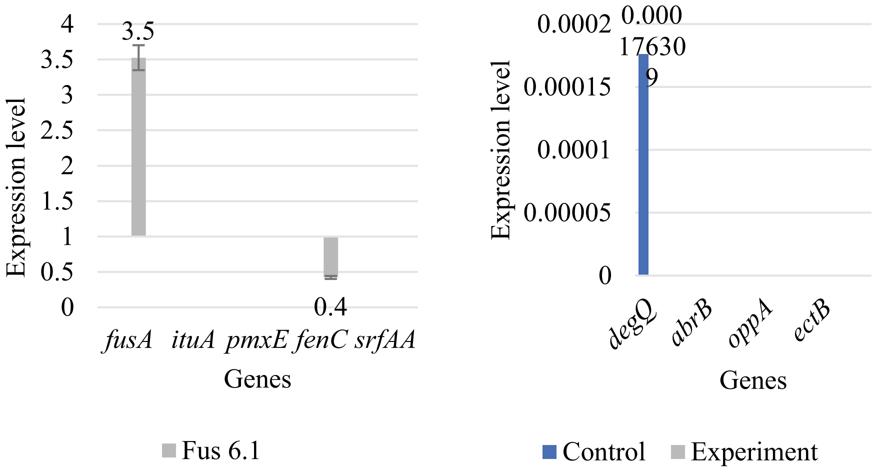

Fig. 2. Changes in the expression patterns of genes responsible for the synthesis (left) and regulation of NRPS (right) in strain F2 relative to the control level (the gene responsible for the synthesis of the 16 s ribosome subunit was used as a reference gene)

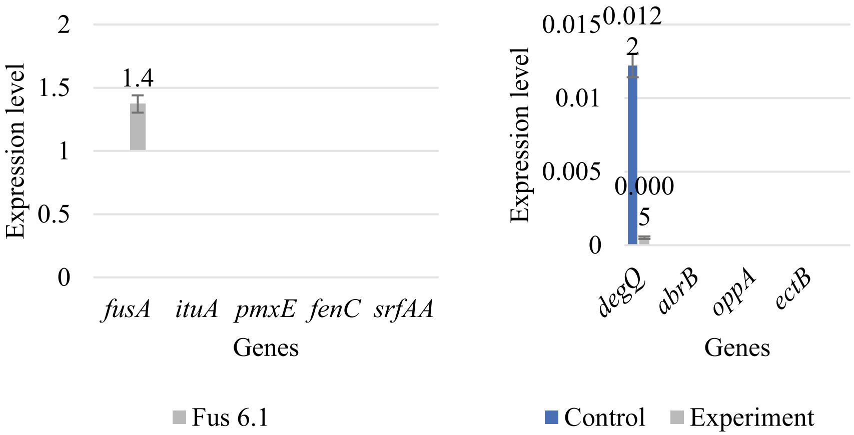

Fig. 3. Changes in the expression patterns of genes responsible for the synthesis (left) and regulation of NRPS (right) in strain F3 relative to the control level (the gene responsible for the synthesis of the 16 s ribosome subunit was used as a reference gene)

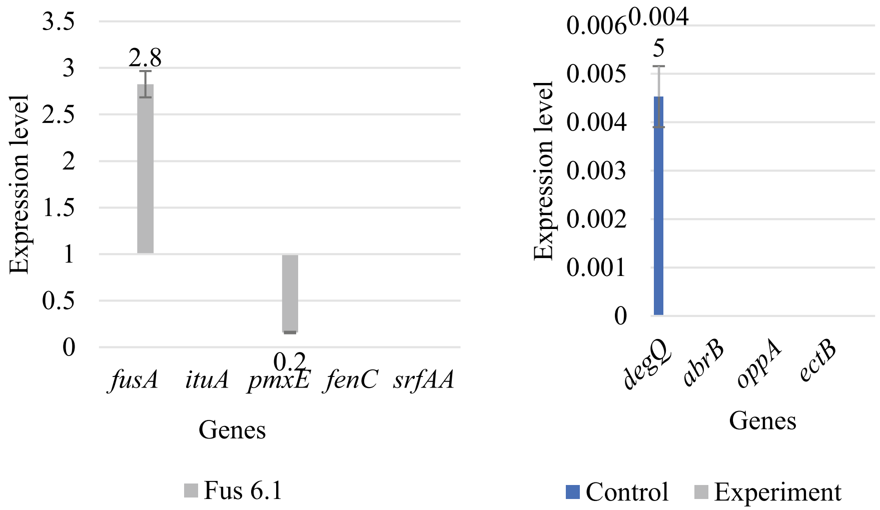

Fig. 4. Changes in the expression patterns of genes responsible for the synthesis (left) and regulation of NRPS (right) in strain F4 relative to the control level (the gene responsible for the synthesis of the 16 s ribosome subunit was used as a reference gene)

When analyzing the data on NRPS gene expression in strain F4, it was found that only fusaricidin and polymyxin were expressed in this strain (Fig. 4).

In this case, it can also be seen that the expression level increased for fusaricidin (up to 2.8-fold in the presence of fungus Fus 6.1) and decreased for polymyxin (down to 0.2).

For all the regulator genes, however, it can be summarized that in all the samples studied, expression was detected only for the degQ gene. At the same time, in the experimental samples (in which the tested strains were co-cultured with the fungus F. oxysporum strain Ras 6.1), the expression was not detected at all or, as in the case of strain F3, it was much lower than the control level.

Since DegQ is a negative regulator for fusaricidin, this effect may be directly related to the suppression of this regulator by the presence of F. oxysporum on nutrient media with the strains under study. In other words, this regulator's action is suppressed by other molecules to competitively inhibit fungi with fusaricidin.

6 Conclusion

As a result of studying the regulation of NRPS expression, it was found that the strains studied responded to the presence of F. oxysporum by producing a persistent antifungal response mediated by increased expression of fusaricidin. At the same time, the expression of the regulatory gene degQ, which is a negative regulator of fusaricidin synthesis, is suppressed for a stronger antifungal response, indicating the high potential of spore-forming bacteria as agents of biological control of fungal infections in animals when creating and applying probiotics based on them.

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Innovative Complex for In-Soil Fertilizer X Tender + Cenius for Mini-Till Technology

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Abstract. Effective production of agricultural products in Russia at the level of leading world countries (USA, Germany, France, etc.) became possible after significant reform of the agro-industrial complex with the transition to the most modern technologies with full compliance with all components and mainly agronomic, technical, economic. The materials of the scientific and analytical article present the results of research on obtaining high yields with good quality agricultural products using technologies of innovative intra-soil differentiated application of mineral fertilizers with a combined X Tender + Cenius aggregate manufactured by Eurotechnika JSC of the Russian Federation.

Keywords: Harvest · Technologies · Technics · Fertilizers · Introduction · Innovation · Subsurface

1 Introduction

Of all the innovative world technologies Mini-Till, No-Till, Strip-Till in Russia, the energy-resource-moisture-saving Mini-Till technology is used in the largest volumes [1–15]. With the introduction of this technology, the formation of the maximum possible, with good quality, yield of agricultural crops is possible only with the complex application of various types of mineral fertilizers—which requires innovative, highly efficient, combined tillage and fertilizing aggregates with subsurface application fertilizers, which corresponds to the development trends of world agricultural technologies and the production program of the agricultural machine-building company AMAZONEN-Werke with its enterprise in Russia, Eurotechnika JSC (Samara).

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2 Purpose and Methods

The aim of the work was the need for a deeper study of the efficiency of intra-soil application of mineral fertilizers to create an innovative high-performance combined X Tender + Cenius combined unit. A preliminary study of the effectiveness of intra-soil fertilization was carried out by AMAZONEN-Werke, in particular, on an experimental unit Pegasus (Fig. 1) together with the Samara State Agricultural Academy—now the Samara State Agrarian University, which served as the basis for the creation of a highly effective innovative soil-cultivating and fertilizing complex Xtender + Cenius with the possibility of traditional and differentiated fertilization in different soil horizons using the Mini-Till technology.

Fig. 1. Experimental soil-cultivating and fertilizing unit "Pegasus" of the "AMAZONEN-Werke" company

The Samara State Agricultural Academy carried out technological experiments to determine the effectiveness of subsurface fertilization in the cultivation of maize for green mass and sunflower. In the process of research in experiments, vegetation observations were carried out for the development of eight varieties and hybrids of maize for green mass and eight hybrids of sunflower. For comparison, we used the method of scattered surface application of mineral fertilizers by spreaders "AMAZONEN-Werke" with different doses of NPK fertilizers for the planned yield: $N_{30}P_{30}K_{30}$, $N_{45}P_{45}K_{45}$, $N_{60}P_{60}K_{60}$, $N_{90}P_{90}K_{90}$. Research was carried out in the fields of Federal State Budgetary Educational Institution of Higher Education "Samara State Agrarian University" on soils represented by ordinary chernozem, medium-humus, medium-thick, heavy loamy with a density in the layer 0–30 cм—1,09 g/cm^3, hardness—1,17 mPa, reserve of productive moisture in the layer 0–30 cm—36 mm, 0–100 cm—129 mm, the content of available forms of nutrients: easily hydrolysable nitrogen—93 mg/kg, mobile phosphorus—176 mg/kg, bulk potassium—165 mg/kg, exchangeable soil acidity—165 mg/kg.

In comparative studies of the effect of surface and subsurface fertilization on the yield of green mass of corn (with individual ears) for various hybrids, a stable increase in yield was obtained with a maximum level of 73–76 c/ha at the highest dose N60P60K60. However, intra-soil fertilization was more effective (taking into account the price of fertilizers) with an increase in green mass—64 kg/ha with the optimal amount of fertilizers N45P45K45 (Fig. 2).

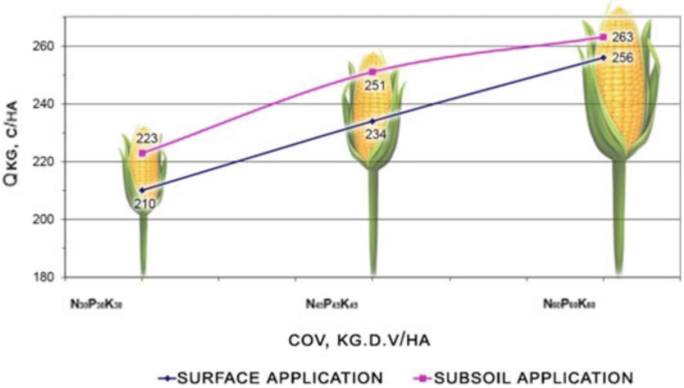

Fig. 2. Comparative yield of corn with intrasoil and spread application of mineral fertilizers

It was the same in experiments with sunflower. With the surface-spreading method, the increase was 6.4 c/ha (44.8%), and with the subsurface method—8.8 c/ha (60,7%). That is, intra-soil fertilization under the sunflower was more effective than their application to the surface in a spread on average by 2.3 c/ha, or 16% of the "control" (Figs. 3 and 4).

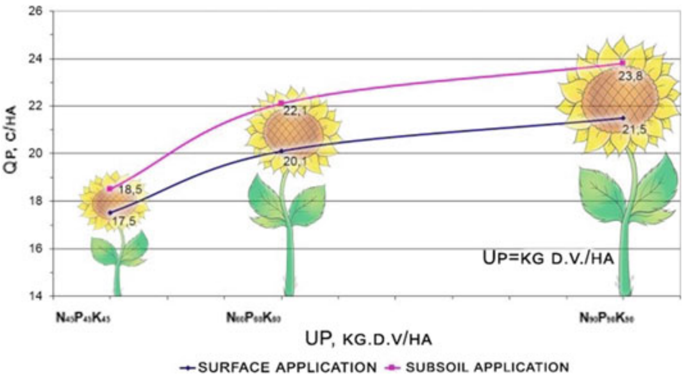

Fig. 3. Influence of different methods of fertilization: surface and subsurface, with different doses of NPK in sunflower cultivation

Thus, numerous studies on more efficient intra-soil fertilization were confirmed, which, in contrast to European technologies in areas with sufficient moisture, in Russia in most regions in areas with a deficit of precipitation is considered to be much more effective. In accordance with global trends in the development of units for subsurface fertilization, the company has developed a combined complex (Fig. 1), consisting of a unit with a large volume (4,2 m^3) ×тender bunker (Fig. 2) and—"Cenius" cultivator, with special working bodies for intrasoil longline fertilization (Fig. 3). The XTender metering system includes two servo-driven metering units for different application rates from 2 to 400 kg/ha. There are different metering rollers to choose from, depending on

Fig. 4. Combined aggregate of the company "AMAZONEN-Werke" for subsoil application of mineral fertilizers: 1—Xtender + Cenius; 2—large Xtender fertilizer hopper—4,2 m^3; 3—"Cenius" cultivator working body for soil cultivation and intra-soil fertilization

the type of seed and the properties of the fertilizer. As an option, Amazone also offers the TwinTerminal 3.0, which is well known in the field of seeding technology. To control the machine, either the Amazone ISOBUS terminal or the tractor ISOBUS terminal is used, which also makes it possible to differentiate fertilization according to fertility maps [5, 6].

The well-known mulch cultivator "Cenius" (Fig. 5) with a wide set of working bodies and working stands is used in the agro-industrial complex of many regions of Russia for surface tillage and deep loosening.

In the new cultivators, the C-Mix 320 mm duckfoot share is used for working at a depth of 3–10 cm and is ideal for shallow stubble cultivation. The main tasks of the duckfoot share include cutting stubble over the entire surface and breaking capillarity, mixing plant residues on the soil surface [20]. The chisel with side knives C-Mix 350 mm makes it possible to work most efficiently at a depth of 6–12 cm, its main tasks are similar to those of a duckfoot share: continuous undercutting and intensive mixing of crop residues. This tool consists of a combination of 80 or 100 mm chisels with guide plates and removable side knives (left and right). The C-Mix 100 mm with a 100 mm guide plate works with high quality in a depth range of 10–20 cm and is a universal working tool, therefore it is recommended for use on all types and types of soils. In combination with the helical guide plate, it provides intensive mixing of crop residues

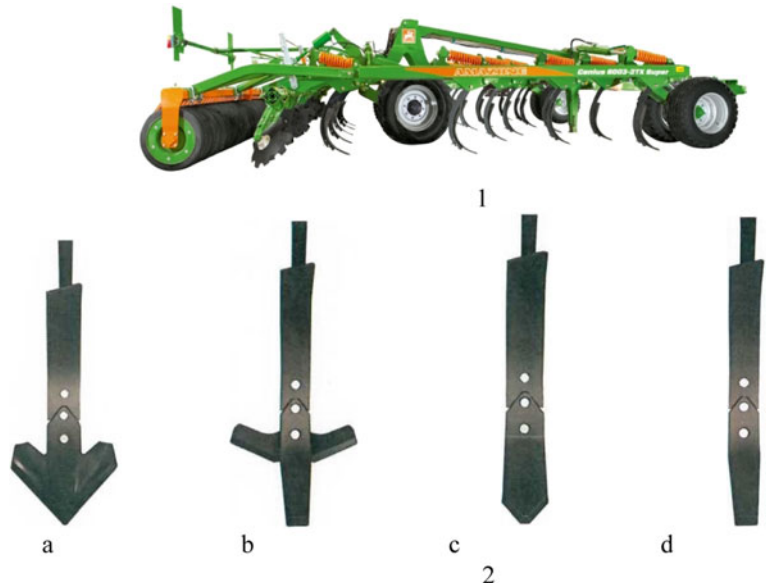

Fig. 5. Trailed mulch cultivator Cenius 8003 2TX Super (1); with working bodies (2): **a**—lancet paw C-mix 320; **b**—C-mix 350; **c**—C-mix 100; **d**—C-mix 80

with the soil throughout the entire working depth. C-Mix 80 mm with 80 mm guide plate is the most "deep-working" implement, allowing you to work the soil up to 12–30 cm. Recommended for basic tillage and deep loosening. In combination with a helical guide plate, it intensively loosens and mixes the straw. In combination with side knives, it can be used for stubble cultivation [18]. It is with this working body that the developer recommends deep slotting. To do this, it is necessary to dismantle the two central rows of working stands and increase the distance between the stands to 56 cm. Thus, it is possible to achieve a working depth of up to 40 cm. In this way the Cenius TX can carry out shallow, medium and deep cultivation at different stages. For shallow stubble cultivation in the first pass, the C-Mix 350 mm (up to 12 cm) or C-Mix 320 mm (up to 10 cm) implements can be used. They provide continuous undercutting, good mixing of crop residues with the soil at a shallow depth (up to 12 cm) and a quick provocation of the predecessor's volunteers. The second treatment can be carried out with C-Mix 100 to a depth of 10 to 20 cm. At the same time, not only is there an excellent mixing of plant residues with the soil (in the presence of a large amount of straw in the field), but also a fight is carried out against the sprouted carrion of the predecessor. The same cultivator can work at depths of up to 30 and 40 cm (crevice), using the C-Mix 80 working bodies and at the same time avoiding excessive soil compaction [19]. Depending on the type of soil, different rollers are used for intensive crumbling and good reconsolidation. At the same time, the rubber-wedge rollers carry out strip reconsolidation, which ensures uniform emergence of cereal weeds, while open and uncompacted soil areas guarantee unhindered gas exchange and can absorb additional rainwater. In addition to the wedge ring rollers, other rollers are also offered for the new cultivator generation: the ring cutter roller is used primarily for reconsolidation on dry, heavy and lumpy soils. For work on light soils and in the presence of large tractors, a light tubular roller is provided. Tandem rollers are usually used for seedbed preparation [17]. The toothed roller can be used to ensure an even reconsolidation of the soil over the entire working width. The range of Cenius cultivators, both mounted and trailed, represents a wide range of cultivators in working widths from 3.0 to 8.0 m.

In addition, in the system of resource-saving technologies of the agro-industrial complex of the Russian Federation, soil cultivation machines with disc working bodies are widely used, after the passage of which the mulching layer required by agricultural technology is created. Disc harrows-discators of the German company "AMAZONEN-Werke" produced by JSC "Eurotekhnika" (Samara) and supplied to agricultural enterprises of Russia – Catros" and "Certos" with a wide range of working widths in mounted and trailed versions with promising elements structures are also equipped with special equipment for shallow tillage with simultaneous application of mineral fertilizers when aggregated with X-TenderT, but in a trailed version (Fig. 6).

Fig. 6. An innovative soil cultivation and fertilizer complex in the trailed version X-TenderT with a Catros disc harrow

The combined complexes Xtender and Cenius began to be implemented in the agricultural sector of the country, so in 2019, on the comparative field of the AF "Zainskiy Sugar" of the holding of JSC "AGROSILA", a differentiated application of fertilizers for sugar beets was carried out on an area of 150 hectares. The combination of the Xerion 4500 Tractor + Xtender 4200 hopper + Cenius 5003-2TX cultivator in practice allowed: 1. With the Xtender 4200 double hopper, spread in one pass; 2. type of fertilizer (potassium chloride and ammophos); 2. Simultaneously apply fertilizers to a predetermined depth (15–20 cm) and carry out the main tillage; 3. Differentiated fertilization according to the task map—from 30 to 290 kg/ha (and each type of fertilizer has its own coil) [16].

3 Conclusion

Thus, today, the domestic agricultural complex of the Russian Federation in agriculture and crop production, using the Mini-Till energy-saving technology, widely known in the world, successfully applies an innovative complex of Russian-made machines (Samara)—JSC "Eurotekhnika" of the German company "AMAZONEN-Werke" (Fig. 7) for more effective, in comparison with the spread surface application of solid mineral fertilizers, intra-soil application [1–18, 19, 20].

Fig. 7. Innovative tillage and fertilizer complex Xtender + Cénius in the agro-industrial complex of Russia

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Further Improvement and Adaptation of the Primera DMC Seeder, Germany

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Abstract. The efficiency of grain production depends on the level of technology that ensures the maximum yield. Progressive agriculture is based on the optimization of all elements of technological processes and, first of all, the composition of machine and tractor units. The article presents an analytical review of the German Primera DMC seeders of the AMAZONEN-Werke company produced by JSC Eurotechnika (Samara), which are in significant demand in Russia, as well as their equipment for differentiated sowing of seeds depending on soil fertility and moisture availability during irrigation.

Keywords: Seeder · Optimization · Differential Seeding · Hydraulic Drive · Seeding Devices · Fertility · Humidity · Irrigation

1 Introduction

The emergence of the Russian Federation as a world leader among exporters of grain, primarily wheat, was largely due to the transition of our country to modern energy-resource-moisture-saving technologies No-Till, Mini-Till and highly efficient technical re-equipment of the agro-industrial complex. Samara State Agricultural Academy (SSACA), now the Agrarian University—Samara State Agrarian University (Samara SAU), using the unique opportunity to be located in the city of Samara, the leading agricultural machine-building enterprise in Russia for trailed equipment JSC "Eurotechnika" of the German company "AMAZONEN-Werke" for more than 20 years of fruitful cooperation with her to adapt the best German technology to the soil and climatic conditions of Russia—Middle Volga region [1–15], paid special attention to the introduction into agricultural production of a high-tech direct sowing seeder—Primera DMC[1–4], the creator of which is the successor of the traditions of the company's development «AMAZONEN-Werke», Member of the Board and Shareholder, Doctor, Professor Heinz Dreyer. Heinz

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Dreyer enjoys a well-deserved authority in Russia, he is a foreign member of the Russian Academy of Sciences, Honorary Professor of the Samara State Agricultural Academy, awarded by the Minister of Agriculture of the Russian Federation A. V. Gordeyev a silver medal "For contribution to the development of the agro-industrial complex of Russia".

2 Purpose and Objectives of Research

Substantiation of the model for the selection of the optimal DMC seeders for agricultural enterprises of any level in terms of the sown area, taking into account the working width and, accordingly, the productivity of the unit, as well as seasonal and annual output with the corresponding energy means—tractors produced and supplied to Russia. 2. Development of recommendations for the use of modernized DMC with a hydraulic drive of sowing devices for differentiated sowing with a change in the seeding rate in irrigated fields with seed saving.

3 Research Results, Discussion

The Primera DMC seeder successfully works both with the latest technologies No-Till, Mini-Till, and traditional ones with guaranteed quality and is in great demand among Russian farmers. It is no coincidence that AMAZONEN-Werke has developed several options for the working width (3.0; 4.5; 6.0; 9.0; 12.0 m), which meets the main condition for completing the machine and tractor fleet enterprises with DMC seeders according to their optimal number for sowing one crop in one field in strictly recommended agrotechnical terms—5 days. The Primera DMC 602 seeder at the All-Russian Field Day in Rostov was awarded the diploma "The best tillage machine (seeder) 2007", at the international exhibition Agrosalon—2016 in Moscow, the Primera DMC 12,001–2C seeder, as a new solution to increase productivity and expand the range of applications, won a silver medal.

1. The work considers the Primera DMC seeders with their main parameters [1–4]. To optimize the machine and tractor fleet of agricultural enterprises, both large holdings and medium-sized and small ones, the main criterion is the working width of the seeders, which ensures the performance of the unit depending on the operating speeds within the recommended agrotechnical terms [3]. DMC Primera seeders with a working width of 3 to 12 m at recommended operating speeds of 10–15–18 km/h with tractors of the appropriate power for the recommended agricultural life of one crop in one field can sow up to 700 ha. At the same time, the calculations take into account the operational productivity, since when the seeding complex is operating according to a rather complex and saturated technology with the combination of sowing with the simultaneous application of solid fertilizers, about 20% of the shift time is spent on filling the unit with seeds and fertilizers and its maintenance. Seeder DMC, with wide versatility and the ability to sow both early, late, grain and row crops. Increasing the working width of seeders by 4 times—from 3 to 12 m allows increasing the productivity of the unit by almost 3 times. The discrepancy between

the proportional increase in the width of the seeder and the productivity of the unit is associated with a decrease in the optimal range of working speeds from 10–18 km/h, with a working width of seeders—3.0; 4.5; 6.0 m—up to 10–15 km/h—with a working width of seeders—9.0 and 12.0 m for operational reasons. That is, an increase in the working width of the DMC seed drills from 3.0 to 12.0 m—4 times with a corresponding increase in the traction resistance and weight of seeders, as well as an increase in the weight of the energy means—tractors, requires an increase in the power of tractors by 4.4 times. Figure 1 shows the DMC seeders optimized in terms of working width, draft resistance and modern energy equipment—tractors supplied to the Russian Federation—Fendt, John Deer. Thus, the systematization of technological, technical and operational characteristics of Primera DMC seeders according to the developed model-nomogram of productivity from the working width and working speed with the estimated production for the agricultural period, season, allows you to complete agricultural enterprises of any level in terms of the sown area and specialization in cultivated crops with the optimal number of seeders for tractors with the required engine power.

Fig. 1. DMC seeders of various working widths (m): **a** 3.0; **b** 6.0; **c** 9.0 **d** 12.0

2. Significant areas of agricultural land in the Russian Federation are located in zones of insufficient moisture, which significantly reduces yields and gross harvests of crops, in addition, experts predict global warming in the near future, which will also require the expansion of lands reclaimed by artificial irrigation. In Russia, the area of irrigated land is no more than 10%. For the implementation of a complex of irrigation measures in agriculture, sprinklers are used, which are designed for irrigation of grain, fodder, industrial and vegetable crops. On an industrial scale, when irrigating from 10 to 100 hectares or more, circular sprinklers are recognized as the most effective (Fig. 2).

a) b)

Fig. 2. **a** Circular action machine; **b** for irrigation in a circle.

The technology of irrigation of a pivot sprinkler provides irrigation mainly in a circle (Fig. 3b), and in difficult situations and in half a circle, ¼ and ¾ of a circle (Fig. 4).

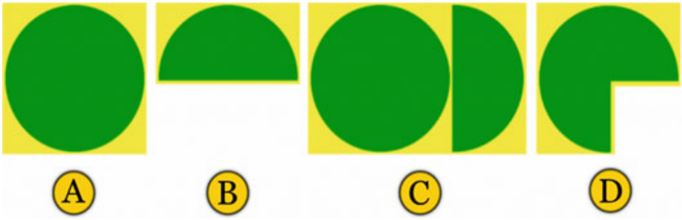

Fig. 3. Possible forms (**A**-**D**) of irrigated areas

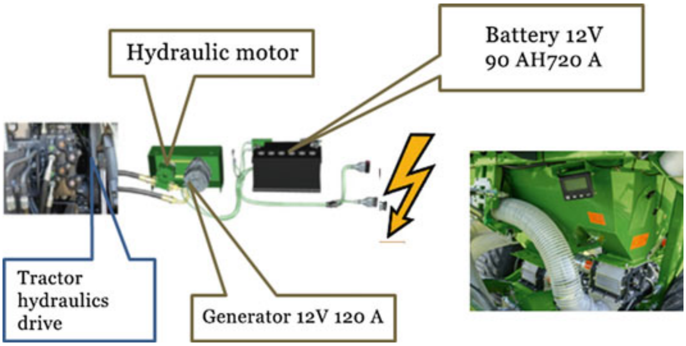

Fig. 4. Servo drive for dosing and ISOBUS-regulation Primera DMC

A significant problem when irrigating with circular sprinklers is non-irrigated zones at the corners of the site, although firms supply additional equipment for this, however, this drawback exists in production (non-irrigated areas). In non-irrigated zones in the corners of irrigated areas, due to a lack of moisture, field crops do not develop intensively with a decrease in yield and harvest, and this is natural.

The yield value in terms of moisture availability is calculated according to the average daily moisture content in the 0–100 cm by layer. In general, the seeding rate depends on the purpose of crop cultivation (for grain, silage, green fodder, etc.), soil fertility, moisture conditions, sowing methods. In arid conditions, which include non-irrigated zones, the seeding rate of crops is reduced, in zones of sufficient soil moisture in irrigated areas, it is increased by 10–15%. The solution to this problem, in relation to the technology of cultivation of agricultural crops, is provided by the creation and supply, upon request, of special equipment for a differentiated seeding rate of the Primera DMC seeder, which is widespread in the Russian agro-industrial complex, when working in the GPS system. Equipping seeders with special equipment for differentiated sowing of agricultural crops solves effective sowing management depending on soil fertility and moisture supply with different seeding rates [2], since the field, as a rule, has an uneven, and significant, change in fertility, affecting the yield of agricultural crops, which solves precision farming, the study of the effectiveness of which is devoted to many scientific works, including the scientists of the Samara State Agrarian University [1–15]. A similar situation is typical for areas of the field with different moisture content during artificial irrigation with pivot irrigation machines. Scientific and production data prove that with high soil fertility, it is advisable to increase the seeding rate of crops to increase productivity and product quality, and with low soil fertility, reduce it in comparison with the optimal recommended zonal norms. Likewise, with uneven moisture supply, it has been proven that with a lack of moisture during the growing season, crops with an increased rate do not develop intensively enough compared to crops with sufficient soil moisture. Considering the high cost of seeds, for example, soybeans, it is advisable to reduce the seeding rate in non-watered areas, which is decided by the equipped Primera DMC seeder. At the same time, the main mechanism for metering the seeds of the seeder is being modernized, that is, the mechanical drive of the metering rolls from the drive and support wheels of the seeder, ensuring the same rotation of the rolls and the same seeding rates for each opener, replaced by a hydro-mechanical one, due to the hydraulic motor, which changes its speed at the command of the control actions of the on-board computer, in which a moisture map is laid—with the allocation of irrigated and non-irrigated soil zones in the field and an algorithm for changing seeding rates, depending on the presence of moisture in the soil [16].

Thus, the drive of the seed distribution reels is carried out by the metering servo drive and ISOBUS-regulation (Fig. 4), which is installed on the Primera DMC seeders. In the Samara region, in one of the agricultural enterprises, a significant area of farmland is irrigated with circular sprinklers, and especially during the cultivation of soybeans. Calculations carried out in accordance with the experience of soybean cultivation on irrigation and a significant decrease in yield in non-irrigated areas, retrofitted with a Primera DMC seeder, it is recommended to reduce the seeding rate (Table 1), which will ensure a decrease in seed consumption and increase the overall economic efficiency.

Thus, the re-equipment of the PRIMERA DMC 9000 seeder with the ISOBUS system for differentiated sowing of the irrigated area of the field when using pivot irrigation machines and technologically non-irrigated machines with a zonal economically justified reduced sowing rate will reduce the cost of seeds and quickly enough (0.7 years) to recoup the additional costs of re-equipping the seeder for variable seeding.

Table 1. Calculation of the economic efficiency of differentiated sowing with changing seeding rates in irrigated and non-irrigated areas of the field

Indicators		Variants	
	Data	18–10	18–12
Field area, ha	S	68,7	72
Run length, m	D	828,9	848,5
Irrigated area radius	R	414,4	424,3
Irrigated area, ha	Circle S	53,9	56,5
Non-irrigated area, ha	Non-irrigated area S	14,8	15,5
The area is not irrigated, %	Non-irrigated area S	21,5%	21,5%
Seed savings with differential seeding			
Seeding rate for irrigation, kg/ha	160		
Seeding rate on dry land, kg/ha	120		
Seed consumption without diff. sowing, kg		10,992	11,520
Seed consumption in the irrigated area, kg		8,629	9,043
Seed consumption on dry land, kg		1,772	1,858
Seed consumption at diff. sowing, kg		10,401	10,901
Saving seeds, kg		591	619
Saving seeds, kg, %		5.4%	5.4%
Soybean seed price, rub/kg	40		
Saving costs for seeds, rub		23,633	24,768
Saving costs for seeds, rub/ha		344	344
Saving costs for seeds per season (1000 ha), rub	1000	344,000	344,000
The cost of equipment for a standard seeder DMC 9000, €	140,800		
The cost of equipping a standard seeder DMC 9000 with the ISOBUS system, €	144,440		
The price of a standard seeder DMC 9000, rub	9,856,000		
The price of the seeder DMC 9000 ISOBUS, rub	10,110,800		
Price difference, rub	254,800		
Payback of the difference in price, years	0.7		

4 Conclusions

Further improvement of agricultural technologies and, first of all, sowing of agricultural crops is possible due to differentiated sowing with digitalization of the seeding rate control and seed distribution process with equipping seeders with special equipment, in particular with a servo drive of the seeding units and a system for automatic control of the seeding units of the seeder, which will reduce the cost of seeds with high yields provided with the creation of favorable conditions for the production of agricultural products with additional profit.

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Modern Technology for Cultivation of Agricultural Crops in Zones of "Risk Farming" with Conservation and Accumulation of Atmospheric Moisture

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Abstract. A further increase in the efficiency of agricultural production in recent years and in future, according to experts, is constrained and will be aggravated by unfavorable natural and climatic collisions associated to a greater extent with the objectively developing atmospheric warming due to an increase in solar radiation, air temperature from overheating of soils in summer period, unproductive moisture loss and a decrease in precipitation during the growing season of plant development. The article presents the research of the Samara State Agrarian University to improve a wide range of constituent elements and technologies in general for the cultivation of agricultural crops that reduce the negative impact of weather conditions in "risky" farming.

Keywords: Technics · Moisture · Disadvantage · Global Warming · Technologies · Dew · Tillage · Cleaning

1 Introduction

In the world, for almost 2 centuries, a sufficiently large scientific and production experience of technical, technological and organizational resistance to unfavorable weather conditions in the production of agricultural products has been accumulated, in our case the conditions for effective cultivation of agricultural products with insufficient moisture are considered—"risky" agriculture. Three main natural factors determine success in agriculture: solar energy, precipitation—air humidity and soil moisture capacity, soil fertility, which in most regions of Russia often deviate significantly from the optimal. Agricultural science and production by improving technologies and techniques, if possible, neutralize these unfavorable factors. Samara State Agrarian University (Samara

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SAU), summarizing the scientific experience of well-known agricultural scientists of the Volga region: academician N.M. Tulaykov, Doctors of Agricultural Sciences: Shulmeister K.G., Burova D.I., Chudanova I.A., Kazakova G.I., Korchagina V.A. etc. taking into account the outstanding world and domestic research, continues scientific work on the adaptation of agriculture to the conditions of insufficient moisture in the development of agricultural crops with more advanced technologies [1, 2].

2 Purpose and Research Methods

The purpose of the scientific work is a comprehensive study of changing and improving factors that improve the development of crops under adverse weather conditions with a moisture deficit. The analysis of scientific works of domestic and foreign authors allows us to determine the priority areas, the solution of which ensures the reduction of risks in agriculture and crop production due to a shortage of crops due to unfavorable weather conditions, for which we carried out the following studies: 1. Repetition of the experiments of Ovsinsky [3] on the use of dew on plant leaves and in the soil with the help of modern technical means. At different times of the day of the summer study period, the air contained from 14 to 88% (July 29, 2015) and from 16 to 91% (August 10, 2015) moisture. A particularly large amount of moisture was in the air at night and in the morning from 22 to 7 o'clock, when the air temperature was minimal—15–200 °C. Colder and heavier air saturated with moisture sinks to the surface of the earth and moisture condenses on colder objects—leaves, soil, that is, dew falls out. At the same time, it is also desirable to moisten the root system of plants when the waterlogged air passes through a loose soil layer mulched with plant residues, which to a certain extent solves the problem of droughts, excludes drying out of the topsoil due to natural reserves, that is, with reasonable innovative farming, moisture, being in large quantities in the air, it can compensate for its lack by the so-called "atmospheric irrigation" [1–3]. Increasing the productivity of farmland, despite recurring droughts and projected global warming, is possible only through moisture-saving technologies based on shallow, mulch tillage and direct seeding [1, 2] with obtaining the best result, in experiments, on the minimum "mulching" processing with medium disc harrows of the "Catros" system (Fig. 1a) with smooth and cut spherical discs and rubber-wedge roller, as well as with heavy harrows Certos when sowing on.

"Mulch" with a direct sowing machine of the "DMC Primera …" (Fig. 1b) by the one of the leading machine-building companies in Russia in the city of Samara-JSC "Eurotech" of the German company "Amazonen-Werke". Based on the scientifically proven and practically tested Russian scientist I. Ovsinsky hypothesis about "atmospheric irrigation" (dew formation on both leaves and roots in soil) due to shallow "mulching" soil cultivation, for 5–7 years, the fields in the Uchkhoz of the State Agricultural Academy in the autumn crop rotation were cultivated only with a disc harrow "Catros-6001", and in the spring, if necessary, they were cultivated with both spring and dart tines, after which all cultivated crops were sown with the Primera DMC 300 direct sowing seeder. In 2013–2014, winter wheat was cultivated on the experimental field with a grain yield of 3 t/ha, plant mass (straw) 4.5 t/ha, which was a good condition for the formation of a surface "mulching" layer. After harvesting from half of the field, the straw was removed


a) b)

Fig. 1. **a** Catros disc harrow, **b** seeder Primera DMC (JSC "Eurotechnika" for moisture-saving technologies)

by baling (option II), and on the other half, the straw was crushed and scattered across the field (option I)—both areas were processed by the "Catros 6001" aggregate. The next 2015, two cultivations were carried out on both plots by the Cultivator KKSh—on June 11, 2 and 9, the field was sown with Sudanese grass "Kinelskaya-100" with a rate of 1 million 200 thousand seeds per hectare. The studies have shown that according to the technology of shallow tillage, leaving stubble on the surface and its intensive grinding during the long-term creation of a "mulching layer", in the acutely dry 2015, the effect of drought did not have critical negative consequences in comparison with traditional technologies without a "mulching" layer. So the studies of soil temperature and moisture, carried out on 07/29/2015. at 17–00 showed (Fig. 2a) that at a daytime air temperature of 31.00 °C in the I-th variant (shallow "mulching" tillage) in the 0–0.05 m layer the soil temperature was 25.50 °C, which is significantly lower than in the II variant (without mulching layer) 39.50 °C, a similar trend was observed in layers 0.05–0.10 m and 0.10–0.15 m. The lower temperature allowed under the "mulching" layer (option I) to preserve to a large extent soil moisture: in the first option it was 44.23%, and in the second only 5.94%. This circumstance (low soil moisture in the root layer) caused the emergence of shoots of Sudan in the second variant 1–2 weeks later than in the first variant and, accordingly, their slower development even with intense summer precipitation. A similar, but less pronounced trend in the dependence of soil moisture on temperature can be traced (Fig. 2b) in a less hot time (08/10/2015 at 1700 h at a daytime temperature of 250 °C). Both in the first and in the second observation time, intense dew fell on Sudanese plants, lasting up to 1400 h. A significant moisture deficit in the soil (especially in the root layer) in the compared variants had a sharply negative effect on the vegetation of Sudan and the formation of green mass — the yield and the entire biological mass, including roots (Fig. 2b). So, during the first mowing (08.16.2015), the total biological yield (roots + stems) in the first variant of "mulching" tillage was 72% higher than in the second variant without "mulching" tillage, and the green mass is almost 2 times more (96%), (Fig. 2b), where the common species of Sudanese plants are presented before the 1st mowing according to the I-st option and the II-nd option, as well as the stalk Sudan with "mulching" a layer of straw. The obtained research results fully confirm the ideas of I. Ovsinsky about the effectiveness of "atmospheric irrigation", when in the 1st option, along with significant dew on the leaves (sometimes dew was observed up to

14 h, regardless of the hot daytime weather), the formation of moisture—the transition of atmospheric moisture into the soil when penetrating by warm, moisture-saturated air, a loose mulching surface layer of the soil.

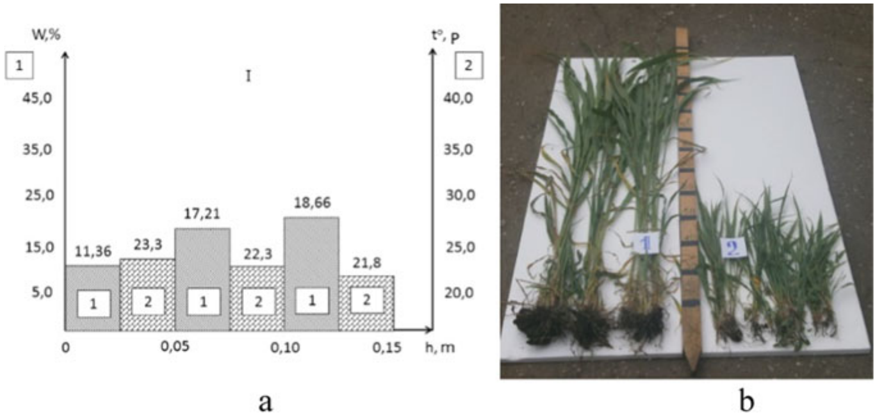

Fig. 2. **a** Moisture dynamics (W, %) and temperature (t^{o}, p) soils in soil horizons (0.00–0.15; 0.05–0.10; 0.10–0.15) with traditional (II) and moisture-saving technologies (I); **b** comparative state of Sudanese

Research on effective moisture storage. One of the effective methods of moisture accumulation is the use of the maximum amount of melt water through intensive snow retention, so, with an average annual fallout of all types of precipitation of 380–450 mm per year and 30% of them—in winter—about 130–150 mm of moisture can be accumulated in a meter-long soil layer for intensive plant growth. Today, the saved stubble of agricultural crops and-strip curtains are effectively used for snow retention. The “No-Till” technology also used, in which the stubble remains intact (meaning by flat cutters), makes it possible to improve snow accumulation to a certain extent; however, during traditional harvesting, the stubble remains no more than 0.2 m high, being a natural obstacle to high-speed 10 m/s) blowing snow. When the remains of the stubble are covered with snow 0.2 m high, due to its low specific gravity, it moves freely across the field even at a wind speed of 2–4 m/s at a height of more than 0.2 m. To create additional obstacles in the path of moving snow, an effective technique will be to leave stubble of full height (0.85–1.5 m), which is possible with the introduced technology of harvesting grain crops by the “stripping” method and leaving after harvesting the stalks of such tilled crops as corn and sunflower. The next, unsolvable problem, sowing crops in a large amount of not chopped stubble (without clogging the working bodies), which, covering the top layer of the earth for better reflection with a light surface compared to a dark soil surface (intensively absorbing heat fluxes), provides more its low temperature. The physical meaning of heating the air penetrating through its layers by solar radiation is based on the absorption of the thermal energy of the sun by the dark soil surface, from which the air heats up, rising to the upper layers, and the soil heats up much more intensely than the air. Our studies have established daily changes in soil temperature and air temperature in the surface layer (0.5–1.5 m)—Fig. 3. The research was carried out in the hottest year in the history of the Volga region, 2010-July 29, in clear weather. At the same time, the air temperature varied from 27.0 °C to 37.0 °C. At the same time, the soil was warmed up from 20.0 °C to 58.50 °C, and as you know at a temperature 42.0–49.0 °C the protein of the seeds begins to break down. In this connection, we have considered various technologies for the cultivation of agricultural crops at different conditions of the stubble. Protective, against increased solar radiation, the functions of the stubble from heating the soil and unproductive loss of moisture depend mainly on its amount, which is determined by the seeding rate, the density of standing before harvesting, the height and diameter of the stems, which is theoretically determined in our works [4]. To confirm this fact, in the severely arid 2010, we conducted research to determine the protective properties of straw against overheating of the surface soil layer (0–10 cm). In experiments in 3 variants, the soil temperature was determined in a layer of 0–10 cm: 1—surface without plant residues (like black steam), 2—the surface is covered with 5 cm thick chopped straw; 3—the surface is covered with chopped straw—10 cm. Simultaneously, the air temperature was measured (the days of the research were chosen clear and the air temperature was recorded from 27.0 to 35.0 °C. The nature of the change in soil temperature depending on the state of the surface (open and covered with straw) is shown in Fig. 3 [5–7] (Fig. 4).

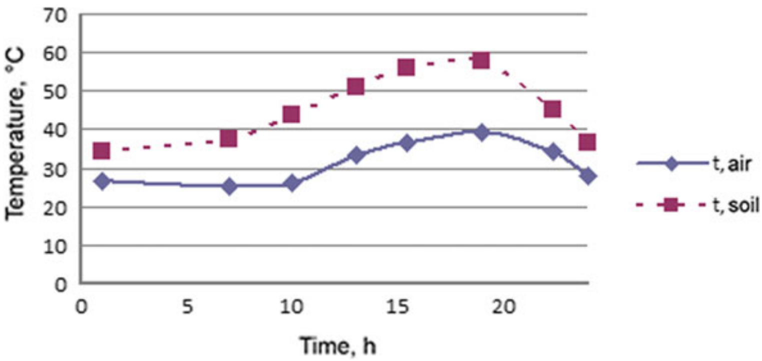

Fig. 3. Changes in the temperature of the upper soil layer and air in the surface layer (0.5–1.5 m) during the day on a hot day (2010, July 29).

At air temperature 30.0 °C soil temperature without straw was 30.50 °C, covered with a 5 cm layer of straw—27.0°C (lower by 3.0 °C), covered with a 10 cm layer of straw—25.50 °C (lower by 4.50 °C). Straw, therefore, affects the reduction of the action of solar radiation due to its reflection on a lighter surface than the soil and, due to the shading of the soil, ultimately reduces by 4.5–5.0 °C its temperature. Moreover, the higher the air temperature, the more positive the protective (against solar radiation) properties of the straw covering the soil. So at ambient temperature 35.0 °C—the temperature in the upper soil layer is higher than atmospheric by 3.0 °C, on an open surface, lower by 10 °C at 5 cm of cover with straw and below by 40 °C with 10 cm of cover with straw, i.e. the change—that is, the change in the decrease in soil temperature is $\Delta = 7.0$ °C. At ambient temperature 30.0 °C—the temperature in the upper soil layer is higher than atmospheric

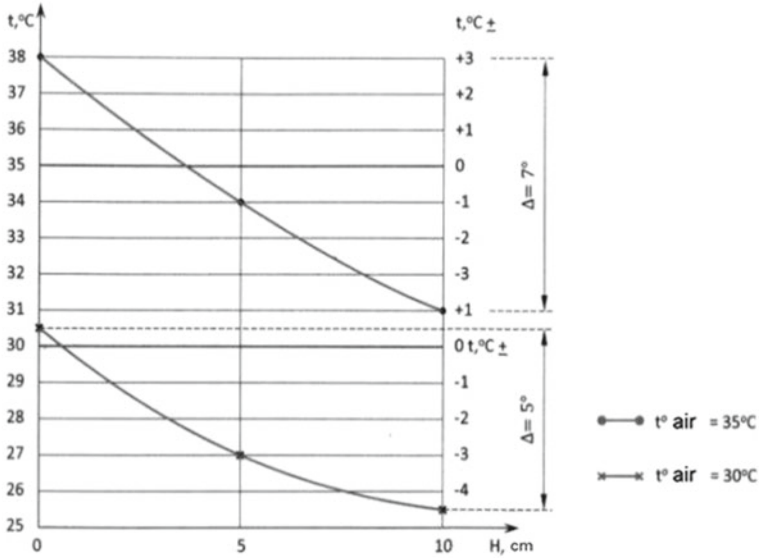

Fig. 4. Influence of the state of the soil surface (without shelter, shelter with straw 5 cm and 10 cm thick) and air temperature on the soil temperature t °C in the root layer 0–10 cm.

at the moment by 0.50 °C on an open surface, lower by 3.0 °C at 5.0 cm of cover with straw and below by 4.50 °C with 10 cm of cover with straw, that is, a—уменьшение температуры почвы составляет Δ = 5.0 °C. Against the background of high, non-chopped grain stubble or stalks of sunflower, or corn, the "Strip-Till" technology is highly effective, according to which the ripper-fertilizer passes over the compacted plant residues, cutting through furrows 0.20–0 wide, 25 m, cultivating the soil in them and embedding the necessary mineral and other fertilizers in two layers. The furrow into which row crops are sown as a rule: corn, soybeans, sunflower has a dark color, it warms up well in spring, providing friendly, early shoots. The row spacings, covered with a thick layer of plant residues, protect the soil from overheating and unproductive moisture loss [8, 9].

Research on the design of headers for stripping ears during harvesting. The new direction in agriculture "Strip-Till" (strip farming) requires leaving stubble without mowing, which corresponds to the technology of harvesting by the "stripping" method [10, 11]. In Samara GAU, more than 15 designs of headers for stripping have been developed and patented with a certain simplification of their design in comparison with mass-produced ones due to an additional adapter, which (Fig. 5) is a hollow drum with stripping devices fixed on it with comb of teeth of various shapes [12]. The adapter is installed on the reinforced sidewalls of the header in bearing housings and on the left side has a hydraulic drive from a special hydraulic motor with the ability to rotate up to 600 rpm.

For work, we have chosen the GShM-50 hydraulic motor, which showed good results in research. The header prepared for the wholesalers was aggregated with the SK-5 "Niva" combine. The research was carried out in the fields of the Volga Research Institute of Breeding and Seed Production during the harvesting by the "stripping" method of

Fig. 5. Stripping headers: **a** Samara SAU; **b** Ozone ZhO-6 (Penza); **c** "Slavyanka UAS-6"; **d** Shelbourne

spring wheat "Kinelskaya-59" and barley "Volgar". Theoretical and experimental studies were based on picking up and grabbing an ear of grain crops with a special toothed comb fixed on a hollow drum in the amount of 5 pieces around the circumference with installation through 72° [13]. The drum revolutions were regulated by supplying oil to the GMSh-50 hydraulic motor (right rotation) from 250 to 500 rpm. The toothed comb "combed" the ears during its rotation or separated the grain from the ear, or tore the ear from the stalk and directed the grain-ear mass to the header auger and along the inclined chamber to thresh it into the combine. After the passage of the combine, the stalks (straw) remained undamaged in the field; grain and ears (individual ears without grain remained on the stalks 1.5–8%) almost all (90–95%) went to threshing, which indicates the working capacity of the header and reliable provision of the harvesting process and field preparation for the Strip -Till [14–17].

3 Conclusion

The significant demand by the world's population for food products and their production in the required quantities with high quality are due to the level of development of agricultural production and its ability to withstand unfavorable natural factors and, above all, droughts. With projected global warming, the problem is exacerbated. In this connection, research is required to improve and introduce modern energy-resource-moisture-saving technologies that reduce the negative consequences of natural factors.

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Results of Experimental Studies of Pneumatic Threshing of Ears with Subsequent Separation of Fractions

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Abstract. At present, the problem is a significant injury to the grain during the threshing process. Therefore, it is necessary to develop a low-traumatic method of separating grain from the ear, excluding the impact on it. It is proposed to use the action of a jet of air on the ear, leading to its rolling over the deck of the threshing device and causing abrasion, resulting in the release of grains. The aim of the research is to study the process of pneumatic threshing of ears and to assess the influence of its parameters on the isolation and injury of grain, as well as on its separation. There was used a pneumatic threshing device, in which threshing is carried out with the interaction of the ear and the deck, carried out under the alternating action of high and low air pressure created by the rotor blades. The pneumatic threshing method ensures less trauma to the grains. The proportion of grains with damage to the endosperm in the pneumatic threshing method is 10–12%, and the proportion of grains with damage to the embryo is 5% less than in the traditional method. The reduction of injury is achieved by the fact that the grains are not exposed to the impact of the working bodies. The rational range of the linear speed of the rotor blades of the threshing device, which provides minimal injury to the grains, is 13.5–15 m/s. As a result of pneumatic threshing, the ears are effectively separated into fractions of whole grain and a light non-grain part, which can be used as feed. The use of the pneumatic threshing method will reduce the injury to grain of spike crops, which will increase the yield of high-quality seeds.

Keywords: Pneumatic · Threshing chamber · Subsequent separation

1 Introduction

Currently, an urgent problem is injury to grain in the process of threshing ears of grain crops, caused by mechanical damage as a result of the shock impact of the moving working bodies of threshing devices [1, 2]. This negatively affects the quality of the seeds [3]. As a result of studying the process of impact threshing, the researchers came

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to the conclusion that this method has exhausted the possibilities for improvement, since when using it it is impossible to avoid the impact that traumatizes the grain [3–5].

Less traumatic is the currently widely used method of threshing by rotary threshing-separating devices [6], in which the grains are released as a result of the abrasion of ears when they move between the working surfaces forming the threshing gap, and impacts on them of the protruding elements of the rotor [7, 8]. As a result of intense contact with the working surfaces of the rotor, the grains are also injured, although to a lesser extent than in a traditional threshing apparatus [3, 7]. Thus, rotary threshing devices provide a reduction in grain injury, but not enough to obtain high-quality seeds [9].

In recent years, the harvesting of grain crops by the stripping method has become widespread, during which ears without stalks enter the threshing device of the combine [7, 10]. As a result, the threshing apparatus of the harvester operates with a low load, which leads to an increase in grain injury [11, 12].

These circumstances necessitated the development of a new low-traumatic method of separating grain from an ear [13].

A promising method of threshing is the destruction of ear scales or weakening of their connection with the caryopsis. In this case, for the separation of grains it is better to use not an impact, but a contact effect on the ear [14]. It is proposed to use the air flow created in the threshing chamber for moving ears and contacting them.

The aim of the research is to study the process of pneumatic threshing of wheat ears and assess the influence of its parameters on the isolation and injury of grain, as well as on the separation of grains.

2 Materials and Methods

To study the pneumatic method of separating grain from an ear, an experimental installation was created, which is a pneumatic threshing device (Useful model RU 195355 "Threshing device for breeding work"), in which threshing is carried out with the interaction of the ear and the deck, which occurs under the action of alternating high and low pressure air generated by the rotor blades (Fig. 1), and the separation of the grain heap is due to the removal of the light fraction into the reduced pressure chamber.

The threshing device includes a cylindrical body containing a threshing chamber and a rotor with blades in the form of plastic plates bent in the direction of rotation. Inside the body there is a plastic deck, the surface profile of which consists of periodically alternating protrusions and depressions. A reduced pressure chamber is placed between the inner surface of the body and the deck. A gap is left between the edge of the blade and the projections of the deck. The reduced pressure chamber is connected to the settling chamber. A centrifugal fan creates the reduced pressure in them.

During the operation of the threshing device, the ears are carried away by the vortex airflow created by the rotor blades and rotate along the deck surface. The threshing of ears occurs when the ear and the deck interact under the alternating action of high and low air pressure created by the blades. When the spike interacts with the projections and depressions of the deck, its abrasion occurs, as a result of which the connection of the caryopses with the spike is destroyed and their release. The alternation of the action of increased and reduced air pressure on the ears occurs continuously until the destruction

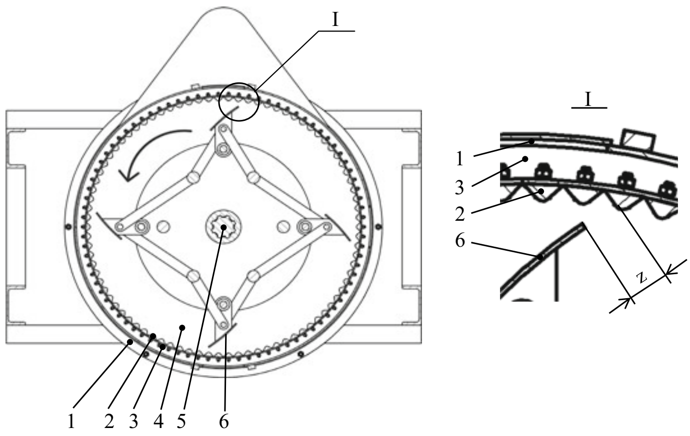

Fig. 1. Diagram of a pneumatic threshing chamber: 1—body; 2—deck; 3—reduced pressure chamber; 4—threshing chamber; 5—rotor; 6—blade; z—blade-to-deck clearance

of the ear and the release of all grains from it. Thus, in the process of threshing, the grains are practically not exposed to the direct impact of the movable working body (blade). The grain separated from the ears under the action of gravity through the sieve enters the unloading chamber and then into the collection container. The separation of the non-cereal part of ears and small particles of crushed grain occurs in a reduced pressure chamber, from where they are sucked into the outlet and enter the settling chamber, where they are deposited in containers for collecting the light fraction.

5 series of experiments were performed, in each of which a certain value of the rotor speed and, accordingly, the linear speed of the blade movement was set by a frequency converter. The frequency of rotation of the rotor was changed in the range of 402–732 rpm (6.7–12.2 Hz), the linear speed of the movement of its blade, respectively, was changed in the range of 13.5–24.6 m/s. Each experiment was performed in triplicate. After the end of the experiment, the isolated grains were examined using a stereomicroscope and the presence of injury was determined, namely, grain crushing, damage to the embryo and endosperm [15, 16]. In addition, the presence of an admixture of a light non-cereal fraction of ears in the isolated grain was determined, for which it was manually sorted and the resulting fractions were weighed.

In this study, the efficiency of the threshing method was evaluated in terms of reducing grain injury, the issues of threshing device productivity were not considered.

3 Results

As a result of the experiments, it was found that the process of pneumatic threshing of winter wheat ears was successful and gave satisfactory results. It has been established that the separation of grains from an ear during pneumatic threshing occurs during the contact interaction of the ears with an uneven deck surface.

The effect of the linear velocity of the blades on the value of the proportion of grain with damage to the embryo and the proportion of crushed grain was studied (Fig. 2).

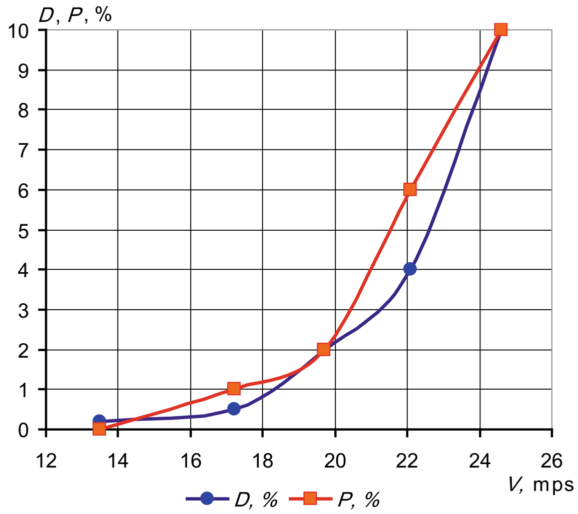

Fig. 2. Dependence of the proportion of grains with damage to the embryo and the proportion of crushed grain on the linear velocity of the blade: *V*—rotor blade linear speed, *D*—fraction of crushed grain, *P*—proportion of grain with damage to the embryo

It was found that the maximum values of the proportion of damaged grains are observed at a maximum linear speed of the rotor blades of 24.6 m/s. With a decrease in the speed of the blades, the proportion of injured grain also decreases. At a minimum blade speed of 13.5 m/s, the proportion of grain with damage to the embryo and the proportion of crushed grain are reduced to almost zero.

Based on the data presented in Fig. 2 graphical dependencies, it can be concluded that the range of linear values of the blade speed of 13.5–20 m/s is the most favorable for low-trauma grain threshing. It is irrational to use lower values of the blade speed, since in this case effective contact and interaction of the ear and the deck will not be ensured due to the insufficient value of the increased air pressure created by the rotor blades.

As a result of processing the experimental results, it was found that the proportion of grains with damaged endosperm increases with an increase in the speed of the rotor blades (Fig. 3).

The minimum value of the proportion of grains with damaged endosperm was obtained at a blade speed of 13.5 m/s and amounted to 23%. In increasing the blade speed from 13.5 to 20 m/s, the proportion of grains with damage to the endosperm increased from 23 to 45%. The proportion of grains with more than 30% endosperm damage is high; therefore, the rational range of the linear velocity of the blade movement is 13.5–15 m/s.

It was found that as a result of pneumatic threshing there is an effective separation of grain and light non-grain fraction of ears (Fig. 4).

It was found that with a decrease in the linear speed of the rotor blade, the proportion of light non-grain particles not separated during threshing in the total mass of the separated grain increases, reaching a maximum of 5.5% at a minimum speed of 13.5 m/s. With an increase in the linear speed from 13.5 to 24.6 m/s of the blade, the proportion

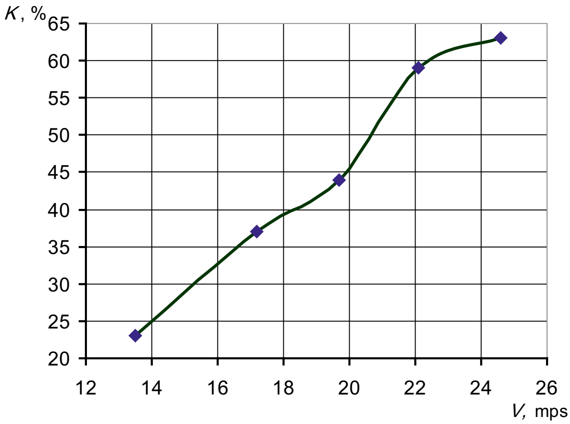

Fig. 3. Dependence of the proportion of grain with endosperm damage on the linear velocity of the blade during pneumatic threshing of winter wheat ears: *K*—proportion of grains with endosperm damage; *V*—rotor blade linear speed

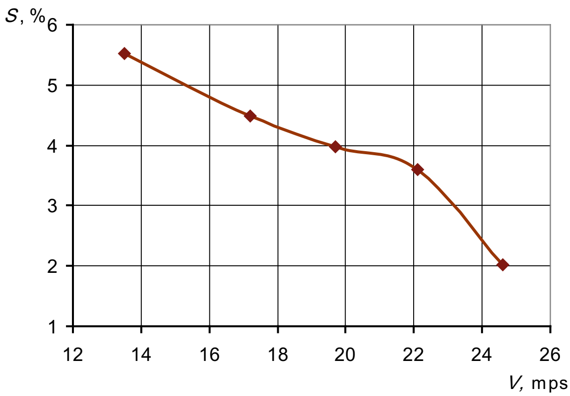

Fig. 4. Dependence of the proportion of the light non-grain fraction in the total mass of the isolated grain on the linear speed of the blade: *S*—proportion of light non-grain fraction in the total mass of isolated grain; *V*—rotor blade linear speed

of the light fraction decreases from 5.5 to 2%. These values are acceptable. An increase in the proportion of unselected light particles up to 5.5% with a decrease in the speed of the blades is compensated by the significant decrease in the proportion of injured and crushed grain occurring at the same time.

4 Discussion

Comparison of the values of the proportion of injured and crushed grain during pneumatic and traditional combine threshing showed that it is the pneumatic method of threshing that reduces grain injury. In particular, the proportion of grain with damage to the endosperm in the pneumatic threshing method is 10–12% less than when threshing with a combine harvester. The proportion of crushed grain during pneumatic threshing corresponds to its proportion after threshing with modern combines, and the proportion of grains with damage to the embryo is 5% less. It should be noted that at a minimum speed of the blades of 13.5 m/s, the embryo is not injured and the grain is fragmented practically. This allows you to significantly increase the safety and germination of seeds.

Based on the results of the experiments, it was concluded that the rational range of the linear speed of the rotor blades is 13.5–15 m/s. It is irrational to use lower speed values, since then the effective interaction of the ear and the deck is not ensured due to the insufficient value of the increased air pressure created by the rotor blades.

But the proportion of grain with damaged endosperm, although less than with traditional threshing, is quite significant—23% even with a minimum blade speed of 13.5 m/s. This requires a certain improvement in the threshing device for the implementation of the pneumatic threshing method [17–19].

The reduction of injury to the grains in the process of pneumatic threshing is explained by the fact that they are practically not exposed to the direct impact of the working bodies of the threshing device, in this case, the rotor blades. The separation of grains from the ear occurs during the contact interaction of the ears with the relief surface of the deck under the action of an airflow, while they are subjected to less mechanical stress than in traditional threshing devices with percussion working bodies. Reducing grain injury is also ensured by the fact that the surfaces of the blades and the deck are made of polymer material.

It has been established that as a result of pneumatic threshing, the ears are effectively separated into fractions of whole grain and light non-grain part. However, reducing the linear speed of the rotor blades, which is effective in reducing grain trauma, results in a slight increase in the light grain fraction in the isolated whole grain. This problem can be solved by including a unit for additional separation of grain separated in the threshing chamber into the pneumatic threshing device.

5 Conclusion

Comparison of the proportion of injured and crushed grain with the proportion of damaged grain during traditional combine threshing has shown that the pneumatic threshing method provides a reduction in grain injury. The reduction of injury is achieved by the fact that the grains in the process of threshing are not directly exposed to the impact of the working bodies of the threshing device [20, 21].

The rational range of the linear speed of the rotor blades of the pneumatic threshing device, which provides minimal injury to the grains, is 13.5–15 m/s.

As a result of pneumatic threshing, there is an effective separation of ears into fractions of whole grain and light non-grain part, a part that can be used as feed for farm animals.

The use of the pneumatic threshing method and the corresponding threshing device will reduce the injury of grain in ear crops, which will increase the yield of high-quality seeds.

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Encryption of Images Using the Modified AES Algorithm and Its Comparison with the Original AES

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Abstract. In today's world, optimization is what needs to be talked about. The explosive growth of the Internet and communication technologies has made the widespread use of images inevitable. The special characteristics of the image, such as high bit rate with limited bandwidth, redundancy, bulk capacity, and correlation between pixels, make standard algorithms unsuitable for image encryption. As cybercrime has reached an all-time high, pre-encryption of data is required for protection. From personal data traded on the dark web to application vulnerabilities, our data is constantly monitored, making encryption paramount. When it comes to encryption, AES (Advanced Encryption Standard) is the gold standard for security. It is a subset of the Rijndael block cipher, which uses a 128-bit data block and a 128-bit, 192-bit and 256-bit key size, giving three different versions of AES, namely AES128, AES192, and AES256. It is a symmetric encryption algorithm that uses the same key for encryption and decryption. The article proposes an algorithm based on a modified AES key extension, in which the encryption process is a bitwise exclusive or an operation of a set of image pixels together with 128-bit key that changes for each set of pixels.

Keywords: AES key extension · Image encryption · Modified algorithm · Image privacy

1 Introduction

Digital image is defined as two-dimensional rectangular array. The elements of this array are designated as pixels. Each pixel has intensity value (digital number) and a location address (row, column). Many applications, such as military image databases, confidential video conferencing, personal online photo albums, medical imaging systems, and cable TV, require the fast and efficient way to encrypt images for storage and transmission. Numerous encryption methods have been proposed in the literature, and the most common way to protect large media files is by using conventional encryption methods.

The AES cipher is a block combined cipher and uses the so-called "square" architecture, i.e. all transformations are performed within one square. Such a square has a size of 16 × 16, is filled in columns and is called a matrix of states [1–4].

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https://doi.org/10.1007/978-3-030-81619-3_17

2 Mathematical Model and Solution Method

It should be said that the AES algorithm operates with bytes, i.e. numbers from 0 to 255, with all bytes being a finite Galois field GF (28) constructed using the irreducible polynomial

$$m(x) = x^8 + x^4 + x^3 + x + 1 \tag{1}$$

When performing operations of addition and multiplication, remember that they must be performed in this field. Addition can be performed as bitwise XOR between the elements of the field, and with multiplication the situation is somewhat more complicated: the numbers must be represented as polynomials of degree 7, then these polynomials must be multiplied with each other according to the usual rules, and then the remainder of division by $m(x)$ must be found. The corresponding number will be the result of multiplication.

The key size in AES can be 128, 192 or 256 bits. Depending on this version of the algorithm, they are designated AES-128, AES-192 and AES-256. The number of encryption rounds also differs—10, 12 and 14 rounds, respectively.

The data block encryption scheme is shown in the Fig. 1.

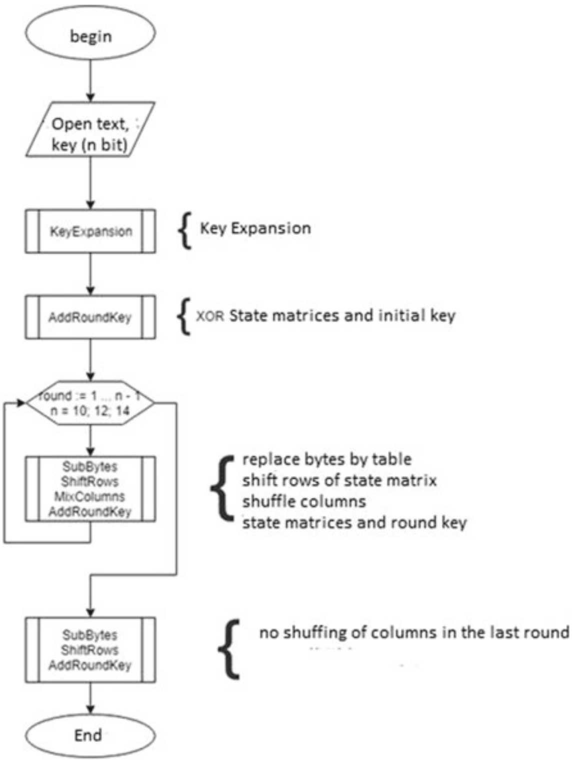

Fig. 1. AES encryption scheme

In this diagram, KeyExpansion is key expansion procedure. The point is that the initial key is 16, 24, or 32 bytes long. This is not enough to encrypt a block in 10, 12 or 14 rounds. Accordingly, the key must be expanded [5].

The extension is as follows:

1. The initial key must be represented as a concatenation of bytes into words of 4 bytes. That is, in AES–128 these will be words (w_0, w_1, w_2, w_3), in AES-192 there will be 6 such words, and in AES-192-8;
2. Denote

$$k := len(key)//32, \tag{2}$$

   where len (key) is the length of the initial key;
3. In AES-128 and AES-192, receiving words w_i, where $i = [4; 43]$ and $[6; 52]$ is as follows:

   3.1 If $i(modk) \neq 0$, then $w_i = w_{i-1} + w_{i-k}$; Otherwise $w_i = t + w_{i-k}$, where

$$\mathrm{t = SubWord(RotWord(w_{i-1})) + Rcon_{i/k-1}} \tag{3}$$

   where RotWord and SubWord are analogs of the ShiftRows and SubBytes procedures (to be described later), but applied to one word; Rcon = {0 × 01000000, 0 × 02000000, 0 × 04000000, 0 × 08000000, 0 × 10000000, 0 × 20000000, 0 × 40000000, 0 × 80000000, 0 × 1b000000, 0 × 36000000}—the array of round constants;

4. B AES-256:

   4.1

$$If\,(imod8) \neq 0:$$

$$\mathrm{If(i\ mod4) \neq 0, \quad then\ w_i = w_{i-1} + w_{i-8}} \tag{4}$$

$$\mathrm{If(i\ mod4) = 0, \quad thenw_i\ = SubWord(w_{i-1}) + w_{i-8}}$$

   4.2 Else $w_i = t + w_{i-8}$,

$$\mathrm{t = SubWord(RotWord(w_{i-1})) + RCon_{i/8-1}}. \tag{5}$$

For decryption, a sequence of inverse transformations to the given ones is used, which turns out to be possible, since all operations performed in each round are reversible [6]. The decryption is shown schematically in the Fig. 2.

It should be noted that AddRoundKey transformation does not need to be inverted since XOR operation is inverse to itself.

Python contains the built-in module, thanks to which it is possible to encrypt data using the AES algorithm, but an independent implementation is preferable for training,

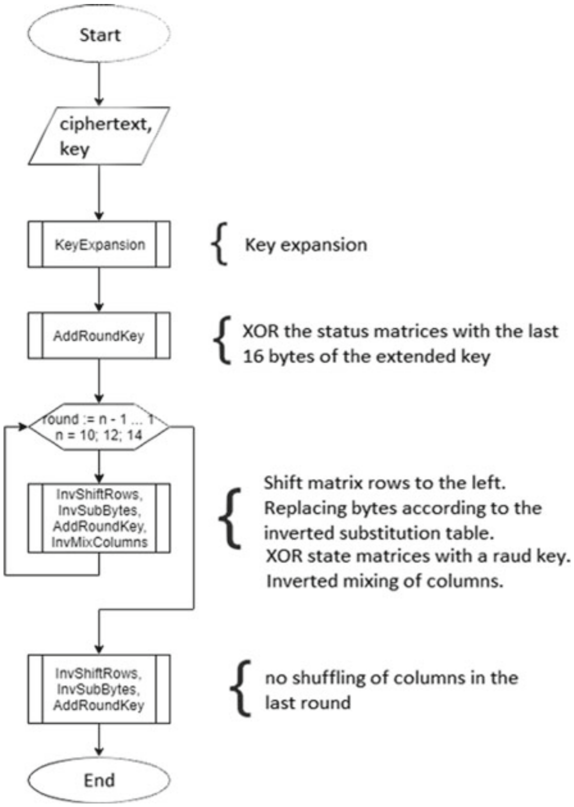

Fig. 2. AES decryption scheme

so it will be necessary to describe in the programming language all the functions used for encryption and decryption.

The properties of linear block codes are used in many applications. For example, the syndrome-adjacency uniqueness property of linear block codes is used in trellis shaping, one of the best-known shaping codes. The same property is used in sensor networks for distributed source coding [7, 8].

Any block ciphering in general is the law of mapping the set of input blocks of an original message to the set of ciphertext blocks. Moreover, this law is highly dependent on the private encryption key.

The block cipher is substitution cipher over the very large alphabet (tens and hundreds of bits). Potentially, complete correspondence table between input and output data can describe any encryption using the replacement method. However, in order to characterize only one mapping per 64-bit block (that is, an alphabet of 264 elements) you need

$$64 \times 2^{64} - 270 \tag{6}$$

memory bit. This mapping will only be applied for any one specific key value. Therefore, modern block cipher is the law that describes this transformation algorithmically.

There are always trade-offs with any kind of encryption. You could easily have the standard that is exponentially more secure than AES, but it would take too long for encryption and decryption to be of any practical use. In the end, the Rijndael block cipher was chosen by NIST for its all-round capabilities, including both hardware and software performance, ease of implementation, and security.

The US government went on five-year mission to evaluate various encryption methods to find a new standard that is secure. The National Institute of Standards and Technology (NIST) announced that it made its final choice in late 2001.

Their choice was a specific subset of the Rijndael block cipher with fixed block size of 128 bits and keys of 128, 192, and 256 bits. It was developed by Joan Damen and Vincent Ryman, two cryptographers from Belgium. In May 2002, AES was approved as US federal standard and quickly became the standard encryption algorithm for the rest of the world.

AES has three different key lengths. The main difference is the number of rounds that data goes through during the encryption process, 10, 12, and 14 respectively. In fact, 192-bit and 256-bit provide more security margin than 128-bit.

In today's technological landscape, 128-bit AES is sufficient for most practical purposes. Highly sensitive data processed by individuals with extreme threat level, such as TOP SECRET documents controlled by the military, should probably be processed using 192 or 256-bit AES cyphering.

It can use 192 or 256-bit encryption where it possible. In most cases it is not necessary. It has not come without cost: the additional four rounds of 256-bit encryption make it about 40% less efficient.

AES is based on the design principle known as substitution-permutation network and is effective in both software and hardware. Unlike its predecessor DES, AES does not use the Feistel network. AES is a variant of Rijndael with a fixed block size of 128 bits and a key size of 128, 192, or 256 bits. In contrast, Rijndael is specified with block and key sizes that can be multiples of 32 bits, with a minimum of 128 and a maximum of 256 bits.

AES operates on a 4 × 4 high order byte array called state. Most AES calculations are done in a specific final field.

For example, 16 bytes: $b0$, $b1$, ..., $b15$ are shown in the Fig. 3.

$$\begin{bmatrix} b_0 & b_4 & b_8 & b_{12} \\ b_1 & b_5 & b_9 & b_{13} \\ b_2 & b_6 & b_{10} & b_{14} \\ b_3 & b_7 & b_{11} & b_{15} \end{bmatrix}$$

Fig. 3. Representation as two-dimensional array

The key size used for the AES cipher determines the number of rounds of transformation that transform the input file, called plaintext, into the final output file, called ciphertext. The number of rounds is as follows:

- 10 rounds for 128-bit keys.
- 12 rounds for 192-bit keys.
- 14 rounds for 256-bit keys.

Each round consists of several processing steps, one of which depends on the encryption key itself. A set of reverse loops is used to convert the ciphertext back to the original plaintext using the same encryption key [8].

Several cryptosystems such as data encryption, steganography, digital signature have been proposed to enhance the security of secret images. However, one of the common disadvantages of these methods is their centralized storage policy, when the entire protected image is usually stored on single storage medium. If an attacker discovers anomaly in the storage medium on which the protected image is located, he or she can intercept it, try to decrypt the secret inside, or simply destroy the entire storage medium, and once the storage medium is destroyed, the secret image will also be lost forever.

3 Proposed Algorithm

The algorithm is based on the MAES key expansion method [9].

Now let's look at the modified key expansion technique. AES key extension. Changes:

```
pth=im13;

pt = hex2dec(pth);
keyh = {'12' '4e' '15' '16' '28' 'ae' 'd2' 'a6'...'ab' 'f7' '15' '88' '09' 'cf' '4f' '3c'};
key = hex2dec(keyh);
s = aesinit(key); %inserting key in a image
ii=0;
% ----------------------------------------------------------------------
% ECB test of AES-128
ct = aes(s, 'enc', 'ecb', pt);% encoding of image
enc_time=toc(tstart);
for i=1:s11(1)
for j=1:s11(2)

ii=ii+1; ct1(j,i)=ct(ii);
end
end
ct1=uint8(ct1);
```

Modifications to AES (Key Exception).

Several changes made to the aforementioned key expansion process improve the quality of the encryption as well as amplify the avalanche effect in the resulting cipher image.

```
%%
pth=im13;
pt = hex2dec(pth);
keyh = {'12' '4e' '15' '16' '28' 'ae' 'd2' 'a6'...'ab' 'f7' '15' '88' '09' 'cf' '4f' '3c'};
key = hex2dec(keyh);
s = aesinit(key); %inserting key in a image
ii=0;
% % ECB test of AES-128
ct = aes(s, 'enc', 'ecb', pt);% encoding of image
 for i=1:s11(1)
for j=1:s11(2)
ii=ii+1; ct1(j,i)=ct(ii);
end
end
ct1=uint8(ct1);
pt2 = aes(s, 'dec', 'ecb', ct);
 ii=0;
for i=1:s11(1)
for j=1:s11(2)
ii=ii+1;
pp1(j,i)=pt2(ii);
end
end
```

Steps involved:

1. Key selection: the sender and receiver agree on 128-bit key.
2. This key is used to encrypt and decrypt images. This is a symmetric key encryption method, so they must transmit this key in a secure way. The key i presented in the form of blocks k [0], k [1]… k [15]. Where each block is 8 bits long

$$(8 \times 16 = 128\,\text{bits}). \tag{7}$$

3. Multiple Key Generation: The sender and receiver can now independently generate the keys required by the process using the modified AES key extension method described above. This is a one-time process; these extended keys can be used for future messages any number of times until they change their initial key value.
4. Encryption: is done in gaps where we process 16 pixels in each span. We do two XOR operations and subbyte conversion for each set of pixels. Since we are doing two XORs using our extended key for each set of pixels, it is not possible to get the key from the plain image and the encrypted image, and we also use the s-box values used in AES to improve non-linearity. Two XOR or Nor operations result in key disclosure for decryption purposes.
5. Decryption: The decryption process is similar to encryption, but we use the reverse subbyte conversion and also the reverse XOR order using the extended key.

4 Results of Research

As result of the obtained measurements, you can project them in the Fig. 4 (Table 1).

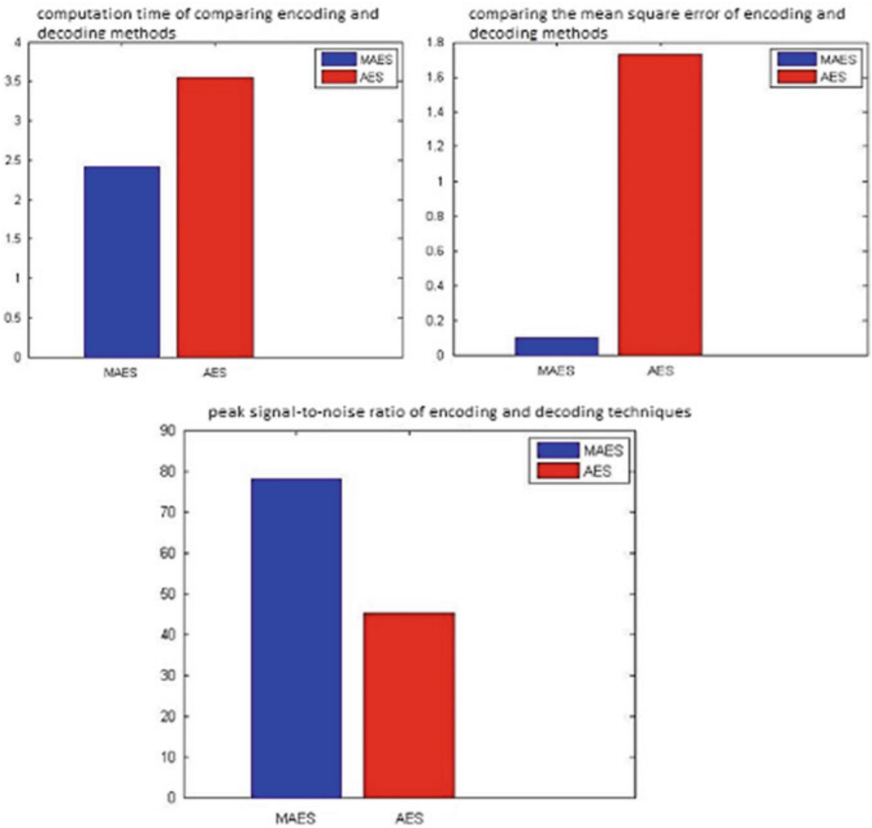

Fig. 4. Side-by-side comparison of AES and MAES algorithms

5 Discussion and Conclusions

This article proposed a new modified version of AES to develop a secure symmetric image encryption method. AES has been extended to support an image encryption keystream generator that can address the textured zones problem found in other known encryption algorithms. A detailed analysis showed that the new scheme provides a high level of security and can be easily implemented both in hardware and software. The keystream generator has an important impact on encryption performance [10–15].

Table 1. Analysis

Algorithm AES	Algorithm MAES
Noise: 69397.000000 Root mean square error: 1.734925 PEAK: 255.000000 Peak signal-to-noise ratio: 45.737997 NC: 0998100 Encoding time: 34112637 Decoding time: 4460517 Entropy: 5114933 Total execution time 43.058996	Noise = 0 Root mean square error = 1.0000e-003 PEAK = 255 Peak signal ratio/noise = 78,1308 Total elapsed time … 0.5.641608

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Post-Quantum Encryption Scheme with Supersingular Isogenies

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Abstract. This article discusses the questions related to the modification of SIDH (Supersingular Isogeny Diffie-Hellman Key Exchange) cryptoalgorithm. SIDH is a post-quantum algorithm which can be used to establish a shared secret key between two parties. Since several quantum attacks have been discovered recently, classical Diffie-Hellman algorithm is considered insecure and SIDH has become a much better alternative. Article provides a mathematical model of the algorithm with necessary definitions and formal description of the key exchange process. Possible attacks against SIDH are also discussed with detailed review of existing methods that can be used to prevent them. The most effective attack against SIDH is GPST attack that was discovered in 2017. Its formal model is examined with exploring necessary adjustments to make this attack ineffective. Based on this result, a modification which ensures security against the GPST attack is implemented. The article contains a description of the implementation with samples of its interface. Performance of the implemented software is estimated by the Mann-Whitney U-test.

Keywords: Quantum computer · Information security · Encryption

1 Introduction

For several decades, more and more powerful quantum computers have been actively developed and created, which forces scientists in many countries to modify and develop new algorithms for cryptographic protection of information.

The development of quantum technologies has brought numerous innovations and this fact has a significant impact on modern cryptography. Due to the advent of quantum computers, algorithms used ubiquitously in the past have become vulnerable to recently discovered quantum attacks. Therefore, they cannot ensure security if cryptanalyst has an access to a quantum computer and completely different algorithms should be employed in order to withstand quantum attacks. In this article, one of these modern post-quantum algorithms—Supersingular Isogeny Diffie-Hellman Key Exchange (SIDH) will be considered.

The subject of research is the modification and algorithmic complexity of the SIDH algorithm development. It is the reason for the relevance of this topic investigation.

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The purpose of research is to develop the effective post-quantum SIDH algorithm with modification that can withstand complex quantum attacks. In accordance with intended purpose the next objectives of investigation has been defined:

Investigation of the SIDH algorithm and the attacks to which it is subject.

1. Development of mathematical model for modifying the SIDH algorithm.
2. Implementation of the software based on SIDH algorithm and its modification.
3. Comparison and development of the modification with the existing algorithm.

Description of SIDH algorithm Scientists Luca De Feo, David Jao and Jeremy Plutt developed the SIDH algorithm (Supersingular Isogeny Diffie-Hellman Key Exchange) in 2011 [1–8]. The main advantage of Diffie-Hellman protocol using supersingular isogenies is the smaller key size, in comparison with other post-quantum algorithms, such as modifications of the McElice cryptosystem or lattices cryptography. This allows considering this algorithm promising and able to replace the previous modifications of Diffie-Hellman protocol.

The problem of computing isogenies can be formulated as follows: for some finite field k and two supersingular elliptic curves E_1 and E_2 defined over this field and for which $|E_1|=|E_2|$, the isogeny $f : E_1 \to E_2$ is calculated.

Various attacks have been proposed against the SIDH algorithm, but none of them allow an attacker to crack the algorithm in an acceptable time (even the most effective attacks have exponential complexity) [9–11].

GPST attack is one of the most effective attacks against the SIDH. It was proposed in 2017 and is named after the scientists Galbraith-Petit-Shani-Ti. This attack is based on the using of "oracle"—the function that allows determining the solvability of certain problem based on input data. This function can be written as the following expression:

$$O\big(E, R, S, E'\big) = 1,$$

$$if\ j(E/h[a_1]R+[a_2]S_i) = j\big(E'\big),\ otherwise\ 0.$$

where E, E′ correspond to two supersingular curves, and R, S are some points on the curve E. Values a_1, a_2 are Alice's secret key parameters [6, 7, 9, 10].

In practice, the implementing the oracle comes down to checking the fact that Alice and Bob were actually able to get the common key, since in this and only in this case, the equality of j-invariants will be fulfilled. No additional information is required for the attacker to carry out the attack. The GPST attack was discussed in detail in [7] and [9], which theoretically describes the modification that makes the attack ineffective.

Attack via third-party channels. When implementing this attack, the attacker uses information about the physical processes in the device that performs encryption and can get some information about the selected key.

To protect against the time attack, implementations are used in which the execution time is constant for various curve parameters [11, 12].

2 Mathematical Model and Solution Method

By analogy with classic Diffie-Hellman protocol, SIDH involves the interaction of two participants (Alice and Bob) in order to develop common secret key that they can use for further communication. The protocol consists of four steps.

1. Public key is define, which is large prime number p and supersingular curve E over F_p.
2. Alice and Bob choose two integers each and calculate isogenies, which are denoted by a and b, grounded on the basises of subgroups E and the selected numbers. These numbers chosen by Alice and Bob determine the private key of algorithm and must remain in secret.
3. Alice sends Bob values $E_a, a(P_B), a(Q_B)$, in turn, Bob sends Alice values $E_b, b(P_A), b(Q_A)$.
4. Based on the values obtained in step 3, Alice calculates Eab, and Bob calculates Eba.

It follows from properties of supersingular curves that $E_{ab} = E_{ba}$. This means that protocol was completed successfully, since both participants received the same secret value [13].

Elliptic curve is defined generally over certain field by equation of the third degree:

$$y^2 + a_1xy + a_3y = x^3 + a_2x^2 + a_4x + a_6 \tag{1}$$

The point at infinity also belongs to the set of points on the elliptic curve. If elliptic curves are defined over field whose characteristic is not 2 or 3.,the equation can be written in the canonical form (Weierstrass form).

$$y^2 = x^3 + ax + b \tag{2}$$

Cryptographic algorithms use the elliptic curves defined over finite fields.

Set of elliptic curve points forms the group. The group operation is point's addition, and the point at infinity plays the role of neutral element. Let points P, Q, R' are the points lying on one straight line, and R—is point symmetric to R' about the Ox axis. Then the relation is executed: $P + Q = R$, a $P + Q + R\prime = O$.

Accordingly, the sum of points P and Q is symmetric point to the point R, which lies on the one straight line with the points P and Q (Table 1).

Let us introduce the concept of isogeny between elliptic curves.

Let $E_1 = k(x; y) = \left(y^2 = x^3 + a_1x + b_1\right)$ and $E_2 = k(x; y) = \left(y^2 = x^3 + a_2x + b_2\right)$—two elliptic curves defined over the field F_q with field characteristic, different from 2 and 3.

Let $f : E_1 \to E_2$ rational mapping between elliptic curves, such that:

1. $f\left(O_{E_1}\right) = O_{E_2}$, where O is the point at infinity)
2. There is point P belonging to E1 such that $(P) \neq O_{E2}$.

When conditions 1 and 2 are met, the function f is called an isogeny.

Table 1. Mathematical description of protocol.

(1) Initial open parameters	
The trusted party publishes some prime number p (expressed as $l_{A^{eA}} l_{B^{eB}} f \pm 1$, where l_A, l_B—are distinct primes), and a supersingular elliptic curve E over F_p	
(2) Parameters calculation	
Alice	Bob
Calculate the basis $\{P_A, Q_A\}E\left[l_{A^{eA}}\right]$ Choose secret integers n_A, m_A Calculate the isogeny $a : E \to E_a$ with kernel $K_A = \langle n_A P_A + m_A Q_A \rangle$ Calculate $a(P_B), a(Q_B)$	Calculate the basis $\{P_B, Q_B\}E\left[l_{B^{eB}}\right]$ Choose secret integers n_B, m_B Calculate the isogeny $b : E \to E_b$ with kernel $K_B = \langle n_B P_B + m_B Q_B \rangle$ Calculate $b(P_A), b(Q_A)$
(3) Sending calculated values	
Send $E_a, a(P_B), a(Q_B)$ to Bob	Send $E_b, b(P_A), b(Q_A)$ to Alice
(4) Calculation of the total secret values	
Alice	Bob
Calculate the isogeny a_0: $E_b \to E_{ab}$ with kernel $\overline{K}$ $\langle [n_A]b(P_A) + [m_A]b(Q_A) \rangle$	Calculate the isogeny b_0: $E_a \to E_{ba}$ with kernel $\langle [n_B]a(P_B) + [m_B]a(Q_B) \rangle$
The transmitted secret value:$E_{ab} = E/\{K_B, b(K_A)\} = E/\{K_B, K_A\} = E/\{a(K_B), K_A\} = E_{ba}$	

Next, it is necessary to introduce the concepts of isogeny: degree (deg) and kernel (ker). Let E_1 and E_2 are two elliptic curves over the field k, and $f : E_1 \to E_2$ is isogeny, between them. Consider the field of rational functions for E_1 and E_2, in which $k(E_1) = k(x; y) = \left(y^2 = x^3 + a_1 x + b_1\right)$, and $k(E_2) = k(x; y) = \left(y^2 = x^3 + a_2 x + b_2\right)$,

The degree of isogeny is defined through the mapping $f* : k(E_2) \to k(E_1)$ as follows: $degf = \left[k(E_1) : f * \_k(E_2)\right]$.

Elliptic curve is called supersingular if $E[qr]\left(\overline{K}\right) = O$ for any $r \in [10, 14]$.

Velu formula is used to calculate isogeny:

$$\begin{aligned} X(P) &= x(P) + \sum x(P+Q) - x(Q);\ Q \in F - 0 \\ Y(P) &= y(P) + \sum y(P+Q) - y(Q);\ Q \in F - 0 \end{aligned} \tag{3}$$

where $E : y^2 + a_1 xy + a_3 y = x^3 + a_2 x^2 + a_4 x + a_6$—is elliptic curve,

$G(x; y) = x^3 + a_2 x^2 + a_4 x + a_6 - y^2 - a_1 xy - a_3 y$, F—subgroup E, X and Y—are functions that take all values of P belonging to E [14].

Flowchart of this algorithm is shown in the Fig. 1.

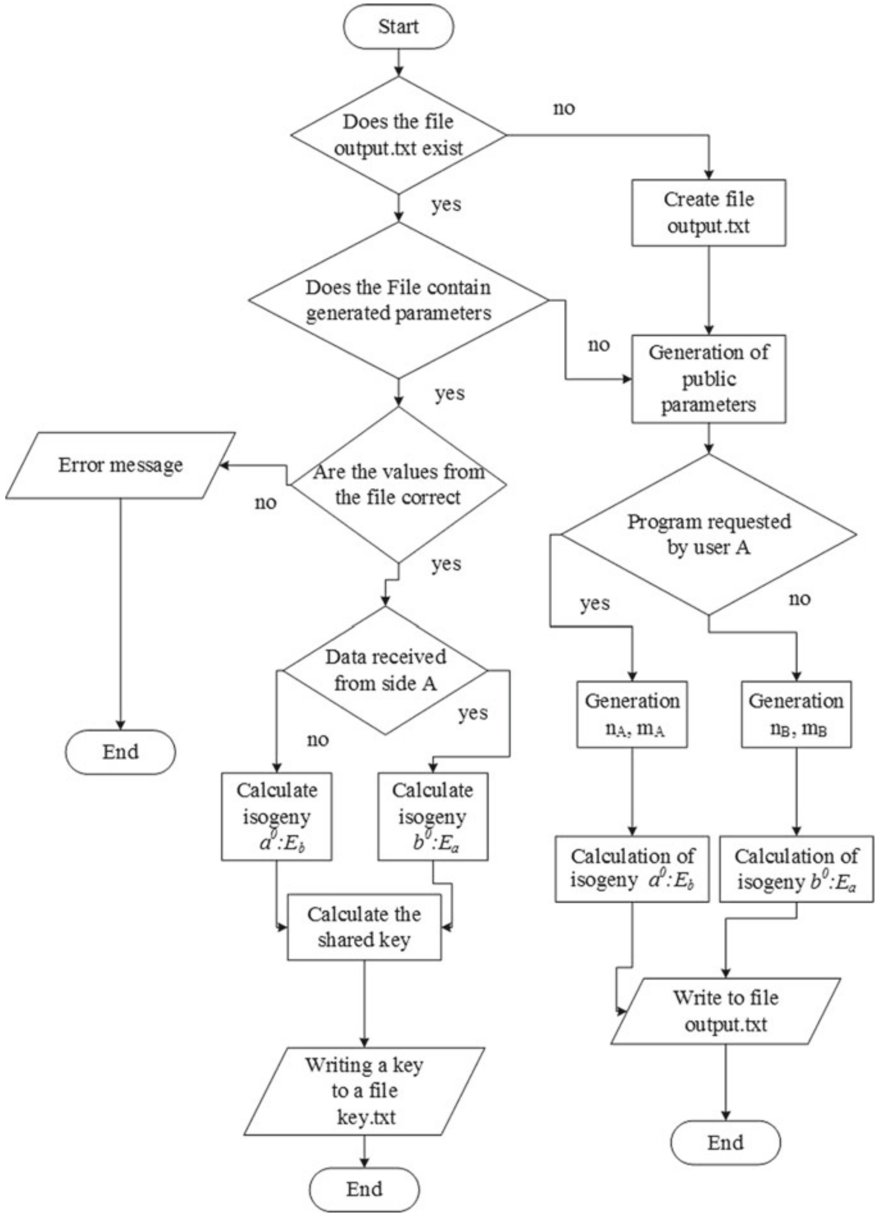

Fig. 1. Flowchart of SIDH algorithm

3 Results of Research

The implemented modification of the algorithm consists of two modules. The first module generates the prime number p and the parameters of the supersingular elliptic curve E, and then computes the isogeny. The second module receives parameters from the text files as input and calculates the shared secret. Then the shared key is written to a separate file and the program ends successfully.

To improve performance, elliptic curves belonging to the class of Montgomery curves are used. These curves are given by the equation:

$$By^2 = x^3 + Ax^2 + x, \ \ where \ B\left(A^2 - 4\right) \neq 0 \tag{4}$$

For Montgomery curves, there are algorithms for quickly performing operations on the points of the elliptic curve and calculating of isogenies [10].

The main feature of the modification from the classic version of algorithm is protection against the GPST (Galbraith-Petit-Shani-Ti) attack.

The classical algorithm uses the smallest values $l_A, l_B (l_A = 2\mu l_B = 3)$ to achieve the maximum performance. However, this allows a successful GPST attack. Our modification uses the values $l_A = 11$ and $l_B = 13$ because they provide quite high performance but make GPST attack ineffective at the same time [13–15].

Consider the GPST attack in which an attacker tries to guess the value that Alice sends. In this case, he needs to search in the event space of size:

$$\Omega\left(l^3(l+1)^3\right) \tag{5}$$

To increase security, it is assumed that the protocol will be executed X times in order to exclude the possibility of calculating the key for an attacker.

$$256 \approx \lg\left(l^{3x}(l+1)^{3x}\right) \tag{6}$$

The value of cryptographic strength of 256 bits is chosen on the basis that it is sufficient to ensure protection against Grover's algorithm.

With $l = 11$ the value $X = 12$, while with $l = 3$ it will be necessary to choose the value $X = 44$, which is inefficient in terms of performance. The choice of large l values significantly slows down the execution of one iteration of the protocol [12, 14, 16].

Software implementation of this algorithm is developed in two programming languages—Python and Java. The computational part of the program is implemented in the Java language, since it provides high performance and reliability of the developed program. The graphical interface of software tool is realized in Python. To generate parameters, it is necessary to click the "Generate parameters" button. The parameter values will be displayed, and saved into the file (Fig. 2).

If the data has been received already from another user, then it is automatically loaded from the file. When you press button, key is calculated and written to key.txt file (Fig. 3).

If the file has been modified illegal (unauthorized), then the developed program will display an error message (Fig. 4).

The scheme of interaction between two modules is shown in Fig. 5.

To compare the performance of the standard SIDH algorithm and its modification, the Mann-Whitney U-test is used. Table 2 presents the ranked list where Sample 1 corresponds to standard SIDH and Sample 2 corresponds to modification.

The critical value is 16 for $p <= 0.1$ and 23 for $p <= 0.5$. As a result of calculations, the value $U = 2$. This means that the differences between the implementations are in the zone of significance at the level of both 0.5 and 0.1 In percentage terms, the program generates parameters 15% faster.

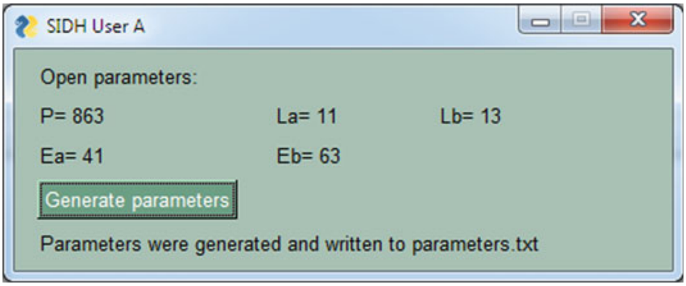

Fig. 2. Generation of parameters with saving to file

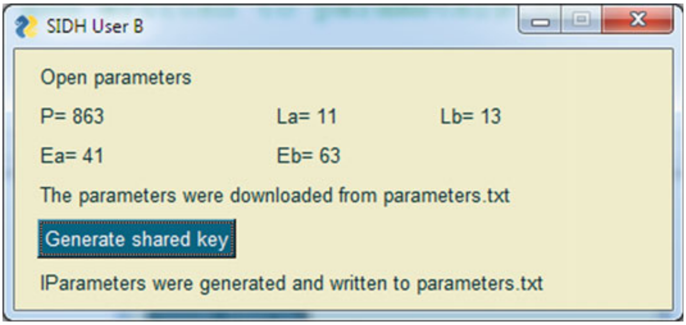

Fig. 3. Generating the shared key

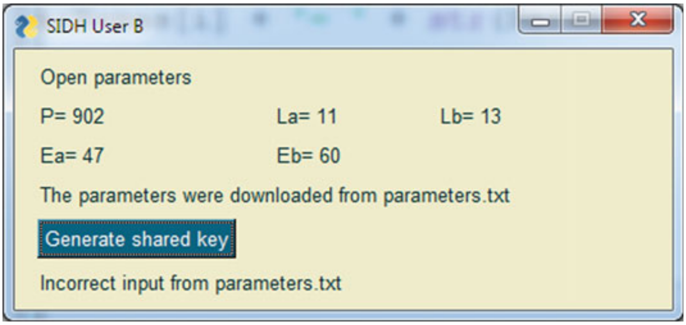

Fig. 4. Error handling

4 Discussion and Conclusions

As a result of investigation, the several purposes have been achieved:

- Theoretical description of SIDH post-quantum cryptography algorithm was considered;
- Modern attacks on the SIDH algorithm and ways to counter them have been studied;

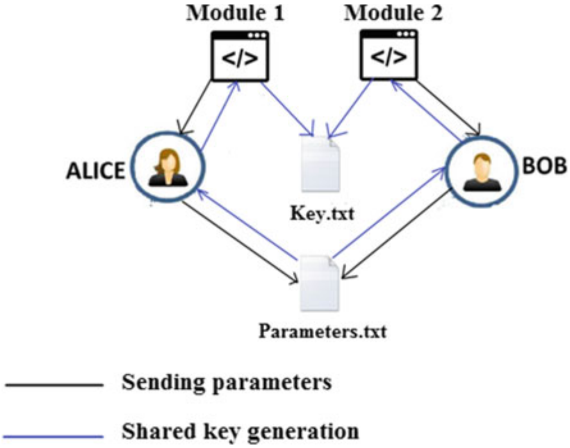

Fig. 5. Scheme of the SIDH algorithm

Table 2. Analysis using the Mann-Whitney U-test

No.	Sample 1	Rank 1	Sample 2	Rank 2
1	12.322	2	11.917	1
2	11.942	6	11.785	3
3	12.307	9	11.012	4
4	12.705	13	11.733	5
5	12.803	15	11.828	7
6	12.310	16	11.827	8
7	12.352	17	11.830	10
8	12.081	18	12.006	11
9	12.409	19	11.765	12
10	12.253	20	12.067	14

- GPST-resistant modification of SIDH post-quantum cryptography was implemented, which provides resistance to attack without losing;
- Software testing was carried out to assure that implementation works without errors;
- Assessment was carried out on the basis of the Mann-Whitney U-test performed to prove that there is no losing in performance in comparison to standard version of SIDH.

Based on the studies carried out, it can be concluded that the main advantage of the developed modification of the SIDH algorithm is its high cryptographic strength, which allows it to provide protection against modern quantum attacks, while the classical algorithm is vulnerable to the GPST attack. In order to protect against the GPST attack, a modification was developed that differs from the standard algorithm by choosing the initial open parameters. It has been experimentally proven that the modification meets the requirements of performance both for generating parameters and calculating a shared key [17, 18].

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Post-Quantum Cryptosystem of Niederreiter, Algorithm and Encryption Scheme: Modification and Optimization

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Abstract. The article discusses issues related to the post-quantum public key cryptosystem based on algebraic coding—the Niederreiter cryptographic system. Comparison of this cryptosystem with others that are also based on linear codes. The value, uniqueness, cryptographic strength, as well as the encryption algorithm and scheme of this system, its modification and optimization are considered. A description of the Niederreiter cryptosystem is proposed. The developed algorithm is a modification of the Niederreiter cryptosystem with improved cryptographic strength. To improve the software implementation, the proposed algorithm was also optimized, analytically analyzed and all its advantages were proved. The work of the embedded software with the Niddereiter cryptosystem and with the McEliece cryptosystem is shown. We performed a comparative analysis of the performance of cryptographic systems not only with each other according to the software algorithm, but also considered individual cases with Hamming codes and with Reed-Muller codes. Comparative characteristics of each of the cryptosystems, their advantages and disadvantages are shown.

Keywords: Post-quantum cryptography · Niederreiter cryptosystem · Cryptostability · Mceliece cryptosystem · Hamming codes · Reed-Muller code

1 Introduction

Information security in the modern digital world is based entirely on the resistance of modern cryptosystems to various cyberattacks. However, the emergence of powerful quantum computers in the modern world can lead to the number of significant problems for cryptosystems in general.

This research considers two post-quantum cryptosystems that are interconnected: the McEliece system and the Niederreiter system. Also Hamming and Reed-Muller codes in comparison with each other and with classical McEliece and Niederreiter algorithms are considered.

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The object of the research is Niederreiter cryptosystem.

The subject of investigation is Niederreiter cryptosystem and its possibility of modification taking into account all modern vulnerabilities.

The purpose of research is to develop effective post-quantum algorithm—the modification of Niederreiter cryptosystem with improved cryptographic strength, as well as optimization of the proposed algorithm, analyze and prove its advantages.

In accordance with set goal, the following tasks were identified—investigate the algorithm of the Niederreiter cryptosystem, develop the algorithm of modifying and optimizing Niederreiter cryptosystem, implement the software tool for Niederreiter and McEliece cryptosystems to compare their performance under the same conditions.

2 Mathematical Model and Solution Method

McEliece is public key asymmetric cryptosystem based on the theory of algebraic coding and developed in 1978 by Robert McEliece [1, 2]. The operation McEliece cryptosystem algorithm consists of several stages. At the first stage, random key generation algorithm is triggered, which outputs the public and private keys. At the second stage, the process of operation of random encryption algorithm begins, giving the cipher text in the output. The last stage will be the work of deterministic decryption algorithm, the output of which will be the original plaintext.

Key generation, this stage takes place in several steps. First, Alice chooses linear (n, k) code C over the Galois field GF(q) that corrects t errors. Note that this code must have efficient decoding algorithm. Next, Alice generates an (n – k) × n parity check matrix H of the code C. At the next step, the participant chooses random (n – k) × (n – k) nondegenerate matrix S over the field GF(q) and some n × n matrix of permutation P. Then Alice computes the (n – k) × n matrix Hpub = SHP. The public key is the pair (Hpub, t). The private key is the set $\left(s^{-1}, H, p^{-1}\right)$ [2].

Encryption. In this case, the messages are all n–vectors with coordinates from the field GF(q) with weight not exceeding t. That is, all errors that can be corrected by the selected code are considered messages.

Bob is going to send the message to Alice, where the public key is (Hpub, t). The encryption algorithm includes the following steps. First, Bob's message is presented as binary sequence m of length n with weight t. And Bob calculates the ciphertext using the formula:

$$c = mH_{pub}T \tag{1}$$

That is, the ciphertext in the Niederreiter cryptosystem is the noisy syndrome of the encrypted error vector.

Decryption. After receiving message *c*, Aliceshould do the following:

$$s = c(S^T)^{-1} = mP^T H^T S^T (S^T) = (mP^T)H^T = \hat{m}H^T \tag{2}$$

Note that, since P is the permutation matrix, the weight $\hat{m} = (mP^T)$ is identical to the weight m and does not exceed t. From this we conclude that the decoding algorithm for C is able to detect the error vector in accordance with the syndrome s [3, 4].

- Alice uses the fast decoding algorithm for the C code to find;
- Alice computes the message:

$$\hat{m}P^{-1} = mPP^{-1} = m \tag{3}$$

Hamming code—is the block code capable of detecting up to two simultaneous bit errors and correcting single bit errors. Reed–Muller code is the linear binary block code. It belongs to the oldest and possibly the most common code families. Reed-Muller codes generalize the Reed-Solomon codes and the Walsh-Hadamard codes [5]. List decoding also refers to Reed-Muller code. In coding theory, this method is alternative to unique decoding of error correction codes for large error rates. These properties make Reed-Muller codes especially useful in the developing probabilistically verifiable proofs.

When r and m are integers with $0 \le r \le m$, the Reed-Muller code with parameters r and m is denoted RM (r, m). When to encode the k-bit message where

$$k = \sum_{i=0}^{r} \binom{m}{i}, \tag{4}$$

the RM (r, m) code creates the codeword consisting of bits [6].

3 Results of Research

As can be seen from the description of Niederreiter algorithm, the following requirements must be met—improve cryptographic strength by improving key generation, explore Reed-Muller codes and Hamming codes [7].

This approach has the following advantages—optimized key generation, comparison and selection of the best cryptosystem with certain codes.

Key generation. In software implementation, we use 4 types of key generation—generation of random nondegenerate matrix S, generation of permutation matrix P, generation of the generating matrix, generation of private key [8].

Text encryption is based on the fact that by choosing cryptosystem, encryption algorithm will be executed in accordance with it. Niederreiter's algorithm consists in fact that initially it is necessary to enter the parameters for Reed–Muller or Hamming code. Based on them, the table of syndromes and errors is built. Having built the table, you need to calculate the public and private encryption keys. Having generated the public key, the process of forming the information vector and the separate vector t begins, after which it is encrypted and the cipher text is output [9].

Decryption. First, it need to decipher the vector. Then it is necessary to calculate syndrome for Hamming or Reed-Muller codes. Having received information vector, t information bits are extracted, after which source text is displayed in program interface [9].

Algorithm implementation. Python was chosen as programming language because it is still competitive, and has many advantages in comparison with others. Figure 1 shows block diagram of implemented graphical interface using standard tkinter module.

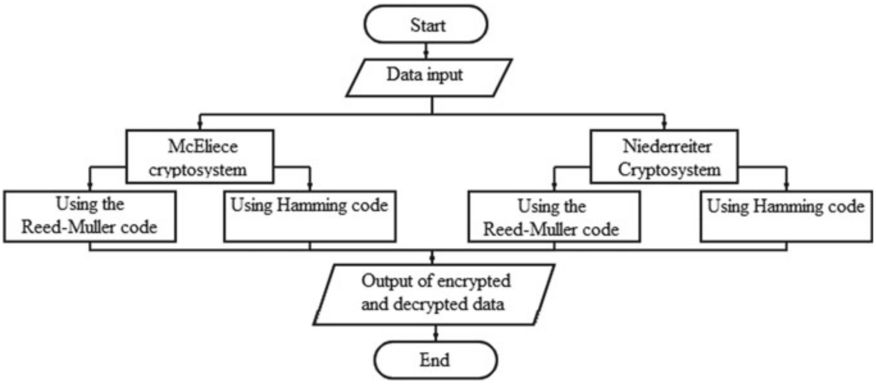

Fig. 1. Generalized block diagram of the graphical interface of the software tool

The software used standard libraries and tools to help the algorithm work, as well as work with time, which made it possible to implement "STOPWATCH" function.

Example of how the software works.

1. Open main.py file; window of software tool will open (Fig. 2).

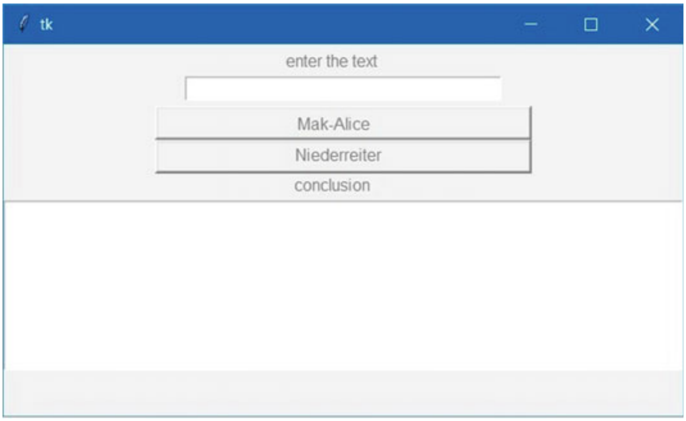

Fig. 2. The initial window of the software

2. Figure 3 shows the area for entering the message to be encrypted. After that, you need to select the cryptosystem with which the message will be encrypted.
3. One of the two codes used is selected by pressing one of the buttons (Fig. 4).
4. The output of the generated keys, the encrypted message in binary form, as well as the calculation of the information vector occurs inside the console.
5. At the end of cryptosystem, console displays the ciphertext translated into symbolic form, the decrypted text and the running time of algorithm.
6. Figure 5 shows the output field where encrypted and decrypted messages.

Fig. 3. Input of the message and selection of the used cryptosystem

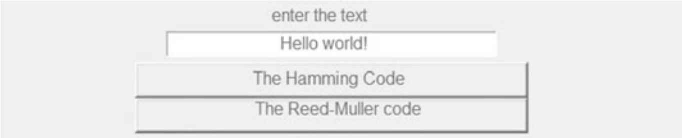

Fig. 4. The choice of the used code

Fig. 5. Output of final data to the graphical interface

Encrypted and decrypted messages are displayed in the window of tool, while the console displays all calculations performed during the operation of encryption algorithm [10, 11].

In order to be able to compare the two cryptosystems with modifications and understand their advantages, the "STOPWATCH" function was used, with the help of which the running time of each algorithm was tracked. Input data was entered into the program interface in the form of messages with different lengths. The first message had five characters, and then the length increased. With the help of these changes, changes in the speed of the algorithms are traced [12–15].

Table 1 shows the speed of classic Niederreiter cryptosystem and modifications with Reed-Muller and Hamming codes. The average value is also displayed using formula

$$\mathrm{x}_{\mathrm{av}} = \frac{x_1 + x_2 + \cdots x_n}{n} \tag{5}$$

Figure 6, the graph of the dependence of the operation time of the Niederreiter cryptosystems with the Reed-Muller code and the Hamming code and the classical Niederreiter cryptosystem on the length of the encrypted message.

Table 1. Comparison of the speed of cryptosystems using the "STOPWATCH" function

No.	The speed of the cryptosystem		The code used in the modification
	Niederreiter's modification (s)	Classic Niederreiter (s)	
1	2.174	0.414	Reed-Muller
2	2.527	0.781	
3	2.686	1.001	
4	3.080	1.367	
5	3.383	1.761	
	2.770	1.065	Average value
1	0.333	0.414	Hamming
2	0.463	0.781	
3	0.657	1.001	
4	0.880	1.367	
5	1.137	1.761	
	0.694	1.065	Average value

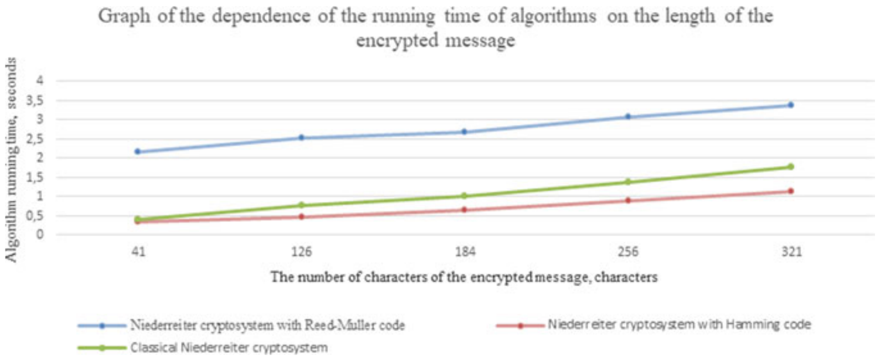

Fig. 6. Diagram 1

Table shows that modification in the form of Reed-Muller code works in 2.6 times slower; at the same time, its cryptographic strength is higher than the classical Niederreiter code. In the case of Niederreiter cryptosystem with Hamming code, it is opposite situation. When increasing cryptographic strength using this code, crypto-system's operating time increases. Noticeable that such system works in 1.54 times faster.

Figure 6 shows the difference in the running time of algorithms. The implementation of Niederreiter cryptosystem with Hamming code is the most successful modification among those presented. It provides sufficient level of cryptographic strength in relation to the time spent.

Table 2 analyzed operation of classical McEliece cryptosystem and its modifications with Reed-Muller and Hamming codes. And the average value was also derived using formula (5). It can be seen from the table that the modification works in 4.6 times slower; at the same time, its cryptographic strength is higher than classic McEliece code.

Table 2. Comparison of the speed of cryptosystems using the "STOPWATCH" function when changing the input data

No.	The speed of the cryptosystem		The code used in the modification
	McEliece's modification (s)	Classic McEliece (s)	
1	1.337	0.152	Reed-Muller
2	1.394	0.176	
3	1.455	0.182	
4	1.641	0.199	
5	1.866	0.224	
	1.539	0.187	Average value
1	0.588	0.152	Hamming
2	0.888	0.176	
3	0.922	0.182	
4	1.067	0.199	
5	1.187	0.224	
	0.930	0.187	Average value

Table 3 shows that Niederreiter cryptosystem with modification in the form of Hamming code works in 3.71 times faster than McEliece algorithm with the same modification. In the case of Reed-Muller code modification, the opposite picture is watched. Niederreiter cryptosystem is much slower than McEliece cryptosystem. On average, the speed of algorithm is in 1.71 times slower.

Figure 7 shows the graph of the dependence of the operating time on the length of the encrypted message, expressed in the number of characters written. In this case, cryptosystems are used with modification in the form of Reed-Muller code. The graph clearly shows the difference in the speed of algorithms. It should be noted that with help of Reed-Muller code in the modified Niederreiter cryptosystem, the cryptographic strength is increased. This is explained by using the information vector. In the course of program execution, when accessing the variable, it does not refer to the variable itself, but to its information vector.

Figure 8 shows the dependence of operating time on the length of encrypted message in Niederreiter and McEliece cryptosystems with modification in the form of Hamming code. The speed of the Niederreiter algorithm increases faster than the second algorithm, while still remaining faster. This can lead to the fact that with larger increase in the size of the encrypted message, the McEliece cryptosystem with the Hamming code will work

Table 3. Comparison of the speed of cryptosystems using the "STOPWATCH" function when changing the input data

No.	The speed of the cryptosystem		Code used
	Niederreiter (s)	McEliece (s)	
1	1.919	1.134	Reed-Muller
2	1.960	1.142	
3	1.998	1.171	
4	2.057	1.206	
5	2.089	1.201	
6	2.090	1.238	
7	2.170	1.283	
8	2.192	1.282	
9	2.245	1.323	
10	2.433	1.384	
	2.115	1.236	Average value
1	0.014	0.508	Hamming
2	0.031	0.503	
3	0.052	0.504	
4	0.084	0.543	
5	0.111	0.540	
6	0.146	0.568	
7	0.201	0.618	
8	0.221	0.632	
9	0.297	0.684	
10	0.408	0.726	
	0.157	0.583	Average value

faster. Therefore, additional research should be carried out on the dependence of the operating time and the message length, increasing the length of the encrypted message.

Based on Fig. 9, it becomes clear that with increase in the message length, Niederreiter cryptosystem with modification in the form of Hamming code works faster than McEliece algorithm. The speed of algorithm increases faster in McEliece cryptosystem. In this situation, if we calculate the average value of Niederreiter's algorithm, which is 4.546 s, and McEliece algorithm, equal to 7.781 s, we can note that the first algorithm is 1.7 times faster than the second. If we compare with the initial data, which were obtained at smaller values of the sizes of the encrypted messages, we can see that the differences in

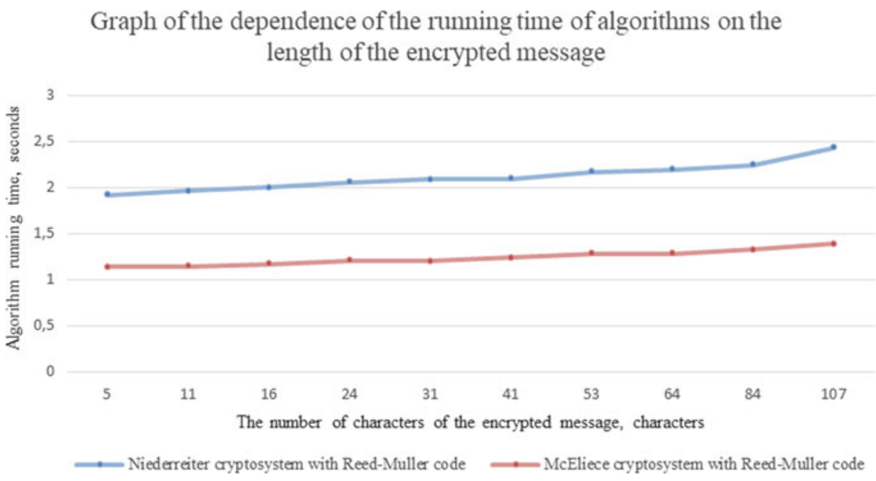

Fig. 7. Diagram 2

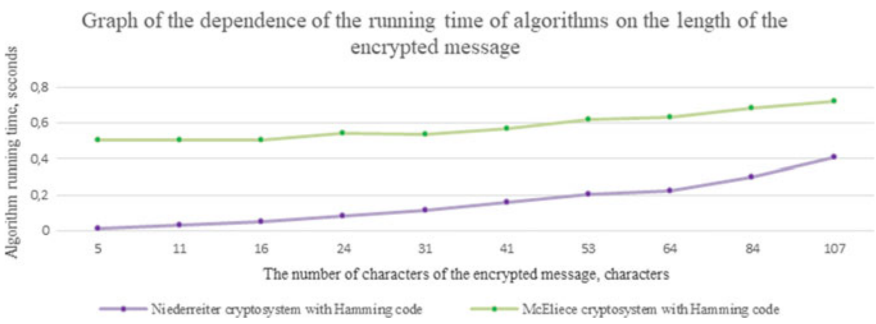

Fig. 8. Diagram 3

performance are different. Niederreiter's cryptosystem was 3.71 times faster with small message sizes. As the length of the cipher text increases, the speed advantage decreases by 54%.

4 Discussion and Conclusions

Software tool with modified Niederreiter and McEliece cryptosystems has been developed to compare their performance under the same conditions, testing of the software was carried out, as the result of which it turned out that the modified Niederreiter cryptosystem with Hamming code works much faster than other algorithms with modifications with satisfactory level of cryptographic strength. In the case of the Reed-Muller code, the performance of McEliece cryptosystem exceeds the performance of Niederreiter algorithm, due to the division of the information vector. The studies carried out once again prove the importance of post-quantum cryptography in the modern world.

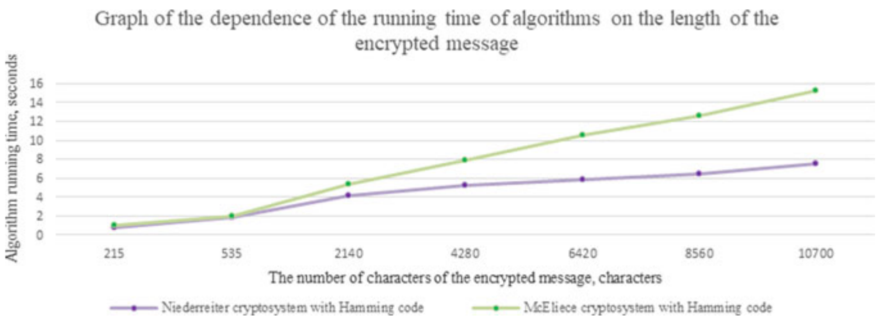

Fig. 9. Diagram 4

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Modification of R. Merkle's Post-Quantum Algorithm

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Abstract. The report discusses the modification of RMSS algorithm (Ralf Merkle Signature Scheme) taking into account modern vulnerabilities. This report presents theoretical description of the post-quantum XMSS algorithm, differences between modification XMSS and classical RMSS, software implementation algorithm with increased cryptographic security and reduced size of the generated information with a small or insignificant decrease in performance, software tests and performance comparing using the Mann-Whitney U-test. This modification of the classical algorithm increase the number of keys available for signing, speed up the operation of creating signatures, and increase its reliability and security. It is using of random bit mask that allows replacing the family of collision-resistant hash-functions with family of hash-functions that are resistant to collisions of the second kind (second-preimage resistance). According to Mann-Whitney U-test results the differences between the classical implementation of the algorithm and the modified version are in the significance zone for both values of the probability of non-acceptance of the null hypothesis.

Keywords: Ralph Merkle algorithm · Electronic digital signature · Hash tree · Post-quantum cryptography

1 Introduction

Technical tools of quantum calculations allow performing computations in several hundred times faster than classical computers. This advantage in computing power makes all standard cryptographic algorithms vulnerable. Based on complexity of factorization of large numbers, the RSA cryptosystems, the discrete logarithm El-Gamal and DSA have become vulnerable, which is strictly proven mathematically.

The application of new methods for organizing cryptographic transformations, for example, based on the ring theory or supersingular isogenies, makes it possible to resist the quantum computers. In this report, the modification of this algorithm will be considered. Merkle algorithm is post-quantum, and this statement determines the relevance of this investigation.

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https://doi.org/10.1007/978-3-030-81619-3_20

Report research object is Merkle algorithm; research subject is the modification of the Merkle algorithm. Purpose of investigation is development of efficient software implementation of the Merkle signature post-quantum algorithm.

In accordance with research purpose, the following tasks were defined:

Investigation of the operation of the Merkle signature algorithm;
Development of mathematical model of the modified algorithm;
Implementation of the software based on the modified Merkle algorithm.

Comparison the performance and memory costs of modified Merkle signature algorithm and its classical version [1–4]. It was classified as reusable digital signature algorithm. Leslie Lamport's one-time signature was proposed as the main digital signature algorithm.

The algorithm uses the combination of one-time digital signature algorithms, for example, such, as Leslie Lamport's signature, WOTS (Winternitz One Time Signature) or WOTS+, and cryptographically resistant hash-function [5, 6].

This algorithm signs the messages and verifies the signatures with high speed, because it uses only hashing and string concatenation for cryptographic data transformation. But with the large Merkle tree (approximately count $\geq 2^{25}$ leaves) its traversal time exponentially increases at creating authentication path, that affects performance [7]. The modification of the algorithm called XMSS (eXtended Merkle Signature Scheme) was proposed in [8], and it was formalized in 2018, the standard [9]. This modification uses bitmasks, which increasing the algorithm cryptographic security.

The algorithm and its modifications have cryptographic resistance to adaptive attacks with chosen message, if hashing algorithm is used that is resistant to collisions of second kind, it does not have visible families of one-way unidirectional functions or families of pseudorandom WOTS functions [8]. The cryptographic strength of the Merkle signature algorithm and its modifications is based on the cryptographic strength of the hash-function used and its resistance to finding the prototype of one-way function. The Merkle signature algorithm is based on the use of one-time signature algorithms, which makes these algorithms interchangeable. This allows ensuring the modularity of software and increasing their reliability, since if vulnerability is found in the used signature algorithm, it can be replaced on with more securing one [10].

2 Mathematical Model and Solution Method

One-time signature algorithms consists of three steps [11]:

- generating private (secret) X and public Y keys;
- creating the signature '*sig*' from the message '*mess*' using the key X;
- verifying the signature '*sig*' using the public key Y.

Initially, cryptographically resistant hash function (1) is defined as:

$$\mathrm{H} : \{0, 1\}^* \rightarrow \{0, 1\}^s \tag{1}$$

which would be used for calculation of the public key Y [9].

Initially, Merkle's algorithm generates the arrays of keys X and Y of length $N = 2^h$ each.

Each pair (X_i, Y_i) from the arrays X and Y is used as the pair: private key-public key for the one-time signature algorithm. The X array is the private key of the Ralf Merkle signature algorithm [12].

When the Merkle tree are creating, the value of the hash function $H(Y_i)$ is calculated for each element Y_i of the public key array Y. The transformed array of public keys forms the zero layer of the tree—the leaves.

Let us denote the layer with the leaves as a_0. This layer contains $l_0 = N = 2^h$ elements. The next level nodes of the tree denotes as a_1, and has size $l_1 = 2^{h-1}$: each j-th element of the a_1 layer is calculated by formula as

$$\mathrm{a_{1,j} = H(a_{0,j*2}||a_{0,j*2+1})}. \tag{2}$$

through the concatenation and their transformation through the hash-function.

For subsequent layers, the following statements are fulfilled: the layer has length $l_1 = 2^{h-1}$ and is calculated through previous i—the 1st layer by the formula (3)

$$\mathrm{a}_{i,j} = \mathrm{H(a_{i-1,j*2}||a_{i-1,j*2+1})}. \tag{3}$$

The last layer a_h has a length $l_1 = 2^{h-h} = 1$ and contains the public key, which is the *root* of the Merkle tree.

To generate Merkle signature the i-th key pair (X_i, Y_i) is selected from the X and Y arrays. For the *mess* message, one-time digital signature sig_i is calculated using private key X_i.

To reduce the cost of storing and transmitting key information over the network, as well as increase the cryptographic resistance (strength) of algorithm, the Merkle scheme involves the creating authentication path. To do this, it is needed to create the path from the root $a_{h,0}$ of the Merkle tree into the leaf $a_{0,i}$, which related to the key Y_i. The vertices that the path passes through are placed in array Auth of length $h + 1$, where $Auth_h$ is the root of tree, and $Auth_0$ corresponds to $a_{0,i}$. The value of each significant vertex is calculated as

$$\mathrm{Auth_j = H(Auth_{j-1}||auth_{j-1})}. \tag{4}$$

where $Auth_{j-1}$ and $auth_{j-1}$ are direct descendants of $Auth_j$, except for $Auth_0 = H(Y_i)$.

To find the authentication path, it is enough to have the value Y_i and array of vertices $auth_1$, $auth_2$, ..., $auth_h$, which is called the authentication path. The *sig* signature of the message *mess* consists of the public key Y_i for confirming the one-time signature, the one-time signature sig_i, and the authentication path. It is necessary to calculate the path to the root of the tree without generating the Merkle tree from the party verifying the signature—signature validator.

If verifying is successful, then constructed the path from $\mathrm{H(Y_i)}$ to the *root* of the tree. If $\mathrm{A_h}$ matches to the *root* of the Merkle tree public key, the verification is successful, and the *mess*message is authentic.

3 Results of Research

For implementation of studied post-quantum algorithm in the software tool form, the modification of Ralph Merkle algorithm was chosen—the XMSS algorithm [9].

The Merkle tree scheme for this algorithm is demonstrated in the Fig. 1.

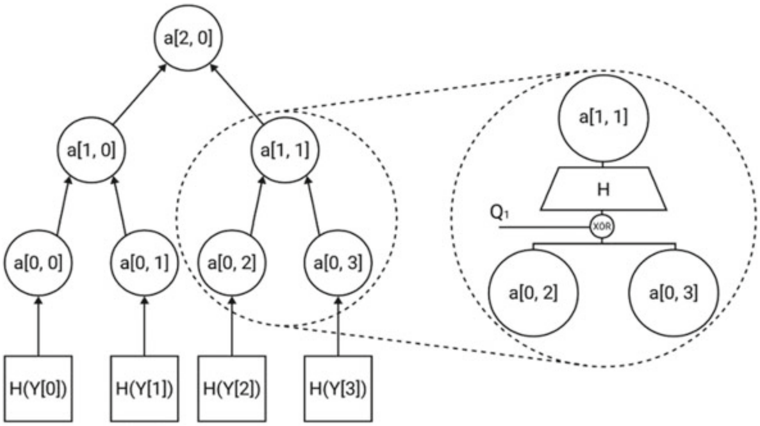

Fig. 1. Merkle tree scheme for XMSS algorithm

The tree is described by the signed message length m in bits, the height h, and the Winternitz parameter w [10]. Using the XMSS tree, you can sign messages of length m bits. All participants in the message exchange know these parameters.

The algorithm differs from the classical Merkle algorithm in that it uses the random bit mask Q_{qi} at the input of each node of the tree, except for the leaves, in conjunction with the hash-function H, which is resistant to collisions of the second kind (second-preimage resistance).

Each subsequent node is calculated using the formula:

$$\boldsymbol{a_{i,j}} = \mathrm{H}((\mathrm{a}_{\mathrm{i}-1,\mathrm{j}*2}||\mathrm{a}_{\mathrm{i}-1,\mathrm{j}*2+1}) \oplus \mathrm{Q}_{\mathrm{i}}). \tag{5}$$

The leaves in the XMSS tree are the values of hash-functions from the public keys $(pk_1, ..., pk_l)$ of the WOTS algorithm. To reduce security requirements and avoid using the family of collision-resistant hash functions, need to use the different leaf structure, which is called the L-tree [11]. It is the tree with the leaves containing strings $(pk_1, ..., pk_l)$ of length l of the relating public key. This construction is self-regulating, since l may not be the power of two. This L-tree, uses hash-function$H$, but applies new bitmasks that are the same for all existing L-trees [9].

In the publication [13] is given the proof of the signature scheme security when the replacing of the usual Merkle tree with the tree for XMSS algorithm.

The Winternitz scheme and its modifications can sign multiple bits in the single operation. It allows adjusting the ratio between the speed of algorithm execution and the size of the signature and key information.

In practice the values 4 and 16 are most often used [14]. To increase the execution speed of signature algorithms, the $w = 4$ parameter was selected.

To reduce memory costs, the key information for the Winternitz algorithm is generated using pseudorandom generators. The use of this scheme makes it possible to reduce memory costs from secret keys of lnbits per every key to a value of n equal to several bits of the pseudorandom algorithm seed [9–12, 14].

The combination of Winternitz parameter $w = 4$ and reducing keys size allows simultaneously reducing the execution time of the algorithm, and significantly reducing the amount of data stored.

The software implementation is written in the Python programming language. The choice of language is based on the speed of prototyping and ease of making changes. The CLI is used as the interface for working with the software.

The XMSS algorithm implemented in the software is shown in Fig. 2.

Fig. 2. Software XMSS algorithm implementation

To work with the program, you need to run the main file. Depending on what the with time parameter was in the measurements file before the program started, it will display either only basic information: a message about generating key, message about signing and signature verification results, or detailed information that includes the specified basic parameters and information about the execution time of all stages of the program [12, 13, 15, 16]. The output of the program when working in the main mode is shown in Fig. 3.

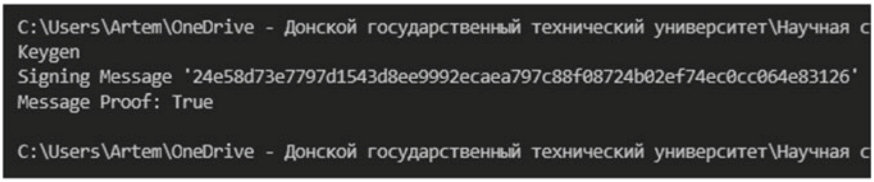

Fig. 3. Using a software for checking basic functions

A comparison of the classical Merkle algorithm and the modified XMSS algorithm is demonstrated in Table 1.

Table 1. Comparison of execution time, memory costs, and cryptographic strength

Type of algorithm	Average execution time (MS)			Memory consumption (bytes)			b
	t_{kgen}	t_{sign}	t_{proof}	Sig	PK	SK	
A modified algorithm	94,323.79	7.36	25.56	11,692	256	11.047 Mbytes	192
A classic algorithm	30.49	9.18	3.56	8152	960	4096 Mbytes	98

Based on the results from Table 1, the following advantages of the modified algorithm can be noted in comparison with the classical algorithm—stable software work (small time dispersion for signing and verifying it), greater cryptographic strength in bits, reduced time to create message signature using WOTS algorithm, small size of key information, key information can be transferred to another device.

The disadvantages compared to the classical algorithm are—greater Merkle tree generation time, signing time is longer, as the key tree is re-created, slight increase of signature size.

To compare the two signature time series, we use the Mann-Whitney U-test. Table 2 contains a ranked list of 15 positions containing the time values of the signature operation of the classical and modified algorithms.

The critical value is 56 for $p \leq 0.01$ and 72 for $p \leq 0.05$. Based on the results of calculations, the empirical value of the criterion is $U = 46$.

We can say that we are having two independent samples that have the same distribution. The signature process using a modified algorithm works on average 15% faster [17, 18].

Table 2. Ranked list for calculating Mann-Whitney U-test

Test number	Sample 1	Rank 1	Sample 2	Rank 2
1	0.009006738662719727	25	0.025650978088378906	28
2	0.007978677749633789	24	0.03914332389831543	30
3	0.005949735641479492	14	0.0020618438720703125	6
4	0.0069806575775146484	22	0.0019936561584472656	4.5
5	0.009974956512451172	27	0.001992464065551758	2
6	0.005984783172607422	19	0.026586055755615234	29
7	0.005982875823974609	16	0.002992868423461914	11.5
8	0.005947589874267578	13	0.0029926300048828125	9.5
9	0.005982398986816406	15	0.0019927024841308594	3
10	0.005984067916870117	17	0.002976655960083008	8
11	0.007949590682983398	23	0.0009965896606445312	1
12	0.009011268615722656	26	0.002992868423461914	11.5
13	0.006979703903198242	21	0.0019936561584472656	4.5
14	0.005984306335449219	18	0.0029129981994628906	7
15	0.006010293960571289	20	0.0029926300048828125	9.5
Amount		300		165

4 Discussion and Conclusions

Based on the conducted research, the key advantage of the developed Merkle algorithm modification is its high cryptographic strength, which makes it possible to provide protection against attacks using quantum computers.

The algorithm have proven protection against adaptive chosen message attacks. It is possible to generate an XMSS tree for each signature, which makes it possible to transfer key information with external drivers. It has been proven experimentally that the modified algorithm reduces the size of key information and the signing message time, while significantly increasing the level of security.

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Adaptive Hydromechanical Drilling Rig Drive

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Abstract. A drilling machine is presented, equipped with a hydraulic drive with self-adaptation according to the load and coordination of the kinematic and power parameters of the main movement and the movement of the working body feed. For research and design of the proposed adaptive hydraulic drive based on mathematical modeling methods, its mathematical model is proposed, developed using the foundations of the theory of volumetric stiffness of hydraulic systems. The solution of the obtained mathematical model was carried out in the software environment for dynamic modeling of technical systems SimInTech. As a result, general dependences of the functional parameters of the adaptive system on the design parameters and technological conditions of its functioning were obtained. The solution of the mathematical model of the adaptive hydraulic drive shows the fundamental possibility of implementing the principle of self-adaptation by load, with external and internal disturbing influences during operation. The results obtained can be used in the design of adaptive systems of technological equipment for various purposes.

Keywords: Rilling machine · Hydraulic drive · Self-adaptation · Mathematical model · Volumetric stiffness

1 Introduction

The creation of intelligent machines is the basis for the design and creation of actuators with a self-adaptive function. The solution to this problem is timely and relevant.

The self-adapting property is possessed by drives with differential links of internal structure elements (patent No. 2582691 Ros. Federation: E 21B 44/00. This class of technical systems includes a device for drilling rock with variable properties (RF patent No. 2582691). The self-adaptation property is realized by a device with negative feedback and positive direct connections [1].

The quality of the self-adaptation process is influenced by external and internal influences (variability of load, resistance of the medium, dry and viscous friction, volumetric stiffness of liquid and pipelines, adaptive connections).

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2 Materials and Methods

At the current level of development of computer technology, the complexity and high cost of the designed equipment, methods of mathematical modeling are widely used at the development stage [2–13]. The development of a special model for calculations and a computational experiment to determine the parameters at the design stage makes it possible to make a reasonable choice of the standard size of the device with self-adaptation.

The authors have developed a mathematical model for solving the problem of designing a device in the environment of dynamic modeling of technical systems SimInTech (Simulation In Technic) [14]. This software product allows you to simulate technological processes in various industries with the simultaneous simulation of control systems.

Figure 1 shows a schematic diagram of an adaptive hydraulic drive of a drilling machine, designed to perform the function of self-adaptation in conditions of force resistance on the working body, which contains: a constant displacement pump (N), a safety valve (KP), a filter (F), adjustable throttles (Dp1) and Hydraulic tank (B) and pipelines.

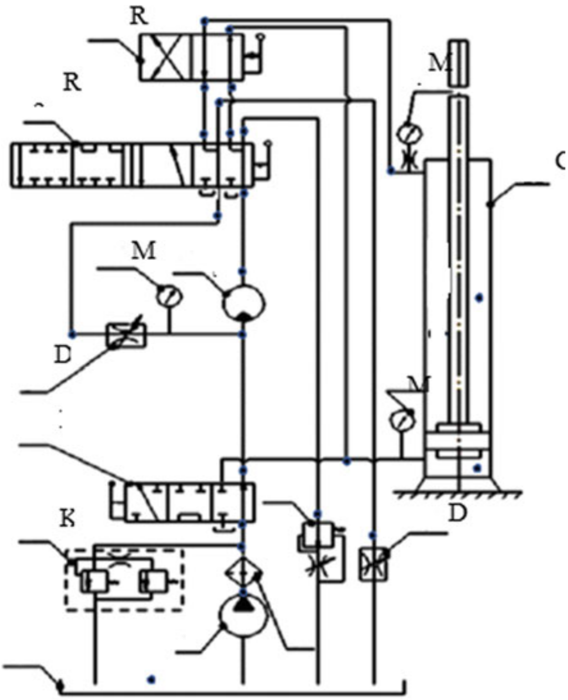

Fig. 1. Schematic diagram of the adaptive drive of the drilling machine

The device is designed to implement the function of self-adaptation to the load (in order to stabilize it) and to coordinate the output motions of the working body of technological machines and equipment, as well as the functions of the power drive itself.

The mathematical dependence for the internal negative feedback of the drive is established by jointly solving the equations arising from the pressure balance equations for the system and the balance equation for the working fluid flow rate in the feedback system.

From the pressure balance in the system follows

$$\Delta p_{thr5} = \frac{1}{w_{HM}} M_{HM} + \frac{1}{f_p} F_p - \left(1 - \frac{f_{p.pcs}}{f_p}\right) \Delta p_{thr10}, \tag{1}$$

where Δp_{thr5} and Δp_{thr10}—pressure drops across throttles 5 and 10; $w_{HM}$and M_{HM}—reduced volume of the hydraulic motor HM and the torque it generates;f_p and$f_{p.pcs}$—the area of the piston of the hydraulic cylinder in the piston and rod cavities; F_p—resistance force from the ground, overcome when moving the hydraulic cylinder rod of the HC.

The balance equation for the costs in the feedback loop has the form

$$Q_{thr10} = Q_{thr5} + v_p \cdot f_{p.pcs}, \tag{2}$$

where Q_{thr5} and Q_{thr10}—flow rates of working fluid through throttles thr1 and thr2; v_p—speed of movement of the piston of the hydraulic cylinder HC.

In this case, the dependence of the acceleration of the piston movement of the hydraulic cylinder HC on the total load on the hydraulic motors of the main movement and the feed movement has the form

$$\frac{dv_p}{dt} = -\,\mathrm{A}\left(\frac{1}{w_{HM}} \frac{dM_{HM}}{dt} + \frac{1}{f_p} \frac{dF}{dt}_p\right), \tag{3}$$

where v_p—speed of movement of the piston of the hydraulic cylinder HC; t—time; A—feedback coefficient depending on the parameters of the nominal operating mode of the system, design parameters of hydraulic machines, chokes and its settings.

From Eq. (3) it can be seen that positive increments of torque on the motor shaft and displacement of the hydraulic cylinder feed piston correspond to a negative increment in the tool feed rate. In other words, as the resistance from the ground increases to the rotation of the cutting tool or the movement of its feed, the feed rate of the tool decreases.

The direct relationship between the speeds and accelerations of the hydraulic motor shaft of the main movement and the hydraulic cylinder rod of the feed movement has the form

$$\frac{dv_p}{dt} = w_{HM} \frac{d\omega_{HM}}{dt}. \tag{4}$$

where ω_{HM}—angular speed of rotation of the hydraulic motor shaft; Q_{wf}—working fluid flow through the flow regulator.

From Eq. (4) it can be seen that with a decrease in the resistance to rotation of the tool from the side of the machined surface, the speed of movement of the piston of the feed hydraulic cylinder increases.

3 Mathematical Modeling of the Movements of the Working Elements of the Device

The equations of motion of the main motion hydraulic motor rotor and the tool feed hydraulic cylinder piston are:

$$J_{HM}\frac{d\omega_{HM}}{dt} = \Delta p_{HM}\,w_{HM} - M_{res}; \tag{5}$$

$$m_p\frac{dv_p}{dt} = f_p p_p - f_{p.pcs} p_{p.pcs} - F_{res}, \tag{6}$$

where J_{HM}—the total moment of inertia of all rotating elements of the system, reduced to the shaft of the hydraulic motor; m_p—the mass of all moving parts of the system, reduced to the piston of the hydraulic cylinder; M_{res}—total moment of resistance to rotation of the working body, reduced to the shaft of the hydraulic motor; F_{res}—the total force of resistance to the movement of the tool from the side of the treated surface, reduced to the piston of the hydraulic cylinder; Δp_{HM}—pressure drop across the hydraulic motor; $p_p$and$p_{p.pcs}$—pressure in the piston and in the rod cavities of the hydraulic cylinder, respectively.

4 Simulation of the Hydraulic Drive System

The mathematical model of the hydraulic drive system for the self-adaptation function under the conditions of force resistance on the working body was developed using the theory of volumetric stiffness [15], which allows modeling as close as possible to the real operating conditions of machines using the partial synthesis method [16], and this significantly accelerates the process of theoretical analysis of the system and increases its accuracy [10–17]. When modeling, special attention was paid to determining the reduced coefficient of volumetric stiffness of high-pressure hoses [18].

According to the theory of volumetric stiffness, the pressure increment at any point in the hydraulic system is determined by the equation

$$dp = C_{redi}\left(\sum Q_{\text{in}i} - \sum Q_{\text{out}i}\right)dt, \tag{7}$$

where $\sum Q_{\text{in}i}$and $\sum Q_{\text{out}i}$—the sums of all costs of the working fluid entering and leaving from the considered (i) system volume over time dtdt; $C_{\text{red}i}$—reduced coefficient of volumetric stiffness of the selected area.

The instantaneous values of the flow rates of the working fluid are determined using the flow rate formula for local hydraulic resistances.

The reduced coefficient of the volumetric stiffness of the metal sections of the pipeline is determined by the known dependencies [15], and the reduced coefficients of the volumetric stiffness of the RVD are determined experimentally.

The pump capacity and the flow through the hydraulic motor are determined taking into account their volumetric efficiency.

5 Research Results

The proposed mathematical model of the device under consideration allows high-precision theoretical studies of operational capabilities when drilling rock at the design stage. The calculation of the drilling system made using the SimInTech software [16, 17] showed the correctness of this statement.

In Fig. 2 shows the graphs of changes in the parameters of movement of the feed hydraulic cylinder piston with a stepwise change in the moment of resistance to rotation of the main working body of the drilling machine from the side of the ground.

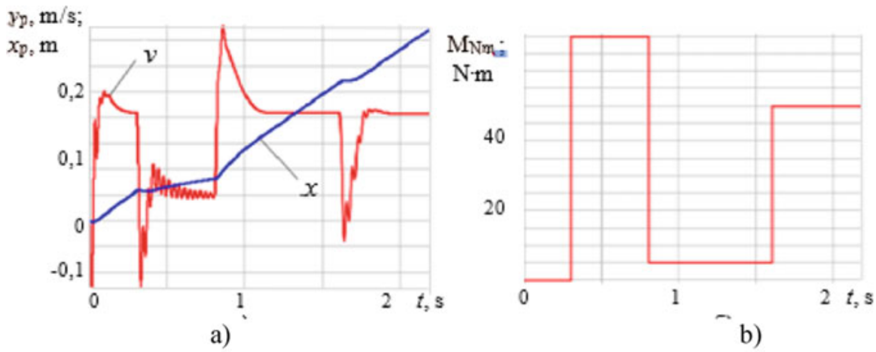

Fig. 2. Changing the parameters of the operation of the drilling machine with a stepwise change in the resistance to rotation of the main working body of the drilling machine from the ground: **a** movement of the hydraulic cylinder piston (x_p) and its speed (v_p); **b** torque of resistance to rotation of the hydraulic motor shaft M_{HM}

Analysis of the calculation results presented in Fig. 2 shows that with an increase in the torque of resistance to rotation of the working body of the drilling machine (Fig. 2b), the speed of translational movement of the tool decreases and can even take negative values (Fig. 2a), which indicates that the system is performing the adaptation function. The properties of the system require additional research [19, 20].

6 Conclusion

The proposed mathematical model allows, at the design stage, to make a preliminary assessment of the quality of work and select the most rational parameters of a drilling system equipped with an adaptive hydromechanical drive, under various operating conditions and varying its design parameters. The results obtained and their analysis indicate that the proposed method for adapting the main and auxiliary movements of the drive system can be successfully applied in other technological equipment, for example, in deep drilling of multilayer metal work pieces.

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Stand for Life Tests of Plunger Hydraulic Cylinders. Modeling and Calculation

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Abstract. An original design of the stand is proposed for carrying out resource tests of plunger hydraulic cylinders with energy recovery. The stand is designed for life tests of high and medium power plunger hydraulic cylinders, which allows saving up to 80% of energy due to its reuse during testing. In the article, based on the use of the theory of volumetric stiffness of hydraulic systems, a mathematical model of the hydro mechanical system of the stand is obtained, which allows to describe with high accuracy the functioning of the stand in the process of testing hydraulic cylinders. Studies of the functioning of the proposed stand, carried out using the obtained mathematical model, have confirmed the high efficiency of the energy recovery method used in the development of the stand's schematic diagram. The solution of the mathematical model was carried out using the SimInNech software package for solving differential equations. The analysis of the results obtained in the calculation of the results allows already at the design stage of the stand to reveal the rational values of its design parameters, which will give a significant saving of resources during its operation.

Keywords: Life tests · Test bench · Energy saving · Energy recovery · Mathematical model

1 Introduction

One of the most important performance properties of mechanical engineering products, including hydraulic machines, is their reliability. Reliability is laid down in the design and construction of hydraulic machines, is ensured in the process of their production and is confirmed by testing. The most important, as well as labor- and energy-consuming, type of testing of hydraulic machines is resource testing, during which the operability of hydraulic machines in the process of long-term use for their intended purpose and their durability are revealed. At the same time, various types of braking devices (mechanical, electrical, hydraulic and others) are used for the power loading of a hydraulic motor, as a result of which a significant amount of energy is irretrievably lost, and therefore a corresponding amount of heat is released, which, in turn, litters the environment. This is especially true when testing medium and high power hydraulic machines.

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In recent years, an active search for a solution to this problem has been carried out, as a result of which a method of resource testing of hydraulic machines of rotary motion with energy recovery has been developed [1]. This method provides significant energy savings when testing hydraulic pumps and hydraulic motors, however, it cannot be directly used when testing hydraulic reciprocating machines—hydraulic cylinders. Energy recovery test methods have also been developed for hydraulic cylinders [2–4].

2 Formulation of the Problem

The proposed work presents an original layout of the test bench for plunger hydraulic cylinders with energy recovery. The stand allows saving energy due to the hydromechanical system of its recuperation. The purpose of this research is to develop a mathematical model and calculate the main functional parameters of the proposed stand.

3 Test Bench Description

Figure 1 shows a diagram of the hydromechanical system of the stand for testing plunger hydraulic cylinders with energy recovery. The stand consists of four main subsystems.

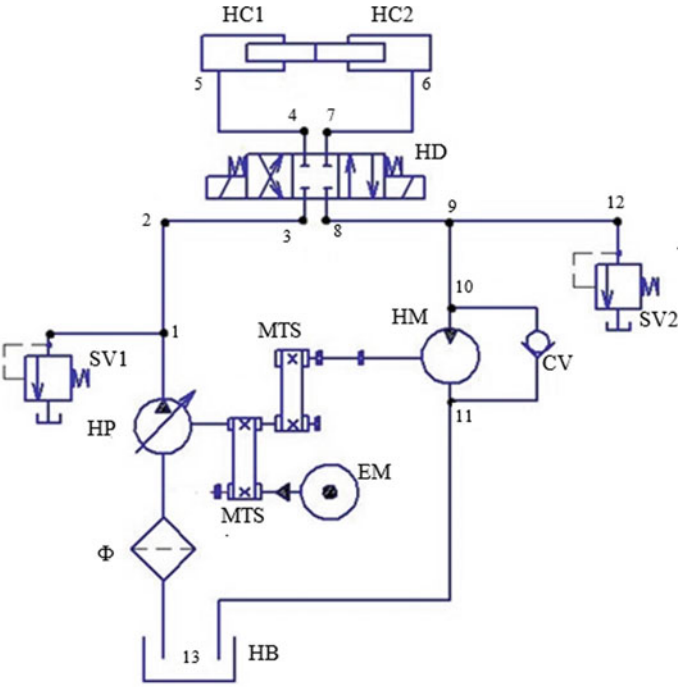

Fig. 1. Diagram of the hydromechanical system of the stand for testing plunger hydraulic cylinders with energy recovery.

Figure 1 shows a diagram of the hydromechanical system of the stand for life tests of plunger hydraulic cylinders with energy recovery. The stand includes 4 subsystems.

1. power subsystem;
2. test cylinder control subsystem;
3. subsystem for converting hydraulic energy into mechanical;
4. energy recovery subsystem.

The power subsystem includes an electric motor EM, as a source of primary energy, variable displacement hydraulic pump HP, safety valve SV1, designed to protect the hydraulic pump HP from overload and filter F, which protects the HP pump from mechanical impurities.

The control subsystem of the tested cylinders directly includes the tested hydraulic cylinders HC1 and HC2, whose rods are kinematically interconnected, the hydraulic distributor HD, designed to change the direction of movement of the rods, when they reach the extreme positions and pipelines connecting them.

The subsystem for converting hydraulic energy into mechanical energy includes the hydraulic motor HM and pressure hydraulic valve SV2 and is designed to convert the hydraulic energy of the working fluid passed through the tested hydraulic cylinders into mechanical energy for its reuse.

The energy recovery subsystem includes a mechanical transmission system MTS1 and MTS2, designed to convert and combine the energy of an electric motor EM and the energy passed through the hydraulic motor of the HM and transferring it to the shaft of the hydraulic pump.

The stand works as follows. The energy generated by the electric motor through the mechanical transmission MTS1 supplied to the shaft of the hydraulic pump HP, which converts it into the hydraulic energy of the working fluid flow and is transmitted through the pipeline to the input of the hydraulic distributor HD. Let at the initial moment of time the distributor HD directs the fluid flow to the input of the hydraulic cylinder HC1, conditionally performing, in this case, the functions of a hydraulic motor. Hydraulic cylinder HC1 converts hydraulic energy into mechanical energy of movement of its plunger, which transfers it to the plunger of the hydraulic cylinder HC2, kinematically connected to it and conditionally performing, in this case, the functions of a hydraulic pump. Working fluid flow outgoing from the hydraulic cylinder HC2 transmitted through the hydraulic distributor HD to the input of the hydraulic motor HM, which converts it into mechanical energy of rotation of the shaft and through the mechanical transmission MTS2 transfers it to the shaft of the hydraulic pump HP, where it is summed up with the energy supplied to the hydraulic pump shaft from the electric motor and is again converted into hydraulic energy of the working fluid flow.

When the plunger of the hydraulic cylinder HC1 reaches the extreme position, the hydraulic distributor HD redirects the flow of the working fluid to the inlet of the second hydraulic cylinder HC2. At the same time, the hydraulic cylinders change “their functions”, and the recuperative system of the stand works in the same mode.

It should be borne in mind that the mechanical transmission MTS2 converts the speed of rotation in such a way that it forces the shaft of the hydraulic pump to rotate with a frequency greater than the frequency generated by the electric motor through the mechanical transmission MTS1, and this is impossible. Thus, the hydraulic pump HP turns into a load for the hydraulic motor HM. The pressure at the inlet to the hydraulic motor is increased to the setting value of the pressure valve SV2, which ultimately makes it possible to change the value of the load on the tested hydraulic cylinders [5].

4 Simulation of the Hydraulic System of the Stand

The complexity and high cost of development and creation of experimental samples of the designed equipment caused widespread use of mathematical modeling methods at the design stage [6–16]. The development of a special model for calculations and a computational experiment to determine the parameters at the design stage makes it possible to make a reasonable choice of the standard size of the stand being developed.

The development of a mathematical model of the proposed recuperative system was carried out based on the use of the theory of volumetric stiffness [17–19], which makes it possible to more accurately take into account the influence of the dynamic properties of the hydraulic system on the dynamic properties of the equipment as a whole [20–22].

In accordance with the theory of volumetric stiffness, the equation of the pressure increment at any point of the hydraulic system has the form

$$dp = C_{ri}\left(\sum Q_{ini} - \sum Q_{outi}\right)dt, \tag{1}$$

where $\sum Q_{ini} and \sum Q_{outi}$—accordingly, the sums of all costs of the working fluid entering and leaving from the considered (i) system volume over time dtdt; C_{ri}—reduced coefficient of volumetric stiffness of the selected section of the hydraulic system.

Then conditionally dividing the hydraulic system of the stand (see Fig. 1) into sections with nodal points, taking as point 12 the volume of the hydraulic tank with a pressure equal to atmospheric, we write equations to determine the pressures at various points of the system:

$$dp_1 = C_1\left(Q_{pa} - Q_{sv1} - Q_{1-2}\right)dt, \tag{2}$$

$$dp_2 = C_2\left(Q_{1\_2} - Q_{2-3}\right)dt, \tag{3}$$

$$dp_3 = C_3(Q_{2-3} - Q_{3-4})dt, \tag{4}$$

$$dp_4 = C_4(Q_{3-4} - v_{4-5})dt, \tag{5}$$

$$dp_5 = C_{c1}(Q_{4-5} - v_{pl1} \cdot f_{pl})dt, \tag{6}$$

$$dp_6 = C_{c2}\left(v_{pl2} \cdot f_{pl} - Q_{6-7}\right)dt, \tag{7}$$

$$dp_7 = C_7(Q_{6-7} - Q_{7-8})dt, \tag{8}$$

$$dp_8 = C_8(Q_{7-8} - Q_{8-9})dt, \tag{9}$$

$$dp_9 = C_9(Q_{8-9} - Q_{9-10} - Q_{9-12})dt, \tag{10}$$

$$dp_{10} = C_{10}(Q_{9-10} + Q_{cv} - Q_{em})dt, \tag{11}$$

$$dp_{11} = C_{11}\left(Q_{em} - Q_{cv} - Q_{9-14}\right)dt, \tag{12}$$

$$dp_{12} = C_{12}(Q_{9-12} - Q_{sv2})dt, \tag{13}$$

where $dp_1 \ldots dp_{12}$—pressure increments at the corresponding points of the hydraulic system of the test bench during dt; $C_1 \ldots C_4$, $C_7 \ldots C_{12}$—reduced coefficients of volumetric stiffness at the corresponding points of the hydraulic system of the stand; Cc_1 and Cc_2—the reduced coefficients of the volumetric stiffness of the working cavities of the corresponding hydraulic cylinders (plunger); Qpa—actual hydraulic pump flow; Q_{em}—actual flow rate of the working fluid through the hydraulic motor; Q_{sv2}—working fluid flow through the pressure valve SV2; Q_{sv8}—working fluid flow through the safety valve 8; $Q_{1–2}$, $Q_{2–3}$, $Q_{3–4}$, $Q_{4–5}$, $Q_{6–7}$, $Q_{8–9}$, $Q_{9–10}$ and $Q_{10–11}$—working fluid flow rates in the corresponding sections of the stand hydraulic system; Q_{cv9} and Q_{v11}—working fluid flow through check valves 9 and 11 accordingly; v_{pl1} and v_{pl2}—speed of movement of plungers of hydraulic cylinders 5 and 7, accordingly; f_{pl}—working area of hydraulic cylinders plungers [23, 24].

The values of the flow rates of the working fluid required for calculating the pressures are determined by the formula

$$Q_i = \mu f \sqrt{\frac{2}{\rho}|p_i - p_{i+1}|} \cdot \mathrm{sign}(p_i - p_{i+1}), \tag{14}$$

where $p_i - p_{i+1}$—pressure values at the inlet and outlet of the corresponding hydraulic resistance; f—flow area of resistance; ρ—working fluid density.

For hydraulic resistances in the form of sections of hydraulic lines, the value of the reduced flow coefficient of the corresponding section of the hydraulic line, determined by the formula

$$\mu = \mu_l = \frac{1}{\sqrt{\lambda_l \frac{l_l}{d_l}}}, \tag{15}$$

where dl and ll—accordingly, the diameter and length of the considered section of the pipeline; λl—the coefficient of hydraulic friction of the pipeline, which is determined taking into account the fluid flow regime and the properties of the pipeline [25].

The values of the reduced coefficients of the volumetric stiffness of the sections of metal pipelines are determined by the formula

$$C_l = \frac{4}{\pi d^2 l} \frac{E_{fl}}{1 + \frac{d}{\delta} \frac{E_{fl}}{E_l}}, \tag{16}$$

where d and l—accordingly, the inner diameter of the considered section of the pipeline and its length; δ—pipeline wall thickness; Efl and El—elastic moduli of the working fluid and the wall material of the hydraulic line, accordingly.

The given coefficients of the volumetric stiffness of high pressure hoses and pipelines made of other elastic materials are determined experimentally [19].

The actual pump flow is determined taking into account the volumetric losses that occur in the pump during its operation (its volumetric efficiency)

$$Q_{\mathrm{pa}} = \frac{q_{\mathrm{p}} \omega_{\mathrm{p}}}{2\pi} \eta_0, \tag{17}$$

where qp—pump working volume; ωp—angular speed of rotation of the pump shaft; η_0—current value of volumetric efficiency pump;

$$\eta_0 = 1 - (1 - \eta_{0.nom}) \cdot \frac{p_{\mathrm{p}}}{p_{p.nom}}, \tag{18}$$

where $\eta_{0.nom}$—nominal volumetric efficiency pump is taken equal to the volumetric efficiency. pump at rated working pressure; $p_{p.nom}$—nominal pump pressure; p_{p}—current value of the working pressure at the pump outlet (pressure at point 1 of the hydraulic system).

5 Simulation of the Movement of Moving Elements of the Hydraulic System

The instantaneous values of the flow area of the valves are determined using the equations of motion of their gates. The equations of motion for the gates of the check valves 9 and 11 will have the form

$$\frac{dv_{cv9}}{dt} = \frac{1}{m_2}\left(\frac{d_{cv9}^2}{4}(p_{12} - p_{11}) - F_{spr9}\right), \tag{19}$$

$$\frac{dh_{cv9}}{dt} = v_{cv9}, \tag{20}$$

$$\frac{dv_{cv11}}{dt} = \frac{1}{m_{11}}\left(\frac{d_{cv11}^2}{4}(p_5 - p_2) - F_{spr11}\right), \tag{21}$$

$$\frac{dh_{cv11}}{dt} = v_{cv11}, \tag{22}$$

where v_{cv9} and v_{cv11}—the speed of movement of the gates of the check valves 9 and 11, accordingly; m_9 and m_{11}—reduced masses of check valve gates 9 and 11, accordingly; h_{cv9} and h_{cv11}—displacements (clearance) of check valve gates 9 and 11, accordingly; d_{cv9} and d_{cv11}—check valve bore diameters 9 and 11, accordingly; F_{spr9} and F_{spr11}—force of action of springs on gates of check valves 9 and 11, accordingly; $\boldsymbol{t}$—time.

The movement of the rotors of the hydraulic motor and hydraulic pump is described by the equations:

$$\frac{d\,\omega_{hm}}{dt} = \frac{1}{\mathrm{J_{hm}}}\left[w_{hm}(p_{11} - p_{12}) - M_{hm}\right], \tag{23}$$

$$\frac{d\,\omega_{hp}}{dt} = \frac{1}{\mathrm{J_{hp}}}(M_{em}i_{14} + M_{hm}i_{12} - w_{hp}(p_1 - p_{at})), \tag{24}$$

where $w_{\mathrm{hm}}, w_{\mathrm{hp}}$—characteristic volumes of hydraulic motor 10 and pump 1, accordingly; ω_{hm} and ω_{hp}—angular speeds of rotation of the shafts of the hydraulic motor 10 and pump 1 accordingly; $\mathrm{J_{hp}}, \mathrm{J_{hm}}$—central moments of inertia of the hydraulic pump and hydraulic motor rotors accordingly; p_{11}—hydraulic motor inlet pressure; p_{12}—pressure at the outlet of the hydraulic motor; p_{at}—the pressure at the inlet of the hydraulic pump (pressure in the tank) is taken equal to the atmospheric; p_hydraulic pump outlet pressure; $\mathrm{M_{em}}$ and $\mathrm{M_{hm}}$—torques generated by electric motor and hydraulic motor, accordingly; i_{12} andn i_{14}—gear ratios of mechanical transmissions 12 (from the hydraulic motor shaft to the hydraulic pump shaft) and 14 (from the electric motor shaft to the hydraulic pump shaft) accordingly [26, 27].

It should be borne in mind that the speeds of rotation of the shafts of the hydraulic motor and hydraulic pump are related to each other by the ratio

$$\omega_{hm} = \omega_{hp}i_{12}. \tag{25}$$

6 Calculation and Analysis of the Mathematical Model of the Stand

Calculations of the mathematical model were carried out according to a specially developed program for the block of solutions of differential equations in the software environment SimInNtch [28, 29]. As a result of calculations, characteristics were obtained that represent the interdependencies of various functional parameters of the hydromechanical system of the stand (speed of movement and movement of hydraulic cylinders plungers, pressures at various points of the hydraulic system, forces overcome by the plungers in the process of their movement, power on various elements of the system, etc.) the process of life tests of plunger hydraulic cylinders.

Figure 2 shows graphs of changes in the functional parameters of the stand for life tests of hydraulic cylinders during its operation.

From Fig. 2b it can be seen that in the process of testing the hydraulic cylinders, the power spent on the operation of the electric motor (4) is much less than the power at which the tests of the hydraulic cylinders (2) take place, since part of the modality that passed through the tested hydraulic cylinders due to its recuperation in the hydraulic motor (3) is returned to the hydraulic pump shaft, where it is summed up with the power supplied from the electric motor and converted into the power of the working fluid flow at the outlet of the hydraulic pump (1).

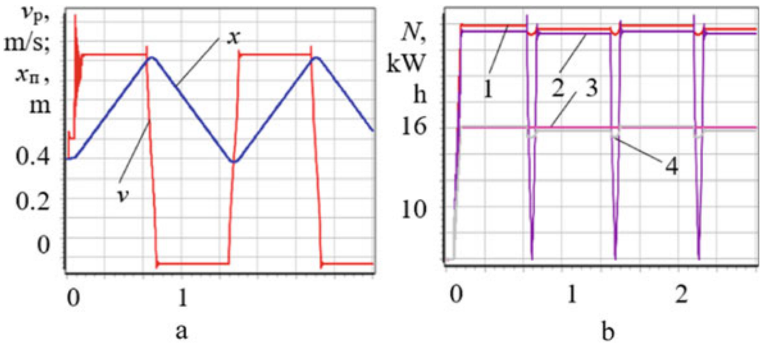

Fig. 2. Graphs of changes in the functional parameters of the stand for life tests of hydraulic cylinders during its operation: **a** speed graphs over time ($v_П$) and moving ($x_П$) of hydraulic cylinder rods during testing; **b** graphs of changes in power over time at various points of the power system of the stand during testing of hydraulic cylinders.

7 Conclusion

The proposed theoretical foundations for modeling the drive system of the stand for testing plunger hydraulic cylinders make it possible to calculate the drive system of the stand for life tests of plunger hydraulic cylinders at the design stage, which significantly improves the technical characteristics of the stand being designed, including issues related to the working conditions of the stand operator. The results of the study of the mathematical model of the stand convincingly prove the high efficiency of using the proposed design of the stand during the life tests of plunger hydraulic cylinders.

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Mathematical Model of a Throttle Flow Divider with an Elastic Regulating Element

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Abstract. *Object*: to propose a mathematical model of a diaphragm-type throttle flow divider, confirmed by experimental and theoretical studies, static load and speed characteristics, equipped with a throttle flow divider, of a synchronous hydraulic system, calculated using the model. *Methods*: comprehensive empirical analysis of a throttling flow divider, design and principle of operation of which exclude the use of spool pair as a shut-off and regulating element. Consideration of the structural mathematical model of membrane type throttle flow divider. Theoretical analysis of source materials. *Findings*: the article analyzes the static load and speed characteristics of the hydraulic system, which includes the considered diaphragm-type throttle hydraulic device, dividing the flow of the working fluid into two parts in a predetermined ratio. The mathematical model of the considered diaphragm throttle flow divider is analyzed. The principle of operation and the device of a throttle flow divider, the shut-off and control element of which is based on the use of a shut-off and control membrane-type element, are considered. *Conclusions*: The obtained results of the empirical and theoretical complex analysis of the investigated mathematical model, design and principle of operation of the membrane-type throttle flow divider fully satisfy the assigned tasks.

Keywords: Ynchronous hydraulic drive · Throttle flow divider · Shut-off and regulating element · Mathematical model · Theoretical characteristics

1 Introduction

Modern trends in scientific progress development in fields of design, optimization, mechanization and mechatronics of various spheres of human life are increasingly raising the issue of effective management of technological equipment, mobile and other equipment. Under the conditions of a complex spatial arrangement of the actuators of modern technological equipment, mobile and other equipment, and an increase in the number of functions performed by them, and control parameters, hydraulic drives are widely used, the structure and design features of which, as a rule, are branched and multi-circuit [1–10]. Due to the complexity of the spatial arrangement of the executive bodies of machines and mechanisms, the question of ensuring clear and

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reliable control of the drive operation and regulation of its parameters in the operation process arises [11–19]. One of the special cases of controlling a hydraulic drive is to ensure the coordinated (synchronous) operation of two or more independent hydraulic motors [20, 21]. The simplest and cheapest way to synchronize the mechanisms of a mobile device or technical equipment is to use a synchronous hydraulic drive with throttle flow dividers [22, 23].

Currently used flow dividers in most cases use spool pairs as a shut-off and control element. However, they have disadvantages that are characteristic of all hydraulic devices with spool shut-off and control elements:

- the technology of manufacturing precision spool pairs is very complex and includes a large number of high-precision expensive operations (grinding, honing, etc.), which increases its cost;
- when assembling spool pairs, such operations as debugging or selective assembly are used, which makes them practically non-repairable, and this, in turn, increases its operating cost;
- they are very sensitive to the quality of the working fluid.

In connection with the above, the use of spool flow dividers in general-purpose hydraulic drives is impractical, especially if they operate in severe conditions at high temperatures and dusty environment, in particular in road-building, agricultural and other machines and units.

For many years, attempts have been made to create a throttle flow divider design that would contain a shut-off and control element that is different from the traditional—spool. As a result, designs of throttle flow dividers with a locking and regulating element in the form of a spring have been developed (A. s. 496416 USSR), round rubber ring (A. c. 653433 USSR), cylindrical reinforced membrane (A. s. 931995 USSR, A. s. 1041773 USSR), choke dividers (Pat. USA 3729014, Pat. Japan 48-8974) and flow dividers-adders (Pat. Great Britain 1224731, Pat. France 1566897 Pat. Australia 430685) with flat pleated diaphragms and variable hydraulic resistances of the flat valve type.

Comprehensive analysis of known structures throttle flow dividers with shut-off and control elements of various types showed that of the greatest interest, from the point of view of application in operating conditions of technological equipment, mobile and other equipment of general and specialized purpose, are membrane-type throttling flow dividers with shut-off and control elements of the flat valve type.

The main disadvantage of diaphragm flow dividers with variable resistances of the flat valve type is that the pressure drop arising on the output resistances during the regulation process acts on the rigid center of the membrane element. The resulting effort is one of the main reasons for their very unsatisfactory performance in the steady state.

2 Materials and Methods

One of the simplest ways to eliminate the influence of the controlled differential pressure on the final control element is to use a flow divider design (A. s. 1156012 USSR), in which the membrane element does not have a rigid center, and the outlet openings are made in the form of narrow slots (Fig. 1). The change in the characteristics of the hydraulic resistance of the outlet slots in this design of the flow divider is carried out using the method of their partial overlap. In this case, the controlled differential pressure acts on that part of the membrane element that lies on the gap and does not take part in further regulation.

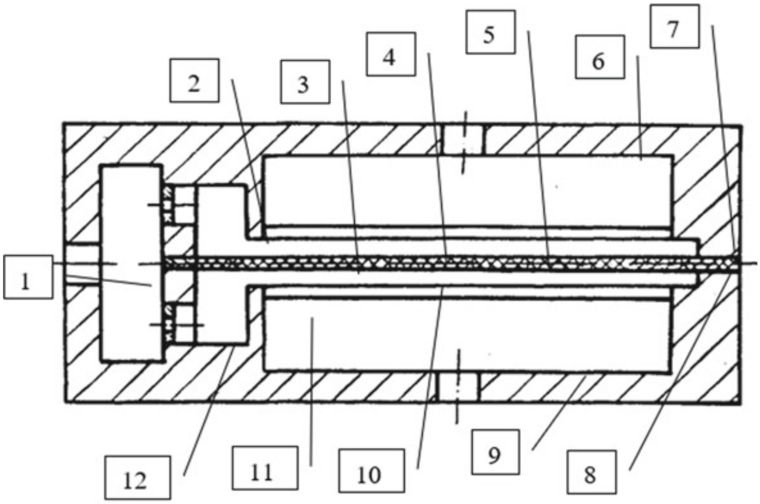


Fig. 1. Design of a flow divider

The presented flow divider consists of a sensitive and shut-off and control elements. The sensitive element of the divider is made in the form of input resistances (chokes) 2 and 12. The locking and regulating element of the divider includes an elastic membrane element 5 and variable hydraulic resistances 7 and 8, consisting of narrow slotted holes 4 and 10 in combination with an elastic membrane element 5.

The presented flow divider functions as follows:

- with a uniform load on the hydraulic actuator motors, the flow of working fluid from the pump enters the inlet 1 of the flow divider, after which it is divided in half and through the inlet resistances 2 and 12 with lower pressure enters the working subchambers 3 and 11. Further, through narrow slotted holes 4 and 10, the working fluid enters the outlet chambers and the associated outlet channels 6 and 9, and from there, with equal flow rates, into the corresponding hydraulic motors;
- with an increase in the load on one of the hydraulic motors, for example, on the hydraulic motor connected to the outlet 9, a decrease in the flow rate of the working fluid through the input resistance 12 occurs, since its flow rate in the entire branch has decreased. This leads to an increase in pressure in the working subchamber 11 as a result of which the membrane 5 is deformed, partially blocking the slot 4, the hydraulic resistance of which will increase and the flow rates of the working fluid

in the branches will be leveled. Thus, the diaphragm-type flow divider automatically reloads the branch with less load on the hydraulic motor [24, 25].

3 Results

The proposed mathematical model of membrane-type throttle flow dividers is designed to determine the forces acting on a flexible membrane in the process of regulating the static division error at various regulated pressure drops (different loads on synchronized hydraulic motors). The design diagram of the functioning of the membrane element is shown in Fig. 2.

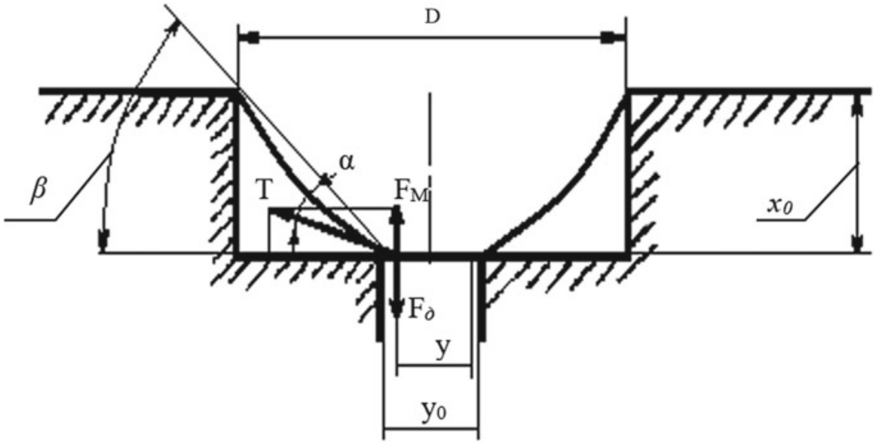


Fig. 2. Diagram of the membrane element

Considering the contact spot of the membrane with the base of the working subchamber as a rigid center, it is necessary to apply, to calculate the flow divider, the formula for calculating membranes with rigid centers (5).

The equilibrium equation for the point of separation of the membrane from the gap can be written in the form

$$F_m - F_d = 0 \tag{1}$$

where: Fm—vertical component of the force acting on the breakout point from the side of the membrane web; Fd—vertical component of the dynamic force of the jet passing through the open section of the slot.

It should be borne in mind that the force T is directed along a tangent drawn to the arc of the membrane from the point of its separation from the base of the working subchamber. Then the vertical component of the force of action of the free section of the membrane on the contact spot over the width of the slot is determined from the relation

$$F_M = T\mathrm{Sin}(\beta - \alpha) \tag{2}$$

where: T—force of action of the free section of the membrane on the contact patch; β—the angle formed by the chord connecting the pinching point of the membrane in the body with the point of separation of the membrane from the base of the working subchamber, lying with it in the same diametrical section and the base of the working subchamber; α—the angle between the chord and the tangent drawn to the sagging arc of the free section of the membrane from the point of its separation from the base of the working subchamber.

The force arising in the membrane web during its deformation within the outlet slit can be determined by the formula

$$\mathbf{T} = \frac{\Delta \mathbf{l}}{\mathbf{l}} \mathbf{E_m} \boldsymbol{\delta}_\mathbf{m} \mathbf{h_{av}} \tag{3}$$

where: l—length of free sagging of the membrane; Δl—elongation of the diaphragm web due to differential pressure; E_m—modulus of elasticity of the membrane web material in tension; δ_m—membrane web thickness; h_{av}—average width of the considered section of the membrane element web.

After carrying out the necessary transformations, we get

$$F_M = \frac{\gamma Q^2}{2g} \frac{2h_{av}\sqrt{\left(\frac{D-y}{2}\right)^2 + x_0^2}}{\mu_{th}^2 f_{th}^2 \mathrm{Sin}\alpha} \mathrm{Sin}(\beta - \alpha)\varphi, \tag{4}$$

where: x_0—control subchamber boring depth; y—the size of the gap overlap (diameter of the contact spot of the membrane with the base of the working subchamber); D—diameter of clamping of the membrane element in the housing; γ—specific gravity of the working fluid; g—acceleration of gravity; μ_{th}—input choke flow coefficient; f_{th}—free area of inlet chokes; φ—split-flow relative error.

$$\varphi = \frac{Q_1 - Q_2}{Q} \tag{5}$$

where: $Q_{1,2}$ and Q—flow rates of the working fluid in the branches and half of the total flow rate at the inlet of the flow divider.

The vertical component of the dynamic force is determined by the formula

$$F_d = Q_1\sqrt{\frac{\gamma}{g}} \Delta p_p \mathrm{Cos}(\beta - \alpha) \tag{6}$$

Adjustable differential pressure across the outlet slit Δp_p taking into account the flow division error, can be determined by the formula

$$\Delta p_{out} = \frac{\gamma Q^2}{2g} \frac{(1 + \varphi)}{\mu_{out}^2 f_{out1}} \tag{7}$$

where: μ_{out}—outlet slit flow coefficient; $f_{p1} = (y_0 - y)\,\delta_s$—free area of the open section of the regulating slot; y_0—length of the exit slit in the open state.

Then

$$F_d = \frac{\gamma Q^2}{2g}\frac{\sqrt{2}(1+\varphi)^2}{\mu_{p(\gamma_0+y)}}Cos(\beta-\alpha) \tag{8}$$

In this case, the regulated pressure drop is determined by the formula

$$\Delta p = \Delta p_{out} - \Delta p_s - \Delta p_{th} \tag{9}$$

where: Δps—opening resistance of the second branch; Δpth—differential pressure across the diaphragm element (differential pressure loss across the sensing elements).

$$\Delta p_s = \frac{\gamma Q^2}{\mu_s^2 f_s^2 2g}(1+\varphi)^2 \tag{10}$$

$$\Delta p_{th} = \frac{\gamma Q^2}{2g}\frac{4}{\mu_{th}^2 f_{th}^2}\varphi \tag{11}$$

where: μ_s—open slot resistance flow rate; f_s—open area of the adjustable slit.

Then the controlled differential pressure across the flow divider is determined from the expression

$$\Delta p = \frac{\gamma Q^2}{2g}\left(\frac{(1+\varphi)^2}{\mu_{out}^2 f_{out}^2} - \frac{(1-\varphi)^2}{\mu_s^2 f_s^2} + \frac{4\varphi}{\mu_{th}^2 f_{th}^2}\right) \tag{12}$$

Values of angles α and β can be determined by the formulas:

$$tg\beta = \frac{2x_0}{D-y} \tag{13}$$

$$\alpha = \frac{lSin\alpha}{\sqrt{\left(\frac{D-y}{2}\right)^2 + x_0^2}} + \frac{yQ^2}{2g}\frac{2l}{\mu_{th}^2 f_{th}^2 E_m \delta_m}\varphi \tag{14}$$

Thus, taking into account the expressions (1), (4), (8) and (12–14) the mathematical model of the operation of a flow divider of the type under consideration in a static mode will take the form of a system of Eq. (15):

$$\begin{gathered}
\frac{2h_{av}\sqrt{\left(\frac{D-y}{2}\right)^2 + x_0^2}}{\mu_{out}^2 f_{out2} Sin\alpha}Sin(\beta-\alpha)\varphi - \frac{\sqrt{2}Cos(\beta-\alpha)}{\mu_{out}(y_0-y)\delta}(1+\varphi)^2 = 0 \\
\alpha = \frac{lSin\alpha}{\sqrt{\left(\frac{D-y}{2}\right)^2 + x_0^2}} + \frac{yQ^2}{2g}\frac{2l}{\mu_{th}^2 f_{th}^2 E_m \delta_m}\varphi \qquad (15) \\
\Delta p = \frac{\gamma Q^2}{2g}\left(\frac{(1+\varphi)^2}{\mu_{out}^2 f_{out}^2} - \frac{(1-\varphi)^2}{\mu_s^2 f_s^2} + \frac{4\varphi}{\mu_{th}^2 f_{th}^2}\right)
\end{gathered}$$

Checking the adequacy of the mathematical model: to construct the load and speed static characteristics of the synchronization system based on a membrane-type throttle flow divider with variable hydraulic resistances in the form of narrow slots of variable length, the system of Eq. (15) is been solved on division error (φ), of the adjustable differential pressure (Δout) and half of the flow rate at the inlet of the divider (Q).

Figure 3 shows the load characteristics: sync error dependence (φ) from the pressure drop (Δout) in the branches of the model of the diaphragm-type throttle flow divider, for different values of the slot width.

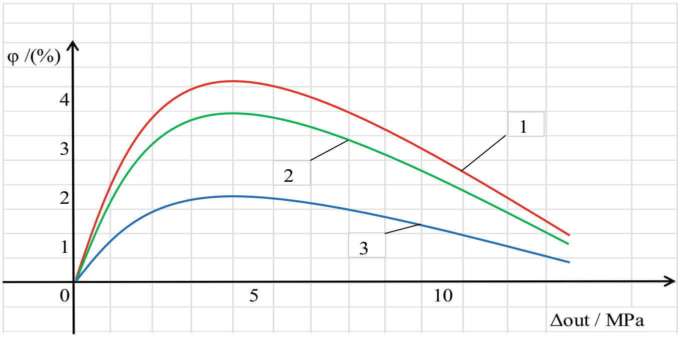
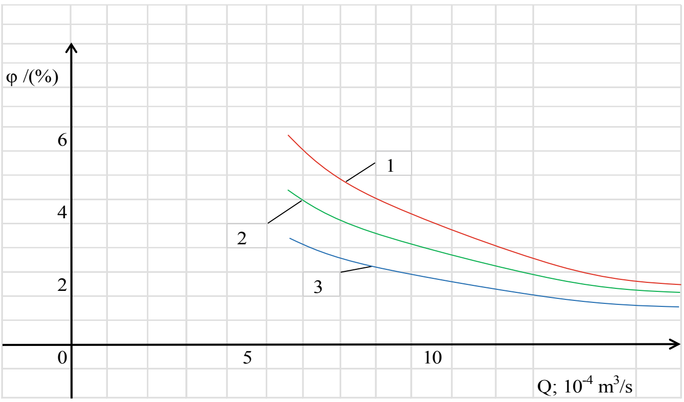


Fig. 3. Load characteristics

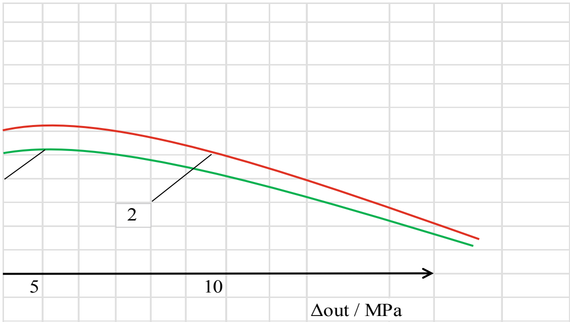
Figure 4 shows the speed characteristics: fission error dependence (***φ***) from outlet (***Q***) at the inlet to the throttle flow divider, for different values of the slot width.



1 – $\boldsymbol{\delta_s}$ = 1,2 mm; 2 – $\boldsymbol{\delta_s}$ = 1,0 mm; 3 – $\boldsymbol{\delta_s}$ = 0,7 mm;

Fig. 4. Speed characteristics

The proposed mathematical model of a membrane-type throttling flow divider with variable hydraulic resistances in the form of slots of variable length allows calculating



1 – first branch; 2 – second branch.

Fig. 5. Loading characteristics of various branches of a prototype flow divider with a membrane element thickness of 1.2 mm

the design parameters of a flow divider that meets the requirements for a flow divider by the corresponding synchronous hydromechanical system [26, 27].

The adequacy of the proposed mathematical model was confirmed by experimental studies in the development of a throttle flow divider for hydraulic drives of cotton pickers (7). In the course of the work, the main design parameters of the flow dividers were calculated, the experimental samples were subjected to both laboratory and field tests.

4 Conclusion

Within the framework of this article, on the basis of the performed theoretical and empirical studies, a mathematical model of a membrane-type throttle flow divider with variable hydraulic resistances in the form of slots of variable length is considered and proposed. Based on the research results, the following conclusions can be formulated that have scientific and practical significance:

- the proposed mathematical model of a diaphragm-type throttle flow divider with variable hydraulic resistance in the form of slots of variable length allows calculating the design parameters of flow dividers that meet the requirements for flow dividers by the corresponding synchronous hydraulic drive;
- the verification of the adequacy of the mathematical model of the membrane-type throttle flow divider, confirmed the operability of the device and its practical potential.

The tasks set in the article have been solved in full.

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Modification and Software Implementation of Mceliece Cryptosystem

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Abstract. This article addresses issues related to the modification of the McEliece cryptosystem. The software development presented in this article is crypto stability, the original McEliece algorithm is post-quantum, unlike its counterparts. The theoretical description of the McEliece cryptosystem was considered. More cryptographically secure combinations are considered for the selection of various parameters, and an estimate of the algorithm's strength is calculated when these parameters are taken into account or not. A mathematical model of the original algorithm was developed. It analyzes the original McEliece algorithm and modifications with leader decoding and decoding over Hamming distance. The result was confirmation that the original algorithm was the most efficient. When analyzing the modifications among themselves, it was concluded that the operating time of the modification in terms of the Hamming distance practically did not differ from the original, but significantly differed from the modification of the leader decoding. The leader decode modification was found to be the most ineffective. The program itself was written in the object-oriented Python 3 language, development environment—IDLE.

Keywords: Cryptographic system · Post-quantum cryptographic algorithm · Cryptographic strength · Leader decoding · Hamming distance decoding

1 Introduction

The idea for developing the implementation of the post–quantum algorithm was the publication [1]. It analyzes modern post–quantum algorithms and their use for creating quantum era cryptosystems, and consider the strengths and weaknesses, the various modifications, and the prospects of using post–quantum algorithms.

The software development presented in this article is crypto resistance and stability. The original McEliece algorithm is post-quantum, unlike its counterparts. The cryptosystem itself is notable because it uses randomization in the encryption process [2, 3]. Previously, the algorithm has not been implemented programmatically, as well as ways to decode it were not considered. This is the relevance of the work.

The object of the research is McEliece cryptosystem.

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The subject of investigation is the algorithmic complexity of the development of the McEliece cryptosystem and its decoding methods.

Research objectives are the development of original algorithm of McEliece cryptosystem using the asymmetric encryption and basing on the algebraic coding theory. In this regard, it has high cryptographic resistance and stability to various types of cyberattacks. Development of decoding methods, analysis and experimental testing of temporal indicators of the selected methods are the aims of investigations also.

In accordance with the set goal, the following tasks were identified:

1. Research of McEliece cryptosystem operation algorithm.
2. Implementation of McEliece cryptosystem software and methods for its decoding.
3. Analyze and compare of temporal indicators at decoding by various methods.

Starting points, McEliece cryptosystem uses asymmetric encryption and is based on algebraic coding theory. This is the first algorithm that uses randomization in the encryption process. The cryptosystem is not widespread, but is possible for using in post-quantum cryptography because it is resistant to the cyberattack based Peter Shor quantum algorithm. This cryptosystem has high rate of cryptographic conversion and the ability to combine error control with protection from unauthorized access (tamper protection).

Enough long time, it was believed that it was impossible to implement an electronic digital signature based on McEliece algorithm. However, it became possible to implement the scheme of electronic digital signature based on Niederreiter cryptosystem, which is the modification of McEliece encryption system.

The analysis of cryptographic strength of considered McEliece encryption system shows that it is necessary to take into account the minimal values of the matrix parameters n (code length) and k (dimensionality) for reliable information protection. Also from parameter t (the number of errors corrected by the code) directly depends on the noise immunity of algorithm. Cryptosystem provides reliable information protection when the minimal boundary requirements for system parameters are fulfilled ($n = 1024$, $k = 524$, $t > 50$), which confirms the number of unsuccessful attempts to hack it.

2 Mathematical Model and Solution Method

McEliece cryptosystem is in development process. This system has undeniable advantages, such as high rate of cryptographic conversion, as well as the ability to combine error control with protection against unauthorized access. This cryptosystem, which is based on asymmetric encryption, uses randomization in the encryption process and can be used in post-quantum cryptography. Importantly, such cryptosystem remain resistant even when using quantum cyberattacks.

Table 1 describes the levels of cryptographic strength of McEliece cryptosystem.

Development of mathematical model of McEliece cryptosystem, McEliece cryptosystem consists of three algorithms:

Table 1. Description of McEliece cryptosystem cryptographic strength levels

Parameters	Cryptographic strength (resistance) levels		
	Sufficient ($2^{80}\ldots2^{123}$)	High ($2^{192}\ldots2^{256}$)	Ultra-high ($>2^{512}$)
Parameters (n, k, d)	(2048, 1300, 137)	(4096, 2584, 253)	(16384, 10322 867)
Secret key size, bits	1 712 528	6 726 208	169 115 648
Public key size, bits	2 662 400	10 584 064	169 115 648
Encryption complexity, bit operations	2.6×10^6	1.1×10^7	1.7×10^8
Decryption complexity, bit operations	6.2×10^6	2.7×10^7	5.1×10^8
Resistance assessment	102	186	636
Evaluation of resistance to quantum cryptanalysis, bit	49	91	310

1. Random key generation algorithm that gives public and private keys;
2. Random encryption algorithm;
3. Deterministic decryption algorithm.

During key generation user ***A*** chooses parameters (***n, k***)—the linear code ***C*** correcting ***t*** errors. Then generating matrix ***G (k × n)*** is calculated for the code ***C***.

Then the user ***A*** generates the random ***k × k*** non-degenerate matrix ***S*** to make the source code difficult to recover. After that, it generates permutation matrix ***P (n × n)***. Then the user calculates the matrix $\bar{G}$ (***k × n)*** by the formula:

$$\overline{\mathrm{G}} = \mathrm{SGP} \tag{1}$$

The resulting pair ***($\bar{G}$, t)*** is the public key. The set ***(S, G, P)*** is the private key [3].

When encrypting, user ***B*** wants to send to user ***A*** the message ***m***, then: user ***B*** represents his message ***m*** as sequence of binary symbols of length ***k***, generates the random vector ***z*** of length ***n*** having Hamming's weight ***t***.

After that, it calculates the ciphertext using the formula:

$$\mathrm{c} = \mathrm{m}\overline{\mathrm{G}} + \mathrm{z} \tag{2}$$

During decryption, user A, having received message c, performs the following actions to decrypt the ciphertext: calculates the inverse matrix P–1, then calculates:

$$\hat{c} = \mathrm{cP}^{-1} \tag{3}$$

User A gets ḿ from ĉ, applicating the decoding algorithm for code C, and calculates the open text by the formula:

$$\mathrm{m} = \acute{\mathrm{m}}\,\mathrm{S}^{-1} \tag{4}$$

As a result, after using the algorithm, user A receives the message sent by user B.

In leader (high-time) decoding, it is considered (n, k)-code, which is given over the field F2, defined by matrices G and H. Next, the tables are creating that are used for the decoder operation. To get the code words for the first table the formula is used:

$$c = iG \tag{5}$$

The second table includes the syndromes and classes leaders (or error vectors that were caused by appearance of corresponding syndrome). Thus, the decoding algorithm that was derived from the word channel v looks as follows:

1. In the first step, the syndrome is calculated:

$$s = vH^{To} \tag{6}$$

If the syndrome ***s*= *0***, the code word ***c*= *v***, then you should skip the second step and go to the third step, otherwise it is need to find this syndrome in the second table [4].

2. In the second step is necessary to summarize the vector ***v*** obtained from the channel and the error vector ***e***, which corresponds to the syndrome of the second table:

$$c = v + e \tag{7}$$

3. In the third step, it is assumed that the word ***c*** is the correct codeword, it can be found in the first table; this will be the resultant information word [5, 6].

Hamming's distance decoding uses codeword table. The vector v obtained from the channel is compared with the list of code words and then it is seen, that in the sense of Hamming distance, the resulting word will be closer to one of the rows of table. It can be assumed that information word corresponds to the vector obtained from channel.

In the first step, the syndrome is calculated, then the corresponding error vector is finding. Then error vector and the vector that was received through the communication channel are summing. The resulting vector is finding in the table of code words.

The corresponding information vector is the result of decoding [7].

Chosen programming language is object-oriented language Python 3. Development environment is IDLE. Main advantage of this software product is implementation of original McEliece algorithm, not developed previously in other sources, which has high cryptographic resistance to the various kinds of attacks.

2.1 Program Implementation

Code with parameters n, k, t is chosen to generate the keys. The generating matrix G, non-degenerate matrix S, permutation matrix P are generated randomly, after which the matrix G′ is calculated, as the product of the three obtained matrices.

The pair (G′, t) is the public key, (S, G, P) is the private key [8–13].

When the user B wants sending to the user A the message m, first he must to generates vector with weight 2, and then he computes the ciphertext c. User A, having received the message c, calculates the inverse matrix P^{-1} and the express $\hat{c} = cP^{-1}$ [14, 15].

Then it obtains ḿ from ĉ using the decoding algorithm for code C.

Finally, it finds m = ḿS–1.

The result of the original algorithm is shown in the Fig. 1.

```
User B:
 wants to send a message to user A m = [1 0 1 0 1 1 0 1]
    generates an error vector with Hamming weight t=2 z = [0 0 0 0 0 0 0 0 0 0 0 0]
    calculates and transfers the ciphertext to the user A
 c = m*G'+z = [1 0 1 0 1 0 0 1 0 0 1 1]

User A:
 receives ciphertext
 calculates c' = c*P^-1 = [1. 1. 0. 0. 1. 0. 0. 1. 0. 0. 1. 1.]
   using the decoding algorithm finds m' = mS = [1. 1. 0. 0. 1. 0. 0. 1.]
   calculates m = m'*S^-1 = [1. 0. 1. 0. 1. 1. 0. 1.]
Messages match, decryption is correct
--- 0.23435235023498535 seconds ---
```

Fig. 1. Operation of McEliece algorithm

If parameters are set, the calculations are performed automatically. It can be seen the whole process of constructing the necessary matrices, with help of which the pair of public and private keys is obtained, and then the interaction of two users in exchange of messages, as well as confirmation that message was received without distortion.

The operation of Hemming's distance algorithm is demonstrated in the Fig. 2.

3 Results of Research

Comparison of the modification with the standard algorithm, the purpose of experimental research—is comparison at the stage of decoding of original algorithm with its modifications. At the analysis of results, let us note the advantages and disadvantages of the given realizations.

For the experimental part we used the function time.time()—start_time, which calculates the total running time of the software product. Table 2 shows the results.

The results of the decoding modules are demonstrated in the Fig. 3.

This graph shows clearly that the use of leader decoding is inefficient. It loads the work of the program on time, and there is the gap of 0.3 from the original algorithm and another its modification. Difference between original algorithm and Hemming's distance decoding one is practically the same.

Module running time 2 is shown in the Fig. 4.

The graph of operation of the decoding modules is shown separately. From two modifications, Hemming's distance decoding has advantage also.

```
User A calculates an 8 * 12 matrix G '= S * G * P =
 [[1 1 1 1 1 1 1 1 0 1 1 0]
 [0 1 1 1 1 1 1 1 1 0 0 1]
 [0 1 0 1 1 1 1 1 0 0 0 1]
 [0 0 0 1 1 1 1 1 1 0 0 0]
 [0 0 0 0 1 1 1 1 0 0 1 0]
 [0 0 0 0 0 1 1 1 1 1 1 0]
 [0 0 0 0 0 0 1 1 0 1 0 0]
 [0 0 0 0 0 0 0 1 1 0 0 0]]

Pair (G ', t) - public key.
Set (S, G, P) - private key.

User B: \ n wants to send a message to user A m = [0 0 0 0 0 0 0 0]
    generates an error vector with Hamming weight t=2 z = [0 1 0 0 0 0 0 0 0 0 0 0]
    calculates and transfers the ciphertext to the user A \ n c = m*G'+z = [0 1 0 0 0 0 0 0 0 0 0 0]

User A: \ n receives ciphertext \ n calculates c' = c*P^-1 = [0 0 1 0 0 0 0 0 0 0 0 0]
   using the decoding algorithm finds m' = mS = [0 0 0 0 0 0 0 0]
   calculates m = m'*S^-1 = [0 0 0 0 0 0 0 0]
Messages match, decryption is correct
--- 0.15816211700439453 seconds ---
--- 0.03997325897216797 seconds ---
```

```
Key generation:
   Selected (12, 8) - linear code.
   Calculate the generating matrix G of size 8 * 12:
[[1 0 0 0 0 0 0 0 1 1 1 1]
 [0 1 0 0 0 0 0 0 1 0 0 0]
 [0 0 1 0 0 0 0 0 1 0 0 1]
 [0 0 0 1 0 0 0 0 1 0 1 0]
 [0 0 0 0 1 0 0 0 1 1 0 0]
 [0 0 0 0 0 1 0 0 1 0 1 0]
 [0 0 0 0 0 0 1 0 1 1 0 0]
 [0 0 0 0 0 0 0 1 1 0 0 0]]

   A non-degenerate 8 * 8 matrix S is generated:
 [[1 1 1 1 1 1 1 1]
 [0 1 1 1 1 1 1 1]
 [0 0 1 1 1 1 1 1]
 [0 0 0 1 1 1 1 1]
 [0 0 0 0 1 1 1 1]
 [0 0 0 0 0 1 1 1]
 [0 0 0 0 0 0 1 1]
 [0 0 0 0 0 0 0 1]]

   A 12 * 12 permutation matrix P is generated:
 [[1 0 0 0 0 0 0 0 0 0 0 0]
 [0 0 1 0 0 0 0 0 0 0 0 0]
 [0 1 0 0 0 0 0 0 0 0 0 0]
 [0 0 0 1 0 0 0 0 0 0 0 0]
 [0 0 0 0 1 0 0 0 0 0 0 0]
 [0 0 0 0 0 1 0 0 0 0 0 0]
 [0 0 0 0 0 0 1 0 0 0 0 0]
 [0 0 0 0 0 0 0 1 0 0 0 0]
 [0 0 0 0 0 0 0 0 1 0 0 0]
 [0 0 0 0 0 0 0 0 0 1 0 0]
 [0 0 0 0 0 0 0 0 0 0 1 0]
 [0 0 0 0 0 0 0 0 0 0 0 1]]
```

Fig. 2. Operation of the Hemming distance algorithm

4 Discussion and Conclusions

As part of this work is implemented:

- Theoretical description of McEliece post-quantum cryptoalgorithm is studied;
- The software tool that implements the operation of the McEliece cryptosystem;
- The software tool that implements the modifications of this cryptosystem;
- Testing of realized software tools was performed.

Table 2. Results of measured time experiment results

No.	The original algorithm	Modification with leader decoding	Modification with Hemming distance decoding	Leader decoding	Hemming distance decoding
1	0,213174105	0,475461721	0,184016705	0,329535723	0,048004627
2	0,277795553	0,446060181	0,200155497	0,287026644	0,04300189
3	0,185458183	0,515637159	0,185013771	0,33403039	0,039005041
4	0,193013906	0,490050316	0,204837799	0,336036444	0,04282546
5	0,194011211	0,426993847	0,203558207	0,280020952	0,045003891

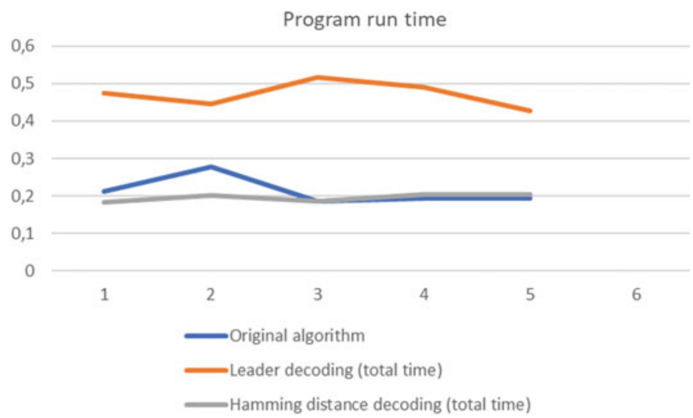

Fig. 3. Module running time 1

Comparative characteristic was carried out by the time criterion of processing.

The considered cryptosystem has undeniable advantages: high speed of cryptographic conversion, as well as the ability to combine error control with protection against unauthorized access. What is important is that such cryptosystems remain crypto resistant and persistent even when quantum cyberattacks is used. In addition, the plus is that so far the McEliece cryptosystem is not amenable to cryptanalysis.

The cryptosystem has some disadvantages that do not affect the cryptographic resistance (strength) of the algorithm, but make it difficult to use.

Experimentally proved the advantage of using the original algorithm, it surpasses its modifications in time. The developed software tool is unique because it has not previously been implemented programmatically in other sources. The post-quantum algorithm is highly crypto-resistant, so attempts to crack it will not yield good results.

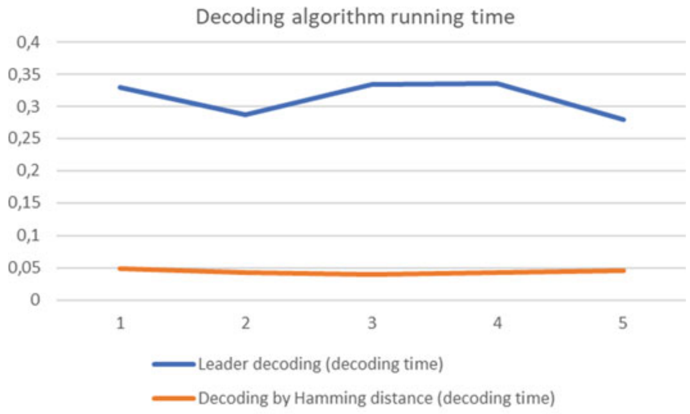

Fig. 4. Module running time 2

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Investigation of the Causes of Defects in the Section of Steel Rope Splicing

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Abstract. The article presents the materials of examinations carried out during a full-scale examination of the process of splicing a steel rope, conducting a magnetic defectoscopy and subsequent observations of the performance of a steel rope at the ski resorts of Krasnaya Polyana. The results of studies of the causes of the formation of "waviness" defects in the splicing section of the steel rope, as well as defects in the form of wire breakage of the steel rope in the splicing section and a defect in reducing and increasing the diameter of the steel rope in the splicing section are presented.

Keywords: Rope transport · Steel rope · Steel rope splicing · Magnetic flaw detection

1 Introduction

For modern designs of steel ropes, the manufacturer declared a high service life for a period of 15–20 years. However, as studies have shown, it is noted that after 5–6 years, structural defects appear at the splices, such as: breaks and external wear of wires, a decrease and increase in the diameter of the rope as a result of damage to the core, loss of internal section, formation of "waviness" [1–16].

For ropeways, according to their design and operational features, the use of endless (closed) steel ropes is characteristic. An endless (closed) steel rope is connected into a closed (one-piece) ring, with the formation of a splicing section on it, called a link. Splicing means a certain length of a section of a steel rope, where by connecting two adjacent ends of the rope, strands of the outer layer are interwoven into the place of the removed organic core, for a length to form butt locks (nodes) of splicing.

2 Results and Discussion

2.1 Investigation of the Causes of the Formation of Defects "waviness" of the Steel Rope at the Splicing of the Steel Rope

Steel rope is a complex mechanical system in which, when bent on pulleys, there is a mutual movement of strands and wires by their relative sliding and rolling [3, 14].

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Physical modeling of the process of splicing steel ropes made it possible to establish the causes of the occurrence of structural defects arising in the section of joining steel ropes [15].

When operating ropeways, a prerequisite for the operability of a steel rope is the uniform distribution of the resultant load between all wires and strands in the cross section of the steel rope. When splicing a rope, it is necessary to take into account not only the tensile load, but also the relative torsion of the rope, thereby preventing the strand from rotating around its axis in relation to the rest. The resultant load Px with uniform loading of the strands of the rope is applied to the center, which provides an equal tangential gap Δ between the strands during its operation. If the resultant load is displaced by the eccentricity value "e" relative to the center of the rope, then the resultant load Rx forms a certain helical line around the rope axis, which leads to uneven loading of the rope strands and displacement of the tangential gap Δ between them (Figs. 1 and 2).

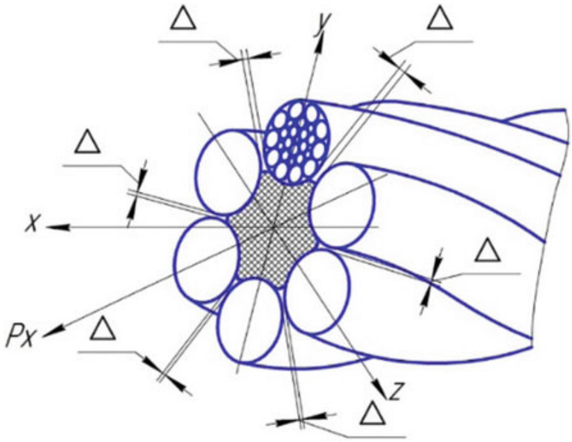

Fig. 1. Model of a rope of construction 6 × 26 (1 + 5 + 5/5 + 10) WS-SPC 1600 B zZ, which has no waviness defect: Δ—tangential gap between strands of wire rope; P_X—resultant load in the cross section of the wire rope.

When the docking locks are formed, along the entire length of the splicing, the geometric integrity of the cross-section of the steel rope is violated along the length of the interwoven strands and the resultant load is redistributed, applied to the center of each strand [3]. The resultant load is displaced relative to the axis of the steel rope by the amount of eccentricity e (Fig. 3).

The impossibility of ensuring the constancy of the lengths of each interwoven strand in the conditions of the existing technology of manual splicing leads to a total displacement of the resultant load in the cross section of the steel rope during its operation. The formation of uneven loading in each docking joint causes a torque, resulting in the formation of a defect "waviness" (Fig. 3).

With the existing splicing technology, the interwoven strands are in a fixed (clamped) state and, when the steel rope is bent around the pulley (drum), do not provide the required mobility of the strands (Fig. 4). In the system of the friction pair "strand-core-strand",

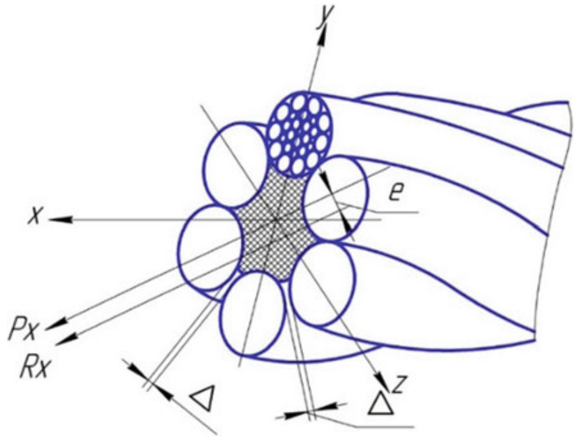

Fig. 2. Model of a rope of construction 6 × 26 (1 + 5 + 5/5 + 10) WS-SPC 1600 B zZ, which has a waviness defect: R_X—resultant load in the cross-section of a defective steel rope waviness; e—the value of the eccentricity of the application of the resultant load R_X

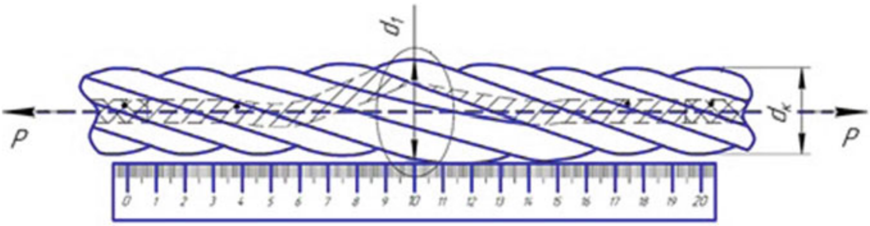

Fig. 3. Violation of the geometric integrity of the steel rope in the docking joint at the splice section.

when the steel rope is cycled around the pulley (drum), in the "knot" docking lock, the effect of "biting" of the interwoven strands occurs, which during operation leads to the formation of the "waviness" defect (Fig. 5) [17–26].

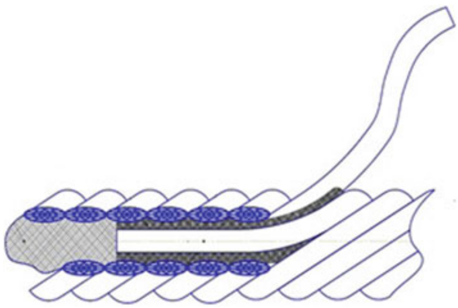

Fig. 4. Model of the cross-section of the docking joint of the "knot" of the steel rope link with the existing splicing technology.

Fig. 5. Photo of a defective section of a rope with a diameter of 48 mm, construction 6 × 26 (1 + 5 + 5/5 + 10) WS-SPC 1600 B zZ with "waviness" defect.

The formation of a waviness defect is characterized by the relative torsion of the steel rope around its axis (Fig. 6). The force redistribution of the tensile load in the splice section, in which a defect appears in the form of "waviness" [9], indicates the mechanism of uneven loading of one or several strands of the supporting-traction rope, which characterizes a poor-quality splicing.

Fig. 6. Photo of a defective section of a rope with a diameter of 48 mm, construction 6 × 26 (1 + 5 + 5/5 + 10) WS-SPC 1600 B zZ with visual twisting around its axis.

2.2 Investigation of the Causes of Defects in the Section of Steel Rope Splicing

As a result of the displacement of the resultant load in the cross section of the spliced section of the steel rope, the level of its safety during operation is significantly reduced. When the defect "waviness" is formed, the geometric integrity of the cross-section of the splicing section of the steel rope is violated, as a result of the displacement of the resultant load. When the rope is bent on the pulley, the load in the cross section of the wire increases due to the additional tensile and bending stresses that arise and exceeds the design characteristics, therefore, the wires of the most loaded strand begin to break with a smaller number of loading cycles (service life), which leads to the formation of a defect in the form breakage of wires (Fig. 7) [14].

Fig. 7. Photo of a defective section of a steel rope linkage with a diameter of 48 mm, construction 6×26 (1 + 5 + 5/5 + 10) WS-SPC 1600 B zZ with a wire break in one of the strands.

Damage to the wires of the inner layer is confirmed by the results of magnetic flaw detection and indicates that the strand, being in a rigidly fixed state in the splice lock, undergoes not only tensile forces, but also compression when the rope is bent on the pulley (Fig. 7).

Full-scale detection of the presence of corrosion on the surface of the wires, indicates damage to the surface layer of zinc as a result of friction of adjacent strands against each other when the steel rope bends around the pulley (drum) and confirms the violation of the geometric integrity of the cross-section of the rotation unit caused by miscalculations along the length of each braided strand in the docking lock (node). The presence of corrosion on the surface of the wires does not belong to rejection indicators, but the nature of the damage to the surface layer indicates an adjacent touch during the relative movement of the strands and wires of the steel rope without lubricants (Fig. 8).

2.3 Investigation of the Causes of Defect Formation in Decrease and Increase in the Diameter of Steel Rope at the Link Section

The resulting uneven loading for all interwoven strands is caused by errors (miscalculations) by a team of specialists with the existing manual splicing technology and is expressed in relative errors along the length of each interwoven strand of steel rope. Errors in the length of each interwoven strand are caused by the influence of hazardous factors on the team of specialists and are caused by the complexity of the technological process and the intensity of work of the team of specialists of the cross-linkers, in the course of the work on the calculation and design of the main parameters of the cross-link.

Fig. 8. Photo of a defective splicing section of a steel rope with a diameter of 48 mm, construction 6 × 26 (1 + 5 + 5/5 + 10) WS-SPC 1600 B zZ with the presence of corrosion of damaged wires of one of the strands.

In conditions of impossibility of ensuring the accuracy of the length of the interwoven strand, there is a lack of support for the strands of the outer layer. When cutting off a strand with excessive length, there is an excessive effect at the point of contact of the strand with the organic core, which leads to a local increase in the diameter of steel rope [7–10]. When cutting a strand of small length, on the contrary, insufficient contact of the strand with the organic core occurs and areas of voids are formed, due to the lack of support for the outer strands, a localized decrease in the diameter of the steel rope occurs. Deviation of the diameter of steel rope from its nominal value by more than 10%, up or down, is a rejection indicator. Operation of steel rope with a structural defect in the form of local increase or decrease in diameter can lead to the outer layer strands damage and the organic core destruction (abrasion) (Fig. 9a and b).

a b

Fig. 9. Photo of a defective section of a steel rope bridging with a diameter of 48 mm, construction 6 × 26 (1 + 5 + 5/5 + 10) WS-SPC 1600 B zZ with the presence of: **a** local reduction of the diameter; **b** local increase in diameter

As a result of the operation of a steel rope, with a defect in the form of a local deviation from the nominal diameter, damage (abrasion) of the polymer organic core occurs in the section of the link with strands of the outer layer (Fig. 10). Damage to the core is characterized by the presence of additional mobility of the strands of the outer layer due to lack of support and is formed as a result of the loss of a lay in the place of localized deviation of the rope diameter from the nominal one.

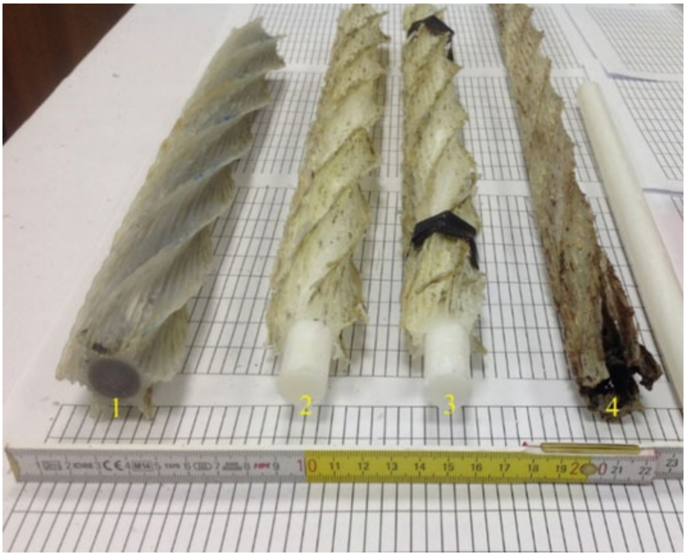

Fig. 10. Photo of fragments of polymeric organic cores at the splicing section of a steel rope with a diameter of 48 mm, construction 6 × 26 (1 + 5 + 5/5 + 10) WS-SPC 1600 B zZ: 1—initial view of the core without damage; 2, 3, 4—cores with mechanical damage from strands

3 Output

The existing manual method of splicing technologically does not allow to ensure uniform loading of all strands to be tucked, due to errors arising in the length of each tucked strand, which directly depends on the human factor (experience and professionalism) during the work.

A structural defect in the form of wire breaks in one of the strands in the splicing section in the presence of a structural defect "waviness" [3, 14] is caused by the absence of lubricants in the docking joints "nodes", when subjected to a tensile load during bending of the steel rope on the pulley (drum) [27–32].

The process of formation of structural defects indicates a violation of the physical and mechanical characteristics of the steel rope at the splicing site and leads to its premature wear. Violation of physical and mechanical characteristics is caused by errors (miscalculations) in the course of work on the splicing of a steel rope, which are caused by the impact of hazardous factors on the team of specialists and lead to a decrease in the quality of work in general. The presence of structural defects in the splicing section of the steel rope indicates a violation of the calculation and design standards for splicing and characterizes the shortcomings in the existing technology for carrying out work on the splicing.

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Municipal Waste Management in an Urbanized Environment Based on Ropeway Technology

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Abstract. The article presents the results of studies that make it possible to increase the efficiency of transport logistics, the culture of production and technical maintenance of the equipment used when disposing of solid household waste in an urbanized environment using rope transport. The method includes reloading household waste from adjoining containers using hinged manipulators installed on a vehicle equipped with at least one standard size with fastening units, a unified container. The latter is equipped with pressing equipment for compaction. After reloading, subsequent delivery is carried out to at least one site, loading and unloading operations are carried out at the said sites from a motor vehicle to vehicles and transported to a waste sorting, processing and disposal point. After that, the method uses conveyor production, based on the use of a cargo suspended cable car for the removal of solid household waste with a sequential combination of transportation, washing, treatment with antiseptic drugs, maintenance, waiting and storage of means for transporting solid waste. The method allows simplifying and reducing technological operations for the collection and transportation of solid household waste, to reduce the time between waste collection and disposal, to increase the efficiency of waste disposal, to improve the ecological state of settlements.

Keywords: Rope transport · Transport logistics · Solid waste disposal

1 Introduction

Human activity is associated with the generation of a large amount of waste. The current situation in the world with the generation and disposal of solid household and industrial waste leads to environmental pollution, irrational use of natural resources and economic damage.

Solid household waste includes waste generated in apartment buildings in the process of consumption by individuals, goods that have lost their consumer properties in the process of using them to meet personal and domestic needs, as well as waste arising from the activities of individual enterprises and legal entities.

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Basically, waste is taken to landfills, the so-called authorized and unauthorized dumps.

Removal of solid household waste is carried out from temporary storage sites to a garbage transfer station or to an object for processing or destruction [1–8].

Removal of solid household waste includes the following main works: coordination of transport routes; coordination of daily and hourly schedules for the movement of garbage trucks; transportation of solid waste from temporary storage and (or) disposal.

Transport services have a significant impact on the efficiency of the entire process of handling solid household waste and the expenditure side of the regional budget.

The process of transportation of solid household waste is greatly influenced by the following factors: population size; development of the road network and transport infrastructure; quality of transport services; the degree of improvement of the housing stock; architectural and planning composition of the city; economic potential and needs.

Specialized equipment performs its work in a technological mode, while the duration depends on the population density in the served area and the location of waste collection sites. After loading and filling the body, the vehicle delivers solid household waste to the places of their disposal or collection points for further transportation.

The existing concept of waste disposal depends on the distance of the settlement to the place of disposal, planning and development of the territory, the type of residential premises (multi-story and low-rise buildings), collection technology, type of specialized technical means [9–16].

The transportation process is of two types: direct export and two-stage with intermediate transshipment at the station. The first option applies only if the distance to the place of unloading is 15–17 km.

The cost of transporting waste from places of generation to the place of their disposal is 80% of the total.

The disadvantages of this method are the use of a larger number of vehicles (road, rail or water), large mileage in the transport system for the removal of municipal waste, the need to create an infrastructure for rail or water transport.

The choice of transport is determined by the established collection technology. Consider the following: the maximum permissible load on the roadway; territory planning (width of driveways, availability of places for turning, etc.); quantity and quality of waste [17–26].

The efficiency of the existing collection system decreases with an increase in the mileage to the disposal site, and the cost of the service increases depending on the distance from the landfills or processing complexes. Another disadvantage is the low compaction ratio.

2 Results and Discussion

Solid household waste has a different origin (in addition to waste generated by the population, it also includes waste produced by restaurants, trade enterprises, institutions, municipal services) and various properties: some municipal waste, for example, is classified as hazardous.

The term "waste management" includes the organization of waste collection and transportation, measures to reduce the amount and/or volume of waste, as well as their disposal (including recycling, incineration, burial, etc.).

The purpose of the proposed method of organizing the collection and transportation of waste is to create a simple, convenient, environmentally and economically beneficial organizational structure for municipal waste management.

The technical result achieved by the implementation of the proposed method consists in reducing the overruns of motor vehicles and the consumption of fuel and lubricants, reducing the load on highways, reducing additional costs for creating the infrastructure of railway or water transport, improving the environmental situation and increasing the production culture.

The specified technical result is achieved due to the fact that in the proposed method for the removal of solid household waste, they are collected by motor vehicles, each of which is equipped with a unified removable container, which is loaded with waste, compacted and vacuumized with the appropriate equipment located on the vehicle. Next, the containers are transported by road vehicles to at least one site (transport and logistics point), with their subsequent reloading onto a cargo suspended ropeway for delivery to landfills or waste processing plants, where the container is moved to an intermediate slowdown conveyor, on which perform the operations of automatic unloading of the container, then along the route, its washing and treatment with antiseptic drugs, routine maintenance and, if necessary, repairs. Further, the container is returned from the intermediate accelerating conveyor to the main route, delivering the container in the opposite direction to the transport and logistics center with further reloading onto a motor vehicle with delivery to the city limits.

The collection and pressing (compaction) of solid household waste into unified containers and their further transportation using a cargo overhead cable transport can significantly simplify and reduce technological operations for the collection and transportation of waste, and reduce the time between collection and disposal of waste.

Transportation of solid household waste by means of a cargo overhead cable transport allows you to quickly deliver large batches of solid household waste to the sorting, processing and disposal point, which has a positive effect on increasing the efficiency of waste disposal [3, 14, 16].

Quick removal from settlements in containers of solid household waste allows to improve the ecological state of settlements.

The figure shows the proposed schematic diagram of the removal of solid household waste.

The proposed method is most effective for use in megalopolises, but it can be successfully applied in any other settlements with any number of population.

For the export of biological, nuclear, toxic, etc. waste containers can be used, certified for the transportation of this kind of waste.

The proposed method is implemented as follows (Fig. 1).

Solid household waste is collected in adjoining containers 1 in residential areas at the places of their collection.

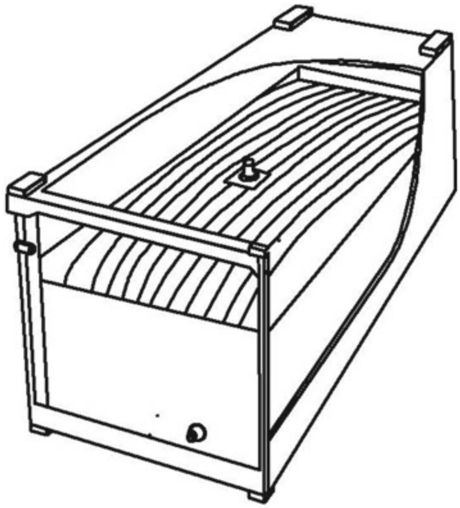

Fig. 1. Unified container equipped with the "bag" option, which is made of a soft impermeable material—flexitank.

Next, the filled containers 1 are reloaded 2 into unified removable containers 3 located on the vehicle 4, sealed and evacuated with the equipment installed on the vehicle 4 and transported 5 to the transport and logistics center 6.

Depending on the size and location of the settlement, there may be several transport and logistics points 6, and they should preferably be located in industrial zones or in sparsely populated areas on the city's borders.

At the transport and logistics point 6, the 7 universal container is removed from the vehicle and loaded onto the cargo suspension ropeway 8.

Freight aerial ropeway 8 connects transport and logistics point 6 with a landfill or waste recycling plant 9 through transport and logistics point 10, where the container is moved to an intermediate decelerating conveyor, 11 is removed from the freight aerial ropeway and fed to unloading 12 [26–28].

Unloading 12 of the universal container 3 is carried out using an unloading device, after which the universal container 3 is stirred for washing and disinfection 13, with the implementation of environmental control of the work performed. Further, the universal containers 3 undergo maintenance and (or) repair 14. Then the universal containers 3 are installed 15 on the cargo aerial ropeway 8 and sent in the opposite direction to the transport and logistics point 6, where 11 are removed from the cargo aerial ropeway, 16 are installed on the vehicles 4 and transported to residential areas of the settlement. If necessary, clean containers 3 at the transport and logistics point 6 can be located in the waiting area 17 [29–32].

The inner volume of the unified container is equipped with a "bag" option, which is made of a soft impermeable material—a flexi-tank, in which solid domestic waste is compacted, their sealing and evacuation, followed by depressurization at the point of sorting, processing and disposal of waste by external heat treatment.

Thus, the proposed method for the removal of municipal solid waste from a settlement is a simple, convenient and cost-effective way of waste disposal, which makes it possible to simplify and reduce technological operations for the collection and transportation of solid household waste, reduce the time between waste collection and disposal, and increase the efficiency waste and its efficiency, as well as improve the ecological state of settlements (Fig. 2).

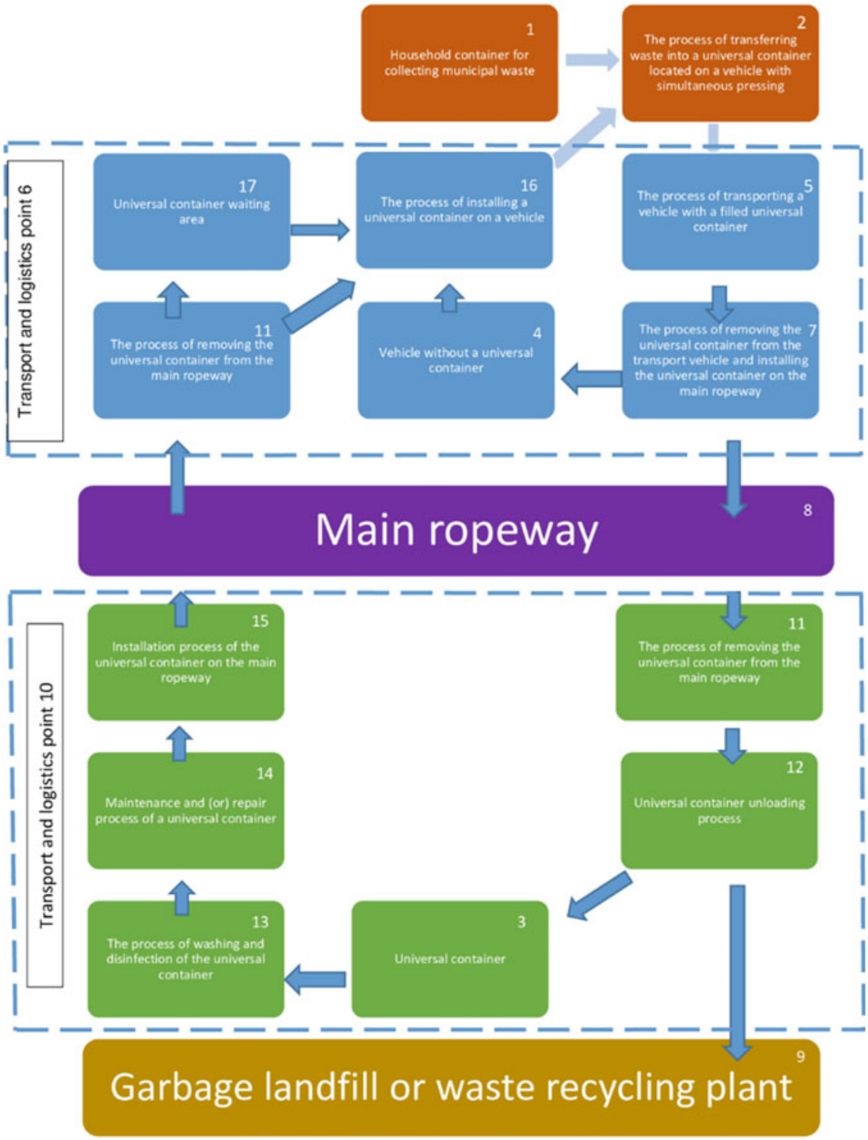

Fig. 2. Proposed schematic diagram of solid waste disposal

3 Output

Today, the transportation of solid household waste by means of a cargo aerial ropeway is a unique product both for the Russian market and for the foreign one, since there are no analogues at the moment.

Transportation of solid household waste by means of a cargo aerial ropeway allows to quickly deliver large batches of solid household waste to the sorting, processing and disposal point, which has a positive effect on increasing the efficiency of waste disposal.

Quick removal from settlements in standardized containers of solid household waste allows improving the ecological state of settlements, which ultimately leads to an increase in the culture of production and the attraction of qualified personnel to this field of activity.

The software part of the solution is an information system for remote administration, scenario management using a server. This information system allows transmitting sensor readings.

This solution helps to improve the efficiency of the transport and logistics process for the removal of solid household waste, namely, it optimizes the waste management process, which will significantly increase the productivity of transportation, reduce financial and time costs. At the same time, the process itself will be fully automated from the start to the end point.

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Simulation of Wind Effects on Fractal Structure

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Abstract. The study of complex geometric shape fractal object aerodynamics is implemented with use of the finite element method and modern software calculation systems. Specially developed terminology for three-dimensional fractal structures is used for the analysis. It is assumed that the fractal structure has an advantage over structures that have a rectangular shape in plan. The ANSYS Fluent module is used to simulate the wind effects on the structure. The values of wind speeds over the entire height of the building and the pressure on the exostructure are obtained during the investigation. Turbulent pulsations zones of the structure are identified. At the same time, it is pointed, that the fractal structure effectively perceives wind flows without the occurrence of extreme speeds and vortices. Investigation of wind effects should be used to assess the aerodynamic comfort of pedestrian zones. An additional analysis of the distribution of wind flow lines is carried out for the modified form of the fractal structure.

Keywords: Fractal · Fractal structure · Finite elements method · Wind effects · Aerodynamic · Modeling · Turbulence · Fractal shaping · Complex geometry · Unique buildings · High-rise buildings

1 Introduction

Direct analyze of the fractal structure functioning is the main purpose of mathematical simulation of wind effects. Determination of the wind pressure on the structure is an important task of designing of high-rise and unique buildings process. Studies of the aerodynamics of complex structures occupy a significant part of the total volume of design work [1–3]. It is necessary to perform physical modeling of wind impact in a wind tunnel and mathematical modeling of wind flows with use of innovative technologies and software packages.

Increase in the mobility of the air at the ground surface cause by pressure of the upper layers of air on the lower layers when the wind flows around the building. Studies have shown that the complexity of wind impact calculations is due to the fact that there are no unambiguous recommendations for the purpose of aerodynamic coefficients for complex structures [4–6]. For high-rise buildings, it is necessary to take into account the increase in wind speed in height during calculating wind loads. Underestimating the aerodynamic coefficients in simulation of wind effects on buildings can lead to structural failure.

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The object of the study is a unique fractal structure with complex geometric shape [7]. The task of studying stress-strain state of the structure is complicated significantly. Originality and novelty of the study lie in the simulation of wind pressure on the complex surface of the exostructure. Experimental data on this investigation were not found. The results of mathematical modeling will be necessary and significant part of the study of the work of structures in the design of a unique object of fractal architecture.

2 Materials and Methods

Investigation includes a specially developed terminology that applies to three-dimensional Mandelbrot fractals with power of more than three [8]. Exostructure—the external structure of three-dimensional fractal, consist of exobase, surface of f-quarks, and crown (Fig. 1). Endostructure—the internal structure of a three-dimensional fractal set.

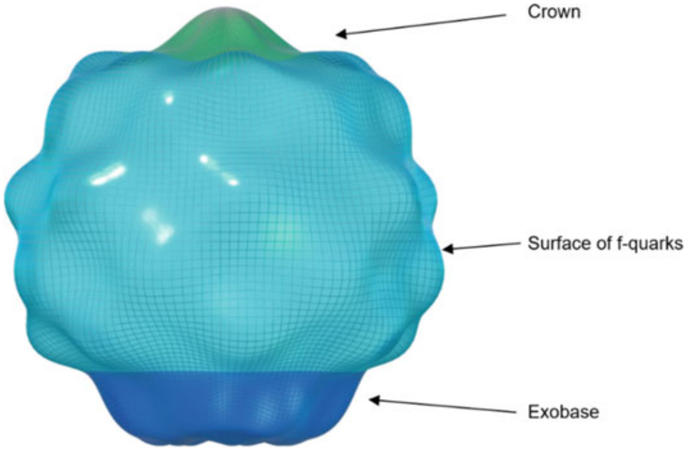

Fig. 1. Exostructure

The modeling of the design scheme of the object of study is carried out at the preparatory stage. The model of the volume fractal structure is implemented in the SCAD software package. Conducting a preliminary analysis of the finite element model of the structure allows determining the main materials characteristics and designing solutions.

The exostructure is formed by universal finite triangular elements 42, the thickness of the plates 0.15 m. Connections in the spatial setting are superimposed along the reference contour of the exostructure. Innovative materials with unique properties should be used to implement fractal structures [9–11]. Analysis of the occurring displacements in the model of the fractal structure showed that the support region of the exobase is a pronounced zone of displacements. This is justified by the features of the fractal structure geometry and the nature of securing the building structure.

The joint activity of the elements of the exostructure and endostructure is studying to eliminate such deformations. During the research the endostructure is approximated by a set of rod elements. Complex model of the first and second generation is adopted as a result of study of the endostructure evolution [8]. It was decided to organize vertical communications in the building in each f-quark of the exobase on base of the results of the analysis. Thus, a system of seven stiffness cores was formed, united by rigid levels and endostructure elements. Stiffening diaphragms are arranged in each of the cores.

The resulting model of the object is exported to the ANSYS software package at the next stage. Ansys software package widely used in solving applied problems of mechanics [12, 13]. A new finite element grid is generated. It's used the SHELL181 finite elements to modeling of the exostructure and BEAM188 finite elements to modeling of the endostructure of the fractal. The material characteristics of the elements are assumed to be similar to the characteristics used in the structure analysis in SCAD. The elements of endostructure have a circular cross-section with a diameter 0.15 m. The rigid fractal structure is formed as a result of the joint work of the exostructure, internal structures of the first and second iterations (Fig. 2).

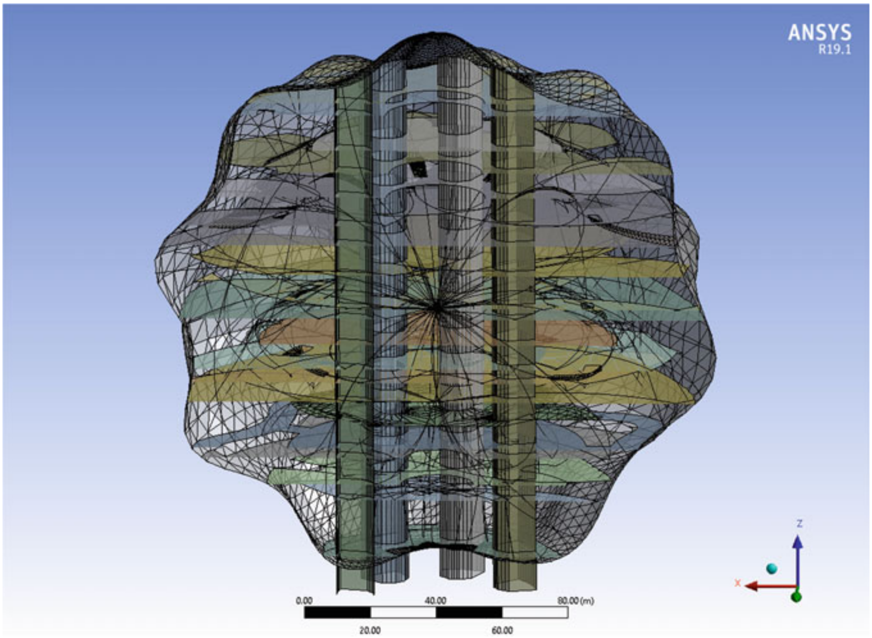

Fig. 2. Model of the research object (section)

The main stage of the study is the simulation of wind effects on the complex fractal structure. The wind effects cannot be described by mathematical equations precisely. There are a number of difficulties in determining the reaction of the structure to the wind impact. The regulatory documents are adopted various theories and methods for determining the wind load. Basically, these methods are based on a number of assumptions and attempts to describe mathematically the observational data of meteorological stations. This can allow to relate the frequency of wind flow changes to the natural vibration frequencies of building or structure. The following dependence of the change in wind speed on the height of the object is accepted in this study:

$$U(z) = Uo\left({}^{z}\!/_{zo}\right)\alpha \tag{1}$$

Uo—average wind flow velocity at altitude zo;
α—coefficient depending on the type of area of study.

ANSYS Fluent module is used to modeling the wind effects on fractal structure. The dimensions of the calculated area for wind flow modeling are taken in such a way that its boundaries do not affect the results of the calculation.

The size of the computational domain vertically shall be not less than five heights of the object, the length of the region in the direction of flow—not less than five heights, behind the object—at least two heights, the transverse size of the area must be at least ten heights without considering the transverse dimension of object of the study. The adopted for the study Finite element grid of the calculated area of the object is shown in Fig. 3.

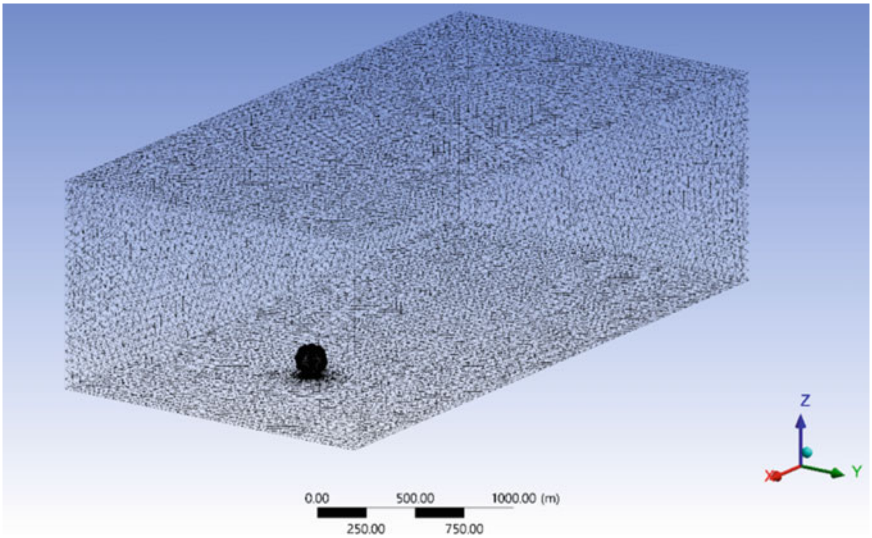

Fig. 3. Finite element grid of the calculated area

The velocity inlet boundary conditions should be used at the input boundary of the region. The turbulence is set by a constant according to the k-epsilon model. In this model the equations of motion are transformed to a form that includes the influence of the average velocity fluctuation (in the form of turbulent kinetic energy) and the process of reducing this fluctuation due to viscosity (dissipation). Two additional equations are solved for the transfer of the kinetic energy of turbulence and the transfer of the dissipation of turbulence in this formulation. The boundary conditions of complete adhesion for shear stresses (No slip) are used on the walls of the calculated area. All velocity components are equal to zero in this type of boundary conditions. Soft boundary conditions (pressure outlet) are used at the output of the calculated area. The boundary conditions of symmetry are set at the upper boundary of the area.

3 Results

The values of wind speeds over the entire height of the building and the pressure on the exostructure were obtained as a result of the numerical experiments of the influence of wind load on an object of complex geometric shape in the ANSYS Fluent module.

The wind flow lines in the center of the structure are shown in Fig. 4. The object of the study is based on the form of a three-dimensional Mandelbrot fractal of 8 power and 1 iteration. The features of fractal shaping affect the air flows. The influents of shape cause that the maximum wind speeds are achieved on f-quarks located in the zone of disruption of the wind flow of the object. Stagnant zones with wind flow deceleration are observed in front of the structure, and tear-off areas with vortex flows are formed behind the object. The expansion of the calm flow zones is not observed due to the complexity of the shape and the considerable height of the object. Turbulent vortex formations are formed not only under the overhanging parts of the structure, but also near the upper part of the exostructure. The crown and the upper part of the surface of f-quarks are located in the zone of separation flow and in the zone of increased turbulent pulsations from the direction of the wind. Note that at an altitude of 171.69 m, turbulent vortex formations occur, while the wind speed does not exceed 47 m/s.

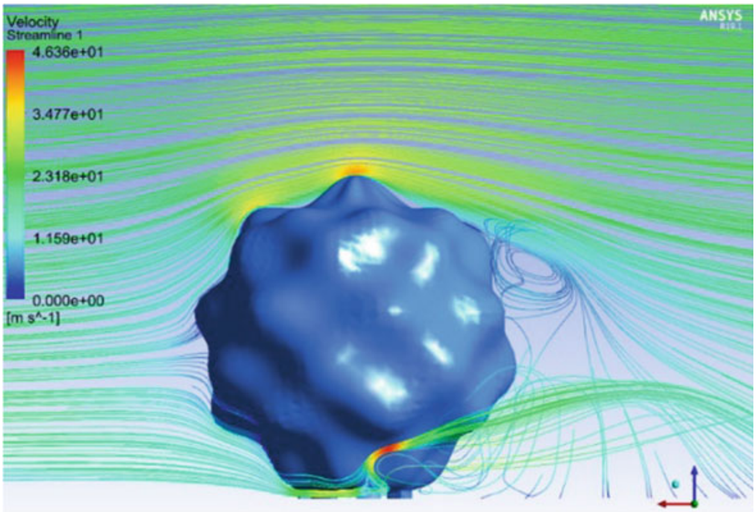

Fig. 4. The wind flow lines in the center of the structure

The change in time of the vertical tearing force of the wind acting on the elements of the object is of a pulsational nature. This is due to the non-stationary turbulent vortex flow around the structure of the object. By this reason it is necessary to consider possible pulsational nature of the loads in further strength calculations of the structure for static and dynamic wind loads. It is recommended to perform a spectral analysis of the structure.

After analysis of the result of the simulation it is concluded that fractal structure effectively perceives wind flows without the occurrence of extreme speeds and vortices. These results of the functioning of the fractal structure are positive. Also, from the point of view of aerodynamics the building of such complex geometric shape has a poorly streamlined configuration, but this fractal structure has an advantage over common structures.

The pictures of the distribution of pressure fields on the exostructure are of the greatest scientific interest. In that way the developed wind pressure model is transmitted to the ANSYS Static Structural module to investigate the stress-strain state of the skeleton of the fractal architecture object. The pressure on the exostructure in the flow direction and on top of the object is shown in Figs. 5 and 6 respectively.

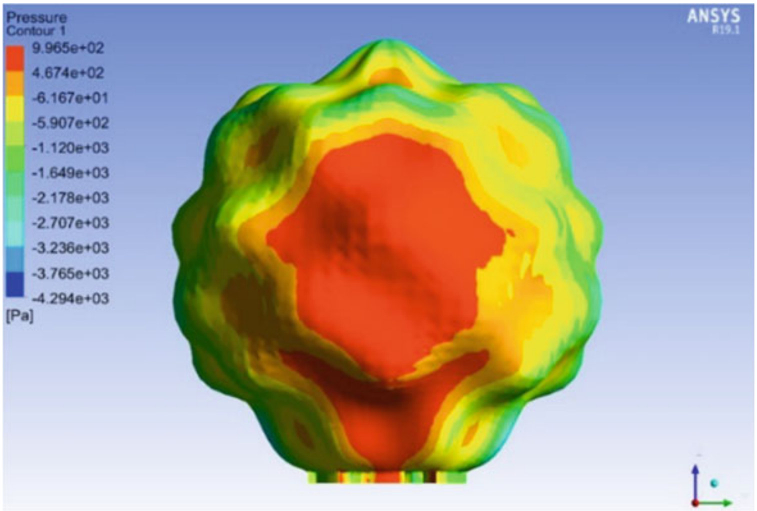

Fig. 5. The pressure on the exostructure in the flow direction

4 Discussion

The use of modern methods of mathematical modeling of applied problems of mechanics greatly simplifies the work of designers. The obtained results of wind effects simulation are applicable for conducting a comprehensive study of the dynamic response of the structure.

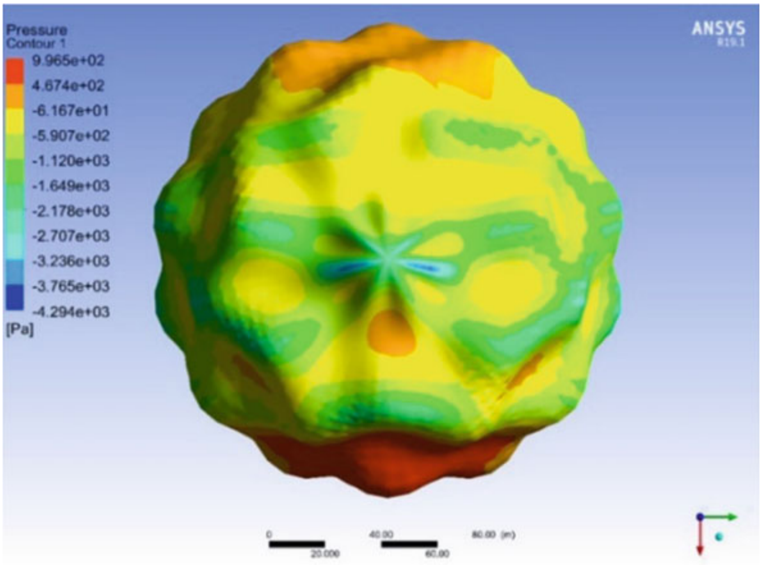

Fig. 6. The pressure on the exostructure on top of the object

During the investigation numerical simulation of stationary and non-stationary turbulent separation wind flow around high-rise buildings is implemented in the ANSYS PC. It is possible to study not only detached buildings, but also a complex of structures with use of the ANSYS Fluent module. The aerodynamic coefficients and wind pressure on the surface of buildings are determined on the basis of numerical modeling.

The study of wind flows can be used not only to determine the loads on the structure of the building, but also to assess the aerodynamic comfort of pedestrian zones [14, 15].

In the additional part of the research was found that in order to reduce the size and number of return eddy currents in the exobase of structure, it is possible to exclude the exobase from the ground part of the structure. At the same time, all the fractal properties of the structure will be preserved.

Figure 7 shows one of the options for varying the shape of the fractal structure in order to reduce the effect of wind pressure on the object. It is assumed, that this modified shape of the structure may stimulate the reduce discomfort in the pedestrian zone. In order to simplify the analysis, the wind flow velocity was calculated at heights of 1.5, 15, 33 and 75 m. Analysis of the results showed that the maximum wind speed reaches 65 m/s. However, turbulent vortex formations are practically absent both at the height of 1.5 m and at the top of the structure. This will ensure a comfortable exploitation of the object of the fractal architecture.

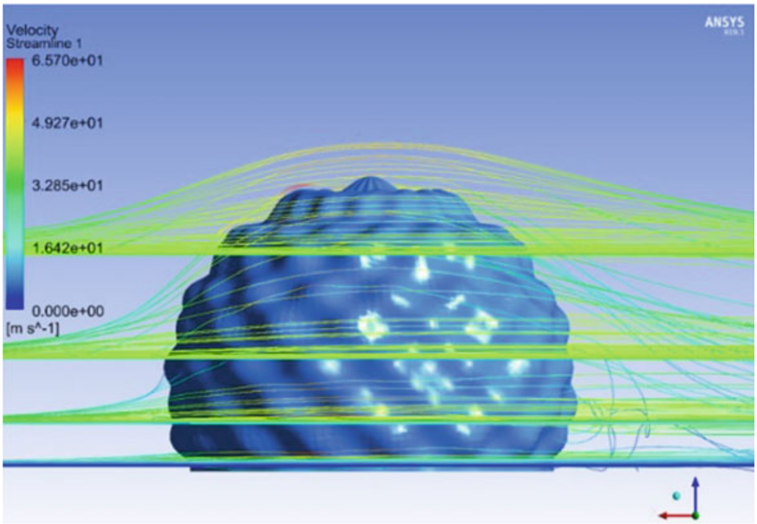

Fig. 7. The wind flow lines in structure of modified shape

5 Conclusions

Simulation of wind effects on fractal structure are more effective with the use of the finite element method and modern computing software systems. Conducting a series of numerical experiments on structures of different iterations and capacities allows us to develop a complex model. This model implemented with account the stability of the structure.

A complex fractal structure and wind impact on an object of irregularly shaped were modeled during study. A model of a unique building of unusual geometry has been developed, this model has an advantage over rectangular structures in plan. The obtained values of the wind pressure on the surface of the structure are used later to analyze the stress-strain state of the object.

Simulation of wind effects is useful not only for calculating the strength and stability of building structures, but also for determining pedestrian comfort.

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A Tool for Locating Logistics Centers Based on Economic and Social Factors

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Abstract. In conditions of modern intensify of the international economic interactions, there increase the practical importance of the concept of "economic gravity" and the influence of related internal socio-political factors. One of the directions of more complete and adequate formalization and modeling the conditions of multiplicity of factors of socio-economic interactions and strengthening of trends of economic uncertainty can be the use of tools of the fuzzy set theory. The proposing tool implements fuzzy algorithms for the location of logistics centers in countries and regions characterized, firstly, by the significance of spatial-intermediary functions for the external economic environment, secondly, by a relatively small volume of internal trade flows, and, thirdly, by the vastness of the territory—such as Russia or Mongolia. To justify the location of logistics centers, the so-called multi-attribute decision-making system was implemented. Elaborated algorithm can be used not only as a tool to improve the efficiency of foreign economic activity of Mongolian firms, but also to optimize the logistics of export-import operations of economic entities of other countries, as well as any territories that perform spatial-intermediary functions relative to external centers of economic gravity.

Keywords: Economic gravity · Logistics centers · Location · Fuzzy set theory · Social-economic factors

1 Introduction

In the 50–60s of the last century, some researchers [1, 2] drew attention to the possibility and fruitfulness of economic interpretations of the traditional physical gravity model. In a simplified and generalized form, their ideas, interpreted as a methodological tool for analyzing foreign economic interactions, can be reflected by the following initial formalization:

$$F_{ij} = k\left(M_i M_j\right) \Big/ D_{ij}^{n} \tag{1}$$

where F_{ij} is an estimate of the "economic gravity" between locations i and j, M is the economic dimensions ("mass") of the locations, D is the distance between them, n ≥

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1, and k is an additional correction coefficient. Most often, individual countries were considered as locations, and the main indicator of the economic size ("mass") is the volume of the gross product of these countries; the role of the main interpretation of this methodological idea was acquired by the spatial gravitational model of foreign trade [3]. It is obvious that the concept of "location mass" is characterized by a high degree of abstraction and implies subsequent concretization by identifying the physical and cost economic "mass", which, in turn, requires determining the degree of marketability of the economy and, accordingly, of the gross product indicators. Economic systems with a low degree of marketability have an equally low economic gravity relative to the outside world, even with significant physical volumes of gross product. The next stage of specification is an indicator of the value of the export quota, i.e. the share of the gross product going for export. If this value is insignificant, even high-marketable domestic production will be characterized by relatively low indicators of external economic gravity. This determines the theoretical and practical significance of the category "tradable goods" and the need to identify the ratio between tradable and non-tradable goods in the structure of the gross product.

The practical significance of the conceptual ideas embodied in the theory of economic gravity can be significantly enhanced by further developing formalized tools for analyzing the interaction of economic systems and objects in the context of their scales and degree of attitude to the external environment, as well as taking into account the nature of the influence of social and political factors on these interactions [4]. The multifactorial nature, diversity of directions and uncertainty of economic-gravitational dependencies predetermines the need for a more detailed application of the tools of fuzzy set theory to formalize the methods of accounting for these dependencies in the practice of economic management.

2 Methods and Discussion

Elements of concretization and generalization proposed by J. Tinbergen, supplemented the indicator of distance between countries by factors reflecting the presence or absence of a common border and membership in trade integration associations, in connection with which the indicator characterizing the vector of gravity reduction began to be defined in a broader context as the costs of foreign trade. In a simplified form, the idea of J. Tinbergen can be formalized as follows:

$$E_{ij} = {}^{k\left(Y_i Y_j\right)}\!\big/_{T_{ij}} \tag{2}$$

where E is the export from country i to country j, Y is the gross product, and T is the costs of trade between countries.

Subsequently, the axiomatics of the gravitational model, while maintaining the main methodological idea, was supplemented by numerous variative-corrective indicators. Among the factors of strengthening the economic-gravitational interaction, the population and the size of the gross product per capita of the country, the area of its territory, etc., were also included; estimates of foreign trade costs were even more detailed, and the aggregate groups of which began to include:

- transport costs
- customs tariffs
- contract costs
- exchange rate volatility
- features of the geographical location
- economic policy
- membership in trade integration associations
- membership in currency unions
- membership in political unions and military blocs
- social and historical factors (linguistic, religious, ties of former colonies and metropolises, etc.)
- information barriers, etc. [5].

In the last third of the twentieth century and at the turn of the century, the methodological idea embodied in the initial formalization of the spatial gravitational model of foreign trade (in fact, only performed the "renaming" in economic terms the dependencies reflected in Newton's gravitational model) received a special analytical development through the technical apparatus of neoclassical econometrics [6, 7]. A significant number of specialized econometric models have been developed and continue to be developed, allowing both a rigorous mathematical interpretation of classical models of foreign trade, and a detailed analysis of all significant aspects of current international trade processes, and, in a broader context, international economic relations in general (including in relation to international investment, migration processes, etc. Moreover, there have appeared concepts that evaluate the gravitational model as a universal general scientific methodological approach that characterizes the fundamental laws of the development and functioning of nature and society.

It's undoubtedly that the idea of economic gravity is applicable to the analysis of various levels of economic interactions—global, international, country-state, mega-, macro- and local-regional, etc. No less obvious is the fact that at each of these levels, economic-gravitational interactions are characterized by features that can be formalized by means of correction coefficients—in formulas (1) and (2), this means the need to differentiate and form the spectrum of variation of the coefficient k. This spectrum of variation should reflect the specifics of the above-mentioned aggregated cost groups, taking into account the spatial-level specification of forms of economic gravity. Thus, the peculiarities of geographical location, contract and transport costs, social and information factors are equally important at all levels of economic interaction, while exchange rate volatility, customs tariffs, membership in trade, currency and political unions are especially important in the context of interstate relations. The latter factors also have considerable weight in terms of the nature of interactions between integration groups and mega-regional associations, the formation and strengthening of the role of which can lead to a radical reformatting of the entire world economic system. In this regard, it's significant the signing in November 2020, the agreement on the Regional Comprehensive Economic Partnership (RCEP), which, under conditions of operation of previously created Trans-Pacific Partnership (TPP), forms a new architecture of international economic relations in the Asia-Pacific region, including such centers of global economic gravity as China, the US and Japan, as well as dynamic markets of newly industrialized countries, quickly building up their "economic weight". There are also continuing discussed the prospects for creating a Transatlantic Trade and Investment Partnership (TTIP); these discussions may become more active due to recent political changes in the United States.

At the same time, economic gravity is also increasing by interaction vectors in the Eurasian space. In 2018, the EU-Japan Economic Partnership Agreement (JETTA) was concluded, according to which economic relations between these global actors are based on the principles of a free trade zone. It's growing the trade and economic "attraction" of the Western European region and China, which consistently occupies the second place in the EU's foreign trade. Further intensification of mutual trade and economic relations will receive a tangible boost in connection with the conclusion of a new Investment Agreement between China and the EU in December 2020. Cooperation is also developing within the framework of the Eurasian Economic Union (EAEU).

3 Results

The increasing of economic gravity requires the formation of an adequate infrastructure of trade and economic interactions. In the conditions of preserving the State form of social organization, this implies easing conditions, optimizing and harmonizing the interstate movement of goods and other economic factors, and rationalizing the structure of economic flows. In this context, the importance of intra-country and border logistics centers and complexes, optimization of their functions and placement, significantly increase.

However, to solve such an important practical problem as the formation of an effective internal location of logistics centers, focused, among other things, on servicing foreign and transit trade, the above-described variants of the gravity model are too general. Important aspects of the problem are that in addition to the function of servicing foreign economic activity, logistics centers, which cost the state hundreds of millions of dollars, are assigned social and political functions—such as the economic development of depressed regions, the demographic development of sparsely populated territories, and improving the quality of life of the population.

One of the directions of more complete and adequate formalization and modeling of phenomena and processes in the conditions of multiplicity of factors of socio-economic interaction and strengthening of trends of economic uncertainty can be the use of tools of the fuzzy set theory [8, 9]. This tool allows us to approach the generalized characteristics of the multidimensional and multilevel nature of socio-economic dependencies, taking into account the multi-vector and "blurred" range of options for economic development of countries and regions [10], including their foreign economic activity in the context of intensification and growth of international trade flows (the temporary reduction of which due to the pandemic does not cancel the effect of long-term essential trends and patterns). Currently, it is necessary to specify the tools of the fuzzy set theory for solving practical problems of economic management [11, 12].

The problem of optimizing the location of logistics centres is of particular importance for countries and regions, through which there pass significant flows of transit goods in terms of, first, a large area of these territories, and, second, the relatively small volume of internal trade flows, therefore just the presence of transit flows become one of the most important domestic economic impulses (and, primarily transportation and communication) development and solution of social problems. Such countries include Mongolia, which is characterized by a pronounced manifestation of the laws of economic gravity at the macro- and meso-levels. While the growth of volume of traffic within the framework of the "The Belt and Road Initiative (BRI)", the economic importance of transit logistics centers in Mongolia will increase for all participants of this transcontinental transport corridor. Mongolia's spatial mediation functions are most important for trade between China and Russia and, to a certain extent, for trade between China and the Western European region. Under the terms of the agreement between the governments of Mongolia and Russia, increased tariff benefits at the level of 52% of the single transit tariff will be applied for container transportation for 25 years (until 2018, this level was 32%).

To justify the location of logistics centers in Mongolia that support the activities of international transport corridors, the so-called multi-attribute decision-making system was implemented [13], which allows finding the best locations of logistics centers, taking into account the indicators of transport and economic interaction and socio-political aspects of these locations (when developing and approbating the proposed tool, the authors analyzed the data presented by A. Galbadrah).

By the implementing the multi-attribute decision-making system, a finite set of X alternatives to localizing logistics centers was formed, based on the territorial-administrative division of Mongolia.

Within the framework of the developed tool, to estimate the values of the economic flow through points x,$\forall x \subset X$, instead of the values of F_x-economic gravity, we will use the indicator $\mu_F(x)$—the degree of belonging of the economic gravity of point x to the maximum value of X.

$$\mu_F(x) = {}^{F_x}\!/\mathrm{SUP}^x(F_x) \tag{3}$$

Based on expert assessments based on the decisions of the government authorities of Mongolia, the weight of the socio-political significance of the ω_S when choosing the location of logistics points is 0.3. Accordingly, the weight of economic gravity ω_F is 0.7.

The rating $R(x)$ of the x-th location of a logistics center is calculated as a convex combination of the assessment of the economic weight $\mu_F(x)$ and the socio-political significance $\mu_S(x)$ [8].

$$\boldsymbol{R(x)} = \mu_F\boldsymbol{(x)\omega}_F + \mu_s\boldsymbol{(x)\omega}_s. \tag{4}$$

The socio-political significance $\mu_S(x)$ of the x-th location of the logistics center, in turn, corresponds to a convex combination of estimates of the $\mu_e(x)$—importance of the economic development of the region, $\mu_d(x)$—the importance of the demographic development of the region, $\mu_q(x)$ importance of improving the quality of life in the region. Each of these estimates can take values from 0 to 1.

$$\mu_s(x) = \mu_e(x)\omega_e + \mu_d(x)\omega_d + \mu_q(x)\omega_q \tag{5}$$

where: ω_e, ω_d, ω_q—accordingly, are the expert assessments of the economic, demographic and qualitative significance of the location of a logistics point in the region; $\omega_e + \omega_d + \omega_q = 1$.

There are a total of 46 border crossing points in Mongolia. Of the 46 border points, 26 are active, 9 of them are permanent. Figure 1 shows the main meridian transport axis connecting the Sukhbaatar and Zamyn-Uud border crossings in the north and south of Mongolia and defining the economic gravity vectors within the overall border crossing structure.

Fig. 1. The main transport axis assuring Mongolia's foreign economic activity. *Source* https://tomongolia.blogspot.com/2011/06/border-crossings.html

Below is a calculation of the "economic gravity" estimate for 7 border points, covering more than 97% of Mongolia's foreign economic transactions.

1. Zamyn-Uud
   The distance of the main flow of intra-national transit at this location of the logistics center is 1026 km.
   The estimate of "economic gravity" (1) between the logistics center of this location and the logistics center for processing the main flow of foreign economic transit is 1.26.
2. Altanbulag
   The distance of the main flow of intra-national transit at this location of the logistics center is 1026 km.
   The estimate of "economic gravity" (1) between the logistics center of this location and the logistics center for processing the main flow of foreign economic transit is 1.26.
3. Suhbaatar
   The distance of the main flow of intra-national transit at this location of the logistics center is 1026 km.
   The estimate of "economic gravity" (1) between the logistics center of this location and the logistics center for processing the main flow of foreign economic transit is 0.56.

4. Tsagaannuur
   The distance of the main flow of intra-national transit at this location of the logistics center is 2305 km.
   The estimate of "economic gravity" (1) between the logistics center of this location and the logistics center for processing the main flow of foreign economic transit is 1.4.
5. Gashuun-Suhait
   The distance of the main flow of intra-national transit at this location of the logistics center is 1640 km.
   The estimate of "economic gravity" (1) between the logistics center of this location and the logistics center for processing the main flow of foreign economic transit is 0.67.
6. Dayan
   The distance of the main flow of intra-national transit at this location of the logistics center is 2305 km.
   The estimate of "economic gravity" (1) between the logistics center of this location and the logistics center for processing the main flow of foreign economic transit is 0.28.
7. Bulgan
   The distance of the main flow of intra-national transit at this location of the logistics center is 2032 km.
   The estimate of "economic gravity" (1) between the logistics center of this location and the logistics center for processing the main flow of foreign economic transit is 0.64.

Table 1 shows the data for these 7 border points, which cover more than 97% of Mongolia's foreign economic transactions.

Table 1. Indicators of economic gravity in relation to the border points of Mongolia

No.	Name of the point	Economic gravity—F_{X}	Belonging to economic gravity—$\mu_{\mathrm{F}}(x)$	Socio-political significance—$\mu_{\mathrm{S}}(x)$	Rating—$R(x)$
1	Zamin-Uud	1.26	0.9	0.99	0.927
2	Altanbulag	1.26	0.9	0.28	0.714
3	Suhbaatar	0.56	0.4	0.014	0.284
4	Tsagaannuur	1.4	1	0.028	0.708
5	Gashuun-Suhait	0.67	0.48	0.07	0.315
6	Dayan	0.28	0.2	0.02	0.146
7	Bulgan	0.64	0.46	0.007	0.324

Significant differences of the ranking of locations by economic gravity and by the gravity taking into account the socio-political component, reflect the productivity of the proposed fuzzy model of the location of logistics points. Attention is drawn to the indistinguishability of the values of economic gravity of the border points Zamyn-Uud and Altanbulag and their obvious difference in rating, taking into account the socio-political component.

In our opinion, the proposed fuzzy tool of the location of logistics centers has both theoretical and practical significance, since its general algorithm, which corresponds to the axiomatics of the concept of economic gravity, can be used not only as a tool to improve the efficiency of foreign economic activity of Mongolian firms, but also to optimize the logistics of export–import operations of economic entities of other countries [14, 15]. The actualization of this approach is also due to the emerging trends of fragmentation and regionalization of the world economy and the associated clustering mechanisms of both traditional and new sectors of "industry 4.0" within the emerging "glocal" economic complexes [16–18]. The developing processes of reformatting value chains on the scale of mainly regional and mega-regional clusters determine the feasibility of generalizing the proposed model in relation to new parameters of interregional economic gravity.

4 Conclusions

Generalized variants of the developed tool can be most applicable to optimize the location of logistics centers in countries where the dynamics of domestic trade is relatively lower in comparison with the dynamics of their foreign trade operations. In addition, regardless of this relationship, the proposed tool is applicable to any territories that perform spatial intermediary functions relative to external centers of economic gravity. In this case, the economic status of these territories is invariant with respect to geographical and administrative-legal specification, i.e., they retain the role of a spatial "conductor" of economic gravity, being represented by local and macroeconomic intra-country regions, individual countries, integration associations, transcontinental and global mega-regions. At the same time, in relation to the level of individual countries, the correction coefficients used the tool are designed to reflect the degree of influence of the intermediary country's economy on the entire system of economic-gravitational relations. This influence may be insignificant and mainly limited to geographical and territorial mediation (typical, for example, for Russia and Mongolia)—or reflect the own economic weight of the intermediary country (Russia partially performs this function only within the framework of the Eurasian Economic Union). Additional correction coefficients are necessary for countries that are characterized by a high level of their own economic development, high indicators of marketability of domestic production and at the same time perform significant intermediary-territorial functions for the world economy; in some cases, they are reflected by export quota indicators exceeding one, which indicates significant re-exports and higher export volumes relative to the value of the gross domestic product.

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Experimental Determination of Ruby Crystal Sizes Used as a Manometer in High Pressure Chambers

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Abstract. To measure the pressure in the experimental research high-pressure chamber, a ruby crystal was used, for which R2 is analytically described—the line of the luminescence spectrum with a confidence factor from 0.9905 to 0.9964, while it was experimentally established that the parameter of non-hydrostatic compression of ruby crystals, which is used as a pressure gauge, with a thickness of 3.0 mm at a temperature of 23 °C and pressure of 583,8 MPa has a value greater than 5 times the specified precision. The use of a ruby crystal with a thickness of 0.5 mm as a manometer makes it possible to obtain an accuracy of recording the pressure of ± 10 MPa.

Keywords: High hydrostatic pressure · Pressure gauge · Ruby scale · High pressure setting

1 Introduction

The use of high hydrostatic pressure up to 1000 MPa affects biological substances in the phase of transition from a solid to a liquid state, the phase of unfolding proteins, inactivation of enzymes, as well as the preservation of a complex mixture of aromas and vitamins. In addition to the aforementioned effects, high hydrostatic pressure inactivates microorganisms, offering a food preservation technology that is gentler on the characteristic properties of food than heat treatment [1–3].

Therefore, high hydrostatic pressure (HHP) treatment is increasingly used in food technology and biotechnology. Currently, pressure is used to freeze and thaw products, pasteurize under high pressure, soften the properties of meat and preserve fresh products.

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2 Theoretical Data

High pressure treatment has the character of an experimental analysis, i.e. the substance is placed in a high pressure chamber. Then the pressure-transmitting fluid (which could be the product itself) is pumped into the chamber through the inlet. Since the temperature is kept at approximately the same level, this increase in mass leads to an increase in density and, thus, an increase in pressure. After a few seconds or minutes, the compression phase ends by stopping the fluid supply. The pressure level is then kept approximately constant for the required time so that the pressure-induced transformations have sufficient time to take place. Finally, the pressure level is reduced by decompression and the product is removed from the chamber.

The analysis of publications on the processes occurring in food during their processing by HHP [4–6] shows that the development of the method of processing organic media by HHP was carried out mainly extensively, that is, in the direction of accumulating experimental data. Until now, there is no unified theory explaining all the variety of phenomena occurring in biological and chemical materials that are exposed to HHP.

A reflection of this state is a fairly large number of patents, the purpose of which is the technical implementation and improvement of the high pressure food processing process, as well as equipment designed and manufactured by individual manufacturing firms [7–9].

As it was written by the academician L.F. Vereshchagin in the preface to Bridgman's monograph: "…if you need to get a pressure above 1000 atm. (100 MPa), the experimenter spends most of his work and time on creating the necessary equipment". This provision is also relevant in modern conditions.

On the one hand, for individual products, the processing of which HHP has been studied sufficiently, industrial installations of high productivity are produced and successfully operated [10]. On the other hand, the need to carry out comprehensive research to find the optimal technological parameters for the processing of various products forces the industry to produce HHP units of low productivity, but making it possible to vary such process parameters as the pressure value, pressure gradient, temperature in the working chamber, duration processing. Also, such installations should be automated and include a high-precision measuring complex for a wide range of scientific research. Detailed and systematic study of food products under the influence of HHP is a necessary stage of its widespread introduction into scientific research, biotechnology and food industry. To solve this problem, it is necessary to develop a set of equipment that allows you to study the effect of high pressures on food products and their components. The creation of such a complex, accessible to a wide range of researchers, can significantly expand the range of tasks to be solved, and will contribute to the popularization of this processing method.

Typical HHP food processing systems consist of a working chamber and a pressure generating device [11, 12]. Compression media usually contain small amounts of soluble oils. When the required pressure is reached in the working chamber, the injection of the compression fluid is stopped, the valves are closed, and the pressure can be maintained without any external energy input. The process is isostatic, the pressure is transmitted almost instantly and its value is constant both in the compression environment and in the volume of food products. The increase in pressure is accompanied by a slight rise in temperature. In this regard, when designing high-pressure installations, it is very important to provide them with modern, high-precision means of measuring process parameters. For laboratory testing of food products and biosystems, high-pressure installations with a pressure chamber volume from 10 to 50 ml are used.

The main factors that need to be controlled in the process of food processing of HHP include pressure and duration of its action, the time to reach the working pressure and its decrease, the working temperature (including its adiabatic rise), the initial temperature of the product, the temperature distribution gradient. in the working chamber with increasing pressure, the pH of the product and its composition, the activity of the water contained in it and the type of packaging material. It is necessary to control a number of special process parameters before and after processing. In the case of using pulsating pressure, the amplitude of the maximum and minimum pressure, its frequency and waveform are added. These process parameters should be displayed in the display form throughout the entire process, as well as recorded on hard media. Control systems should be equipped with signaling devices capable of monitoring any deviations from the specified mode in both cyclic and semi-continuous systems.

Naturally, the main parameter that must be monitored especially carefully is the working pressure in the chamber.

3 Main Part

To manufacture a pressure gauge installed in the experimental setup we created, we used one of the most common pressure standards in experiments, which is the ruby pressure scale, in which the pressure is measured by the shear R1—and R2—of the luminescence lines of the ruby crystal. The most popular is the calibration of this pressure scale by Mao [13], who measured the shift R2—of the luminescence lines of ruby in an argon atmosphere up to a pressure of 80 GPa. The pressure was determined from the room isotherms of Cu and Ag, which were calculated by Carter [14] from the shock data. As it is known, broadening R1—and R2—of the lines of the luminescence spectrum of a ruby crystal with increasing temperature leads to their overlap, and at temperatures above 200 °C the lines merge completely. On the other hand, as the pressure increases, the lines narrow, but as soon as the pressure becomes non-hydrostatic, inhomogeneous stresses in the ruby crystal also lead to a significant expansion of the lines. In this case, the absolute value of the pressure can be obtained only approximately. Under such conditions, the absolute pressure value can be obtained with the required accuracy only taking into account the physical factors affecting the measurement and their mutual influence.

To achieve the specified accuracy of recording the pressure, we determined the required thickness of the ruby crystal. For this purpose, various fixed pressures were created in the chamber, at which the temperature was discretely changed ranging from 5 to 95 °C with a step of about 20 °C. During the experiments, we recorded R_1—and R_2—of the ruby luminescence spectrum lines. The pressure was determined by measuring the change in the position of the more intense R_2—lines of the luminescence spectrum of ruby when the pressure changes relative to its position at atmospheric pressure, using the empirical formula proposed in the work [15]:

$$P \approx 274.6 \cdot (\lambda_{R_2}^{P} - \lambda_{R_2}^{0}) \tag{1}$$

where: P—required pressure in MPa; $\lambda_{R_2}^{P}$—wavelength R_2—lines of the luminescence spectrum of ruby in angstroms at pressure P; $\lambda_{R_2}^{0}$—wavelength R_2—lines of the luminescence spectrum of ruby in angstroms at atmospheric pressure; 274.6—conversion factor [14].

The non-hydrostatic compression of a ruby crystal of a given thickness, which appears due to the difference in pressure values on its plane-parallel surfaces, was determined as a parameter by the formula:

$$\Delta P \approx 274.6 \cdot \left[(W_{R_2}^{P} - W_{R_2}^{0}) \right] \tag{2}$$

where: $W_{R_2}^{P}$—half width R_2—lines of the luminescence spectrum of ruby in angstroms at pressure P; $W_{R_2}^{0}$—half width R_2—lines of the luminescence spectrum of ruby in angstroms at atmospheric pressure; 274.6—conversion factor from [14].

For the convenience of calculations, R_2—the line of the luminescence spectrum of the ruby crystal was approximated by the Lorentz function, which was presented in the form:

$$I(\lambda) = I_0 + \frac{2 \cdot S}{\pi} \cdot \frac{W}{4 \cdot (\lambda - \lambda_{\max})^2 + W^2} \tag{3}$$

where: S —the area under the line of the Lorentz function.

With the use of iterations, it was possible to analytically describe R_2—line of the luminescence spectrum of a ruby crystal with a confidence factor taking values from 0.9905 to 0.9964, which is very close to unity.

For example, R_2—lines of the luminescence spectrum of a ruby crystal with thicknesses 0.5 and 3.0 mm, at the temperature 23 °C, atmospheric and unknown pressure P, as well as their approximating Lorentz functions, are shown in Figs. 1 and 2 at which the value of the unknown pressure was determined by substituting into the formula (1) maximum wavelengths R_2—of the lines of the luminescence spectrum of ruby crystals with a thickness of 0.5 and 3.0 mm at room temperature, atmospheric pressure and pressure P:

0.5 mm:

$$P \approx 274.6 \cdot (\lambda_{\max}^{P} - \lambda_{\max}^{0}) = 274.6 \cdot (6944.86007 - 6942.73953) \approx 582.3\text{MPa}.$$

3.0 mm:

$$P \approx 274.6 \cdot (\lambda_{\max}^{P} - \lambda_{\max}^{0}) = 274.6 \cdot (6944.86542 - 6942.73933) \approx 583.8\text{MPa}$$

The value of the parameter of non-hydrostatic compression of ruby crystals with different thicknesses at the same pressure and temperature was found by substituting the half-widths in formula (2) R2—of the luminescence spectrum lines:

0.5 mm:

$$P \approx 274.6 \cdot (W_{R_2}^{P} - W_{R_2}^{0}) = 274.6 \cdot (5.29763 - 5.75394) \approx -125.3\text{MPa}$$

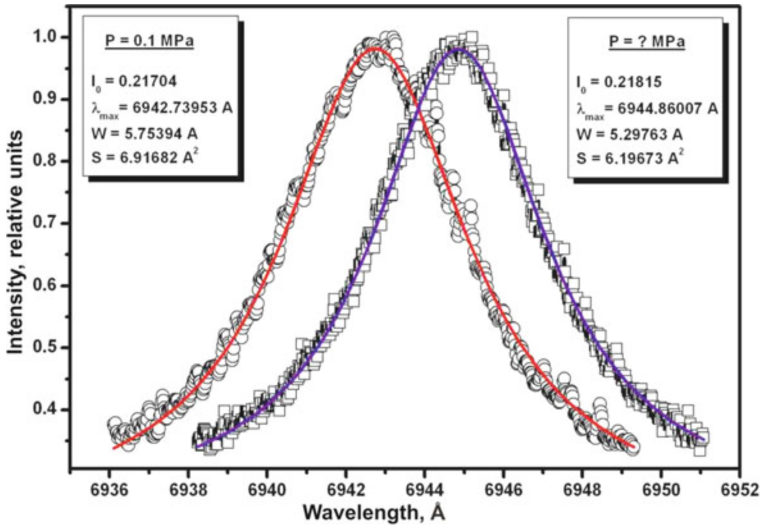

Fig. 1. R_2—lines of the luminescence spectrum of a ruby crystal with a thickness of 0.5 mm at a temperature 23 °C, atmospheric pressure () and known pressure P (). Solid lines—Lorentz functions R_2—lines at atmospheric and unknown pressure, respectively

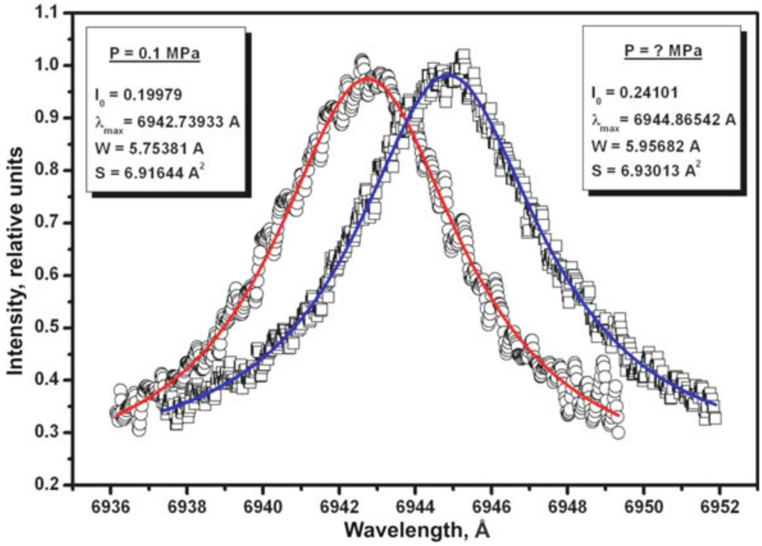

Fig. 2. R_2—lines of the luminescence spectrum of a ruby crystal 3 mm thick at a temperature 23 °C, atmospheric pressure () and known pressure P (). Solid lines—Lorentz functions R_2—lines at atmospheric and unknown pressure, respectively

3.0 mm:

$$P \approx 274.6 \cdot (W_{R_2}^{P} - W_{R_2}^{0}) = 274.6 \cdot (5.95682 - 5.75381) \approx 55.7\text{MPa}$$

4 Output

As a result of the calculation, it was determined that the parameter of non-hydrostatic compression of ruby crystals with a thickness of 3.0 mm at a temperature 23 °C and pressure 583,8 MPa has a value of more than 5 times the specified accuracy. At a temperature 95 °C, due to significant merger R1 and R2—lines of the luminescence spectrum of ruby, the non-hydrostatic parameter increases even more and the absolute value of the pressure is determined with an unacceptable error. For a ruby crystal with a thickness of 0.5 mm, the non-hydrostaticity parameter is negative, which indicates a sufficient uniformity of stresses in the ruby crystal under the influence of the difference in pressures on its surfaces. At a temperature 95 °C this parameter decreases by an order of magnitude, but at the same time its sign does not change, and the absolute value of the pressure is determined with a still permissible error.

Substituting into expression (3) the values obtained at temperatures 5, 25, 45, 65, 75 and 95° half-width values R_2—lines of the luminescence spectrum of ruby crystals with thicknesses 3.0; 1.0 and 0.5 mm at atmospheric pressure and pressures 100, 400, 700 and 1000 MPa, determined that with a ruby crystal thickness of 0.5 mm, the pressure recording accuracy is no more than ± 10 MPa, which corresponds to its specified value. Half-width changes R_2—the lines of the luminescence spectrum of ruby crystals with different thicknesses with a change in temperature and pressure in the region up to 100 °C and 1000 MPa turned out to be linear in the first approximation. As a result of the experiments and calculations, a ruby crystal with a thickness of 0.5 mm was chosen as a manometer, which makes it possible to measure pressure with an accuracy of ±10 MPa.

The developed manometer was installed in a research complex developed by us, which includes an automated high-pressure installation, blocks for heating and maintaining a given temperature of the processed product, and control blocks for the research process. The complex is designed for laboratory studies of the effect of high pressure and temperature on the physical and optical parameters of solid, liquid and viscoplastic products used in various industries, including food. The research complex allows registering the necessary parameters of the investigated object before creating pressure, creating pressure and temperature, with holding the research object in a chamber from several minutes to several days with continuous registration and documentation of pressure and temperature on a personal computer. At the same time, the change in the volume of the sample can be recorded simultaneously, both in the phase of pressure build-up and in the decompression phase. The design of the hydraulic part allows you to adjust the rate of pressure rise and release in the working chamber. The presence of optical windows makes it possible to measure the optical characteristics of the investigated product during compression, holding and decompression. The design of the chamber provides for the possibility of further modernization for the purpose of combined processing (pressure and temperature, pressure, temperature and ultrasound). The main parameters of the research complex are presented in Table 1.

Table 1. The main parameters of the research complex

Indicators	Parameters
Working pressure range	0,1…1000 MPa
Working temperature range	+ 5… + 100 °C
Sample volume	to $5 \cdot 10^{-6}$ m^3
Working diameter of the high-pressure chamber channel	$1.2 \cdot 10^{-2}$ m
Working displacement of the piston	$3.0 \cdot 10^{-2}$ m
Working length of the cylindrical part of the channel	$4.5 \cdot 10^{-2}$ m
Temperature recording sensitivity	0.1 °C
Accuracy of recording temperature maintenance	± 0.5 °C
Pressure registration sensitivity	1 MPa
Accuracy of registration and maintenance of pressure	±10 MPa

To measure the pressure in the chamber, a ruby crystal was used, for which R2 is analytically described—the line of the luminescence spectrum with a confidence factor from 0.9905 to 0.9964, while it was experimentally established that the parameter of non-hydrostatic compression of ruby crystals, which is used as a manometer, with a thickness 3 mm at temperature 230 °C and pressure 583,8 MPa has a value exceeding the specified accuracy by more than 5 times. The use of a ruby crystal 0.5 mm thick as a manometer makes it possible to obtain an accuracy of recording the pressure of ± 10 [MPa].

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Mathematical Modeling of Blur of Object in Image for Using It as Information Criterion

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Abstract. The present paper suggests a mathematical model of a function of object blurring in the primary image. This model can be implemented into software for automated systems of monitoring, control and measuring of moving and stationary objects pertaining to various categories. Function of blurring takes into account the values of parameters of the medium that is located between the monitoring system and a target object, color components of object's image and background, movement parameters of the object and the detector, parameters of means of detecting and primary image processing. The suggested model of image blurring helps present the blurring function as an important information criterion, which allows determining the parameters of movement and state of a target object, properties of the medium where video recording is being made, characteristics of hardware and software measurement system and also assessing the possibility to apply calculation algorithms and schemes of detection, capturing and recognition of particular objects.

Keywords: Primary image · Image blurring · Study object · Parameters of photodetector · Medium properties · Light spectrum · Color components

1 Introduction

The current stage of development of transport, construction, industrial production and security sector is associated with the increasing importance of automated monitoring, control and management systems for both individual processes and entire technological chains and complex technical systems. The primary task for such systems is to determine the parameters of the state and behavior of objects (their speed, direction of moving, their distance from the system, their shape, size, contrast, etc.) [1–3]. To be fulfilled, these tasks can involve solutions both in the optical and in other wavelength ranges, in which the measurement data are presented in the form of a graphic image after the primary processing [4, 5].

To obtain initial data on behavior and state of a target object in the optical observation range, there are used visual-optical, visual, television, photo and video monitoring devices, night observation systems and thermal imagers [4–7].

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2 Research Technique and Results

One of the ways to determine the distance to the object under study through analyzing its image can be considered on the basis of the assumption that the image of the optical system is not blurred when the object is in focus of the optical system, while an object located closer or further will be blurred in the image [7–9]. In fact, blur is a kind of boundary layer between the object's image and the background (medium).

Parameters of the boundary layer besides indicating the quality of the image, can be a full-fledged informative criterion that determines the set of parameters of the entire monitoring and control system, as well as parameters of state and behavior of the object under study [10, 11].

Traditionally, the function of blurring in different directions is advised to determine with the use of a blur circle taking into account the obtained image size, the number and size of photosensitive points of the sensor. The algorithm for assessing an object's image blurring by studying the boundaries involves re-blurring the image via the Gaussian function with known parameters. Further, the gradients of the original and synthesized images are compared and the estimate of all object's boundaries blur is calculated (Fig. 1), which further is applied to the entire object's image.

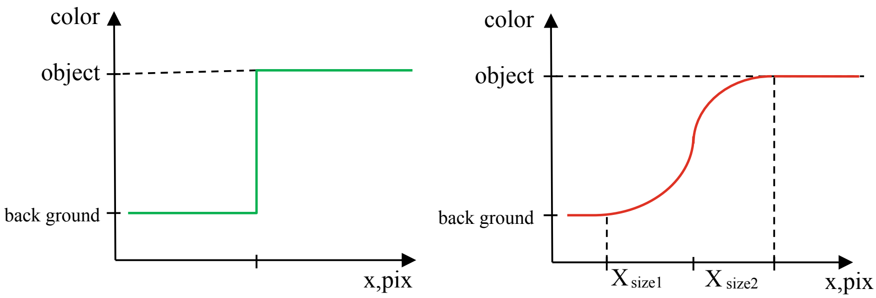

Fig. 1. Ideal edge and edge blurred by a Gaussian function

To determine the degree of blurring of an object's edges, it is often advised to consider the image as a dependence of density on coordinates I (x,y). Then using different levels of resolution of Bokeh iterative scheme [12, 13] one should calculate first-order derivatives for each of the coordinates (gradient projections on axes x and y), second-order derivatives that show changes in projections of the gradient on axes x and y, equate to zero to determine the points with the highest rate of change in density along the coordinates (the center of blur) x0 and y0, and then determine the inflection points of the function for each of the coordinates in the vicinity of found x1 and y0: their coordinates are x1 and x2 and y1 and y2, respectively. Thus, points x1 and x2 will define the boundaries of the object's blur along x axis: $\sigma x = x2 - x1$, while y1 and y2 will define the boundaries of blur along y axis: $\sigma y = y2 - y1$.

The blur function is suggested to be described by seven main factors: the characteristic of medium between the monitoring system and the object under study (medium blur, σ_{mat}); the dependence of blur on color: in fact it is a dependence on the wavelength belonging to the visible spectrum λ (color blur, σ_{col}); features of movement of elements of the detection system, i.e. movement of the target object and the hardware of the monitoring system (motion blur, σ_{mov}); background state features (background blur, σ_{bg}); parameters of detection tools (blur due to the detector, σ_{det}); primary processing of the object image (primary processing blur, σ_{pp}); features of the state and behavior of the target object (blur due to the state of surface of the target object, σ_{sc}).

The blur function limits capabilities of detection systems, causes errors when detecting and recognizing an object, but it also carries additional information about the object that needs to be processed correctly. Blur can determine the minimum distance between the detected objects, the maximum speed of movement of objects for their recognition, the parameters of photo and video detectors required to operate in a remote control, monitoring or diagnostics system in specific conditions and for certain groups of controlled objects [11, 14].

The study object is a passenger car moving in braking mode with a decrease in speed approximately from 50 km/h to 30 km/h. While primary images under the same settings of the photodetector are being obtained, a blur function is formed, which has prevailing components σ_{mov} and σ_{det} [15, 16]. The stationary object under study is a book, the image of which was obtained at a distance of 1.0 m and 0.8 m from the photodetector. The book is in focus and has the smallest blur function due to σ_{det} component. Considering the blurring of other objects with taking into account of the distance from them to the camera lens, the influence of blur function components σ_{col} and σ_{bg} can be stated.

The component of the blur function that takes into account the properties of medium can be represented using the following ratio:

$$\sigma_{mat} = \Delta\lambda \frac{L}{H} \frac{\lambda}{v_f} \frac{dP_{tr}^2}{d\lambda^2} \tag{1}$$

where $\Delta\lambda$ is the colors presented in the image, represented by wavelengths of the optical spectrum; P_{tr} is the transparency function of the medium, which is the sum of the functions of refraction, illumination, temperature fronts and noise; L is the reduced distance from the photodetector to the object; H is the characteristic size of the object; λ is the wavelength of the optical spectrum, corresponding to a certain color in the image; vf is the reduced speed of propagation of light waves in the medium under consideration.

The transparency function of the medium can be described by a dependence smoothly changing from the central axis (the central axis of the photodetector, which is the shortest distance from the detector to the motion path of the object under study) to the image boundary and depending on the reduced distance from the detector to the object, on the characteristic size of the object itself and the size of the primary image:

$$P_{tr}(L) = P_{tr}^0 \left[1 + K_{sp} \frac{P_{tr}^0}{P_{tr}^m} \left(\frac{L}{H_m} \right)^n \right], \tag{2}$$

where n is a nonlinearity index, which shows the degree of change in the parameters of the medium between edges of the primary image; P_{tr}^0 is a transparency function on the central axis of the photodetector; K_{sp} is a coefficient that takes into account the change in the metrics of space when it is displayed as a flat image; P_{tr}^m is an averaged transparency function for the pattern shooting situation; Hm is the reduced width of the space at the level of the object under study that falls on the primary image.

The influence of wavelength λ of the optical range (the influence of color) on the blur function can be represented as follows:

$$\sigma_{col} = \Delta\lambda \frac{L}{H} \frac{K_{col} P_{tr}^2}{v_f \lambda}, \tag{3}$$

where Kcol is a set of determining coefficients showing the difference between the layers of the medium between the photodetector and the object relative to the pattern layer.

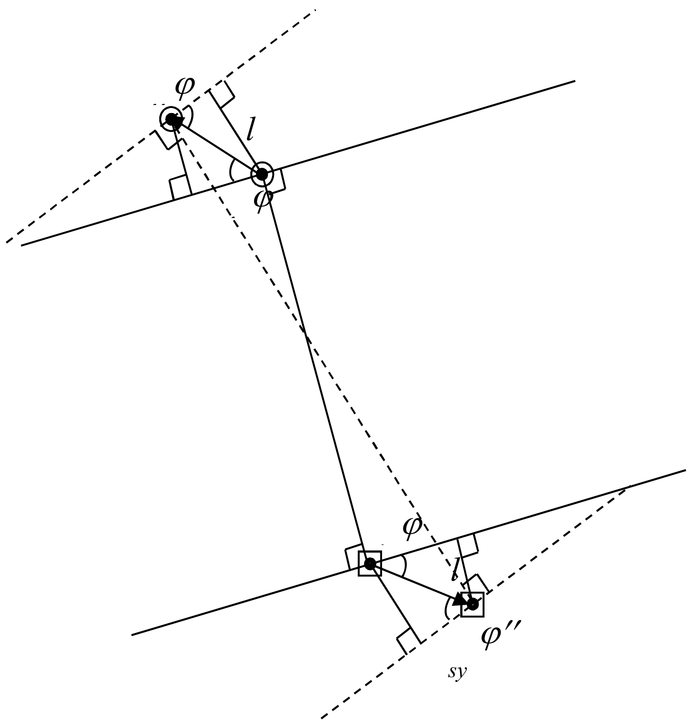

Fig. 2. The scheme of the appearance of blurring of points of the object due to the motion of the detector and the object under study in the horizontal plane

Figure 2 illustrates the appearance of blur during the movement of the target object (highlighted in the figure with a circle) and the detector of the monitoring system (drawn out in the figure with a square). During the formation of a primary image, both the object and the detector can move a certain distance. Let us consider the geometric relationship between the positions of the object and the detector during the acquisition of an image.

This scheme of appearing of motion blur is valid if during the time of the formation of the primary image the paths of motion of the object under study and the photodetector are close to a straight line [14, 15, 17].

The movement is shown by arrows; the distance between objects and perpendicular straight lines associated with them, which are necessary to construct the blur projection onto a plane perpendicular to the camera axis (the line segment connecting the position of the detector and points of the object), are shown by solid lines at the moment of detection start; and by dotted lines at the moment of the end of image acquisition. Movement of the object and the photodetector is proposed to be determined relative to planes perpendicular to segments connecting positions of the object and the detector at the moment of the beginning and the end of acquisition of the primary image, since the image itself and the blurring of individual objects in this image are caught the most sharply on the axis of the camera (in the plane perpendicular to the direction of detection). The movement of the object and the photodetector of the monitoring system in a projection on a plane perpendicular to the segments connecting positions of the object and the photodetector at the beginning and end of image acquisition can be represented as:

$$l_{ob} = \frac{\sigma'_{ob}}{cos\varphi'_{ob}} = \frac{\sigma''_{ob}}{cos\varphi''_{ob}}, l_{sy} = \frac{\sigma'_{sy}}{cos\varphi'_{sy}} = \frac{\sigma''_{sy}}{cos\varphi''_{sy}}, \tag{4}$$

where,l_{ob}, l_{sy} are distances passed by the target object and photodetector of the monitoring system, respectively, for a period from the beginning to the end of receiving a primary image;,σ'_{ob}, σ''_{ob} andσ'_{sy}, σ''_{sy} are motion blur of the target object and photodetector, respectively, in projections on the plane perpendicular to the segments connecting positions of the object and the detector at the beginning (variable with the prime symbol) and end (variable with the double prime symbol) of the period of acquisition of a primary image; φ'_{ob}, φ''_{ob} and φ'_{sy}, φ''_{sy} are angles between the direction of movement of the target object (subscript ob) or the photodetector (subscript sy) and the planes perpendicular to the segment connecting initial positions of the object and the detector (variables with the prime), or to the segment connecting final positions of the object and the detector (variables with the double prime) (Fig. 2).

In general case, motion blur of elements of the data measurement system includes components that appeared both due to the movement of the target object and due to movement of the detector (3). Taking into account the equally probable effect of these values, the final value can be represented in the following form:

$$\sigma_{mov} = f(\sigma_{ob}) + f\left(\sigma_{sy}\right), \tag{5}$$

functions $f(\sigma_{ob}), f\left(\sigma_{sy}\right)$ are determined through values σ'_{ob}, σ''_{ob}, σ'_{sy}, σ''_{sy}

The final choice of the function that determines motion blur of the image reasoned by movement of the monitored object and the camera during the formation and saving of the primary image can be determined empirically [16, 18, 19]. At a significant size of the target object, additional aberrations must be taken into account.

The appearance of blurring of image fragments is also possible due to their distance from the axis of the photodetector and is associated with an angle between the axis of the photodetector and the line connecting the detector (as a point) and the endpoint of the target object. If the blur on the axis of the photodetector is taken as a constrained minimum, then the following relationship can be assumed, which is valid at a linear change in the parameters of the medium over the entire width of the object:

$$\sigma_{sz} = \sigma_{ex} - \sigma_{ax} = \frac{LP_{tr}^{ex}}{v_f cos\theta_1} - \frac{LP_{tr}}{v_f}, \tag{6}$$

where σ_{sz} is a blur associated with the size of the object's image, $f(\sigma_{ax}, \sigma_{ex})$ is a function that connects blurring of the image points on the axis of the photodetector (σ_{ax}) and at the farthest distance from it (σ_{ex}), P_{tr}^{ex} is a function of transparency of the medium at the level of the most distant point of the object under study, θ_1 is an angle between the axis of the photodetector and the line connecting the detector and the most distant point of the object under study.

The possibility of changing the state and behavior of the surface of the object under study (σsc) during observing it was not considered; dynamic contact between different objects, during which they can change their shape and other state parameters, was not considered as well [20–22].

When calculating the component of the blur function associated with the background features σbg, the background is considered as everything that is located behind the target object without taking into account the depth of disposition of individual background elements [23, 24]. This component of the blur function, as well as components characterized by settings of video and photo detectors (σdet), parameters of primary processing and file formats of image recording (σpp), are proposed to be defined empirically with taking into account of objects observed, detectors and extraneous elements used that fall into the final frame.

Since the visible range has a wavelength range of 0.37 to 0.75 microns, the spectrum changes when propagating in a non-transparent space. A general blur can be represented as a function that links all the above blur types:

$$\sigma_{\Sigma} = \sigma_{mat} + \sigma_{col} + \sigma_{mov} + \sigma_{bg} + \sigma pp_{sc_{det}} \tag{7}$$

The presented mathematical model of blurring the elements of the object in the image takes into account many different parameters. This entails difficulties when determining the influence of each factor. For the convenience of performing a comparative analysis for some classes of applied problems, it is proposed to use the blur function reduced to a unit of distance and a unit of a color range:

$$\sigma_{\Delta\lambda L} = \frac{K_{sp}}{v_f}\left[\lambda^2 \frac{d^2\beta}{d\lambda^2} + 2\lambda \frac{d\beta}{d\lambda}\right], \tag{8}$$

where $\sigma_{\Delta\lambda L}$ is a reduced blur function, K_{sp} is a coefficient that determines the geometric parameters of the space near the object, β is a characteristic of the depiction of color components (colors) in a space.

The characteristic of depiction of colors in a space can be represented as:

$$\beta^2 = \frac{1}{H_m^2}\left[\frac{N^2}{P_{tr}^{pr}} - M^2\right] \tag{9}$$

where $N = kH_m\sqrt{\frac{P_{tr}}{P_{tr}^{ax}}}$, P_{tr}^{ax} is a transparency function of the medium on the axis of the detector towards the object under study, $k = \frac{2\pi}{\lambda}$, k is a wavenumber in a free space, M is a transmission parameter of an individual color component in space.

It can be noted that the blur function does not significantly depend on the wavelength (color components); dependence of the transparency function on color components can be neglected; in the general case, we can state that blur is proportional to the range of colors available in the composition, i.e. to the width of the radiation spectrum.

3 Conclusions

The suggested model for representing the function of blurring the object in the image allows indicating that the blurred boundary layer not only characterizes noise components of the image, but also contains important information on state and behavior of the object itself. This characteristic can serve as an important criterion that regulates operation of the automated monitoring and control system under various conditions with taking into account of gradients of particular colors; movement of the target object and hardware of the monitoring system; primary image processing after detection and recognition of the target object.

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Computer Modeling and Identification of Seasonal and Cyclical Components of Retrospective Data for Forecasting and Management

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Abstract. Ensuring the food security of the Russian Federation requires improving the methods of modeling the productivity of agricultural crops, for which various approaches are used in agricultural production, including nonlinear statistical technologies. The article presents the developed method of constructing a mathematical model of time series (TS) for predicting the yield of grain crops in the Statistic system. The forecast is based on representative samples based on the example of two TS—long-term yield levels and statistical data on electricity generation in the Russian Federation. The methodology of mathematical modeling of TS is justified taking into account a priori information about the structure of the simulated TS. The technique involves identifying the cyclical nature of TS at the stage of pre-forecast analysis. For the short-term description of the data, an exponential smoothing model was used. For long-term forecasting, the choice of the seasonal autoregression model and the integrated moving average ARIMA (0,1,1)(0,1,1) is justified, its parameters are determined and its adequacy to real statistical data is proved. Using the found mathematical model, a long—term prediction (period—12 months) was performed on the example of electricity generation in the Russian Federation with a 90% confidence interval. The methodology presented in this paper for analyzing non-stationary time series using computer modeling tools Statistica can also be used to predict retrospective data in various fields of scientific and applied activity for the analysis and forecasting of TS, which are characterized by a seasonal component and a trend.

Keywords: Time series · Yield · Forecasting · ARIMA model

1 Introduction

For the analysis of retrospective data in various fields of scientific and applied activity, more than fifty mathematical and statistical methods are known, the computational algorithms of which are implemented on a PC, in particular, in the environment of the

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Statistica application software package of various versions [1–4]. The possibilities of mathematical and statistical methods, especially those focused on retrospective analysis, when using data from past time periods to identify trends, as well as cyclical and seasonal components, are very extensive. At the same time, as noted in [5], most of these methods are not used for mathematical modeling of phenomena and objects in the agro-industrial sphere. At the same time, using statistical methods, it is possible to construct adequate mathematical and statistical models that can be used both for assessing the state and functioning of phenomena and processes at the present time, but also for predicting their development in the future [6–8].

This is especially important for the analysis of historical data that changes over time, in particular, including the trend, as well as cyclical and seasonal components [9]. Among such data are of interest, for example, yield levels, indicators of electricity generation in the Russian Federation, and many others. Such data sets reflect not only the state of economic sectors, but also the dynamics of the evolution of the country as a whole.

Traditionally, the analysis of the dynamics of indicators, for example, electricity production, is carried out using standard methods. At the same time, they calculate the percentage of electricity generation for certain periods of time [10–12] and draw conclusions about the dynamics of the entire process based on the magnitude of its change. This approach makes it possible to estimate the changes that have occurred over a certain period of time, but it does not allow for scientifically based forecasting of changes in the studied values for future periods of time. At the same time, mathematical algorithms for constructing models that adequately describe, for example, non-stationary time series (TS) are well developed and implemented in the SPT STATISTICA environment [4].

The purpose of this study was to mathematically model cyclical and seasonal phenomena on the example of yield statistics, as well as electricity generation in the Russian Federation, using time series analysis methods in the Statistica environment.

2 Materials and Methods

2.1 Source Data

The main object of the study was the TS of long-term yield levels of grain crops in arid conditions, including winter and spring wheat, barley, etc. [13], taken from official sources of state statistics for the Volgograd region of the Russian Federation (Fig. 1).

To compare the use of the described mathematical modeling methodology, we also used statistical data on electricity generation in the Russian Federation for the period 2012–2019 [14], the dynamics of which are shown in Fig. 4. As can be seen from the diagram in Fig. 4, electricity generation in the Russian Federation is presumably a non-stationary time series, which has a pronounced seasonal component.

2.2 Computer Simulation Methods

For mathematical modeling of such time series, Statistica computer modeling tools were used, in particular, the "Time Series/Forecasting" function in the non-linear Models-Time Series module [1, 2, 4].

This function provides the following tools for analyzing statistics:

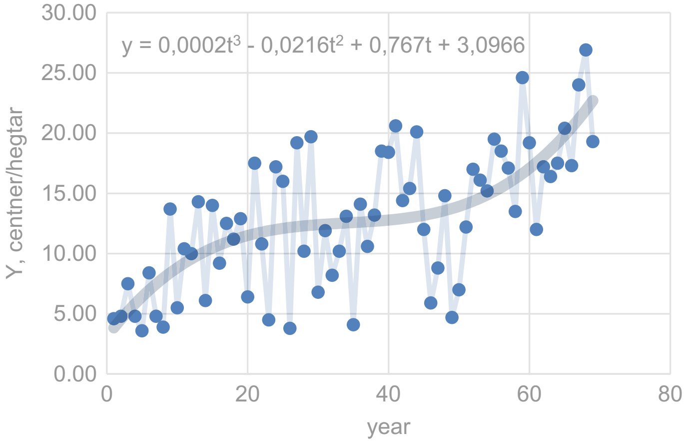

Fig. 1. TS of long-term yield levels of grain crops

- Fourier analysis to identify the seasonal component;
- exponential smoothing for building short-term forecasting models;
- the ARIMA autoregression and integrated moving average model for mathematical modeling and long-term forecasting of the studied processes.

The exponential smoothing model developed by R. Brown for short-term forecasting purposes is based on the use of the following one-parameter recurrent formula [1, 3]:

$$S_t = \alpha^* Xt + (1 - \alpha) * S_{t-1} \tag{1}$$

where: $X = (X_1, x_2, \ldots\ldots X_t)$—the original time series,

α—(parameter "alpha")—the smoothing coefficient.

A feature of the mathematical model (1) is that recent values given more weight than the penultimate, the penultimate—and more than the previous one, etc. When this formula is applied recursively, each new smoothed value is calculated as a weighted average of the current observation and the smoothed series. If $\alpha = 1$, the previous observations are completely ignored; if $\alpha = 0$, the current observations are ignored. Alpha values in the range 0…1 give intermediate results. The advantage of model (1) is that it is easy to implement on a PC. The main drawbacks of this model are that it does not allow for cyclical and seasonal components. In addition, the model does not allow calculating confidence intervals for performing the procedure of short-term forecasting of the studied process [1, 3].

A special feature of the seasonal multiparametric autoregression and integrated moving average (ARIMA) model is that it takes into account cyclical and seasonal components in addition to the trend. The model has the following parameters: autoregression parameter-p, seasonal autoregression parameter P, moving average parameter q, seasonal moving average parameter Q. All these parameters are calculated in the STATISTICA environment in accordance with the Box-Jenkins methodology [5, 11]. According to this methodology, the original time series is transformed by taking first-or second-order differences, resulting in a stationary time series for which the corresponding model parameters are calculated [1, 11].

3 Defining Model Parameters and Forecasting

Computer modeling of the time series levels of electricity generation in the Russian Federation consisted in determining the parameters of two mathematical models that were used to make forecasts for future time periods:

- simple exponential smoothing models;
- ARIMA autoregression and integrated moving average models.

3.1 One-Parameter Exponential Smoothing Model

To determine the parameters of the exponential smoothing model, we used the "Exponential Smoothing and Forecasting" function of the "Time Series/Forecasting" module of the Statistica software package [1, 2, 5]. A single parameter of the model (1) was used for the simulated indicators of yield levels and electricity generation in the Russian Federation (1): $\alpha = 0{,}1$. Thus, the mathematical model of exponential smoothing (1) acquired the following specific form:

$$S_t = 1.0 * Xt + 0.9 * S_{t-1} \tag{2}$$

According to this model, in particular, the electricity generation in the Russian Federation in each month of the studied period is determined primarily by the value of this indicator in the previous month, i.e., mainly by the value of the 0.9*St-1 term in expression (2). At the same time, the influence of a number of values of power generation (variable Xt) is insignificant, since its contribution to the total value Is represented by the term 0.1 * Xt in expression (2).

Using the parametrized model (2), a short-term forecast of the values of electricity generation in the Russian Federation for 2019 was performed, which are shown in Fig. 2 in comparison with real data.

As can be seen from the graph in Fig. 2, there is a satisfactory correspondence between the actual yield values and the values calculated using the exponential smoothing model.

However, it should be noted that the short-term forecast of yield values was made without determining the confidence interval, since this is not provided for by the calculation algorithm using this model, which was noted in paragraph 2.2 when describing the characteristics of such a model.

3.2 The ARIMA Model

Long-term forecasting with the calculation of the confidence interval is possible using the ARIMA model, finding the parameters of which is a step-by-step research procedure, which is used later.

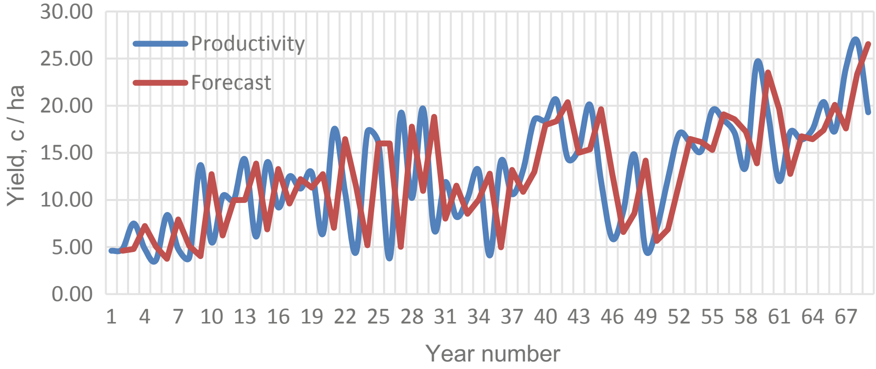

Fig. 2. Grain yield modeling using the exponential smoothing model (2)

At the first step of mathematical modeling of the dynamics of electricity generation in the Russian Federation, it is necessary to answer the question whether this statistic is a non-stationary time series. In this regard, a preliminary study was conducted to determine whether there are cyclical or seasonal components in the time series under study. To do this, using the "Spectral (Fourier) analysis" function of the "Time Series/Forecasting" STATISTICA module, a Fourier spectral analysis of statistical data for the period 2012–2018 was performed. As a result, a periodogram was constructed, which had a narrow single peak at the value of the number of months $t = 12$. This peak indicates the presence of a seasonal cycle with a period of 12 months, and no other irregular cycles were observed in the studied time series.

Thus, it is established that electricity generation in the Russian Federation for the period 2012–2018 had a stable seasonal cycle with a period of 12 months, or 1 year. Thus, the studied statistics have one of the signs of non-stationarity of the time series [1–3].

The next step of computer mathematical modeling was to determine the trend in the time series under study. Using the graph in Fig. 1, it is difficult to do this visually. To identify the presence of a trend (or its absence) in the data under study, an autocorrelation analysis was performed using the "ARIMA and autocorrelation functions" function of the "Time Series/Forecasting" module of the STATISTICA software environment. The sample autocorrelation function shown in Fig. 3 was constructed. The graph shows that the sample autocorrelation function does not have a pronounced tendency to decay. The peak of a stable seasonal cycle with a period of 12 months is clearly visible. All this indicates that the time series is non-stationary, i.e. there is a weak trend [1].

The ARIMA model with three parameters (p,q,d,) was chosen as a mathematical model for describing the studied statistics. To determine the value of the parameter d, first-order differences were calculated, resulting in a time series that was checked for stationarity using a partial autocorrelation function. It turned out that the time series of the first differences became stationary, which allowed us to choose the value of the model parameter $d = 1$. For other parameters of the ARIMA model, the following values are selected: $p = 0$ and $q = 1$.

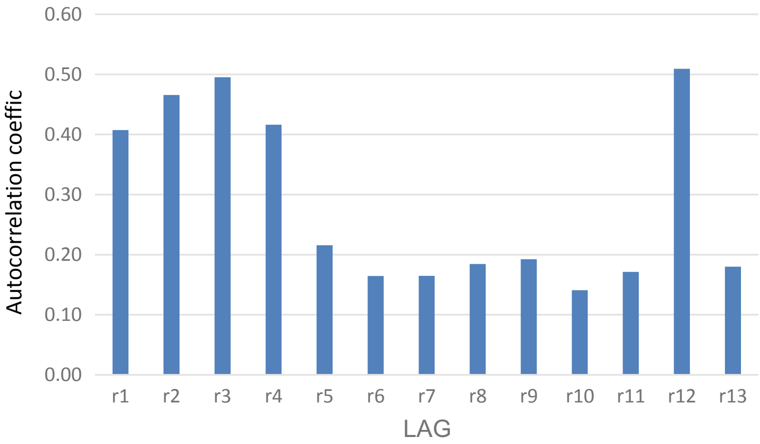

Fig. 3. Autocorrelation function of grain yield data TS

Since the studied time series, as shown above, has a pronounced seasonal component with a period of 12 months, it is necessary to make a seasonal adjustment to the ARIMA model [1]. Therefore, seasonal parameters with the following values were introduced into this model: the seasonal autoregression parameter Ps = 0, the seasonal difference Ds = 1, and the seasonal moving average parameter Qs = 1. Thus, the following ARIMA model was formed (0,1,1) (0,1,1).

The parameters of this model, calculated using the computer package STATISTICA, were significant at a level below 0.05, which confirms their statistical significance. In addition, to check the adequacy of the found ARIMA(0,1,1)(0,1,1) model to real data, a number of residuals were analyzed for compliance with its distribution with the law. This analysis showed that, despite some outliers, a number of residues in General correspond to the normal distribution, which indicates the adequacy of the found ARIMA model-(0,1,1) (0,1,1) to real data (Fig. 4).

Using the found ARIMA (0,1,1)(0,1,1) model, the forecast of electricity generation in the Russian Federation for the future period of 12 months is made: from 1.09.2019 to 1.07.2020. The results of the calculations with a 90% confidence interval is shown in Fig. 1. As can be seen from the comparison of Fig. 1 there is good correspondence of the dynamics predicted values of electricity generation in relation to the whole time series for the considered period.

The methodology presented in this paper for analyzing non-stationary time series using computer modeling tools STATISTICA can also be used for short-and long-term forecasting of retrospective data in other areas of scientific and practical activity. In particular, the methodology can be used to analyze and predict the yield of grain crops, which, like electricity generation, has a seasonal component and a trend.

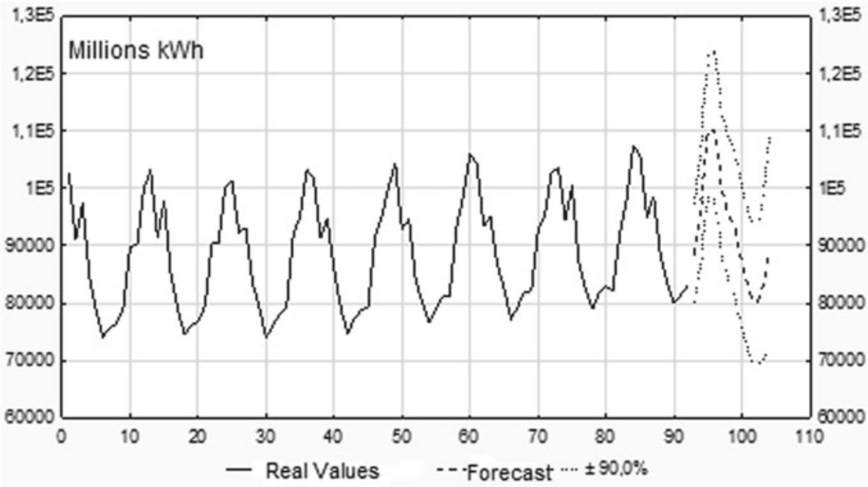

Fig. 4. Electricity generation in the Russian Federation by month

4 Conclusions

Based on the analysis of retrospective data, a research methodology was developed and mathematical modeling of the dynamics of electricity generation was performed. It is shown that the data under study form a non-stationary time series with both a trend and a seasonal component.

For mathematical modeling of such a time series using a one-parameter exponential smoothing model using Statistica, the value of the parameter $\alpha = 0.1$ is set. Using the found model, short-term forecasting of electricity generation in the Russian Federation for 2019 is performed. and the calculated values were compared with real data, which showed a fairly close match, which can be used for short-term operational forecasting.

A multiparametric seasonal autoregression model and integrated moving average ARIMA (p,q,d,)(Ps,Ds,Qs) was chosen as a mathematical model for long-term forecasting of electricity generation in the Russian Federation. Based on data on electricity generation in the Russian Federation for the period 2012–2019, the time series is non-stationary and has a trend and seasonal component. Statistica computer modeling tools define the model parameters as ARIMA (0,1,1) (0,1,1). The adequacy of this model to real statistical data is proved. Using the found mathematical model, a long—term forecast (period-12 months) of electricity generation in the Russian Federation with a 90% confidence interval was performed.

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Mathematical Models for Determining Areas of Static Stability in Electrical Networks with Distributed Generation Plants

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Abstract. There is now an increased interest in distributed generation (DG) plants located in close proximity to power consumers; at the same time, it is assumed that a significant number of the DG facilities utilizes renewable energy resources. The wide use of DG technologies in electrical energy systems (EES) requires development of new control algorithms in normal, emergency, and postemergency modes. The issues of determining limit loads for the EES equipped with DG plants are of particular importance. These plants can be removed from the consumption centers, which leads to a 'narrowing' of static aperiodic stability (SAS) areas. This paper presents the results of studies aimed at developing methods for determining the SAS areas in the EES equipped with DG plants. On the basis of the limiting mode equations, an effective technique for determining the EES stability areas with DG plants for various network structures were propose, and the results of building SAS areas for an electrical network with distributed generation were present. Additionally, simulation of transient processes in the EES under study were carried out for various points in the space of the mode controlled parameters in MATLAB.

Keywords: Electric energy systems · Distributed generation plants · Limit modes equations · Static aperiodic stability areas

1 Introduction

Calculations of the static aperiodic stability (SAS) [1] limiting modes are important when designing and operating electrical energy systems (EES). Such modes have their independent value, but they are also an integral part of other electrical energy problems related to providing a required level of the EES reliability and cost effectiveness [2, 3].

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The issues of determining the limiting modes are of particular interest for power supply systems equipped with distributed generation (DG) plants, and especially for the plants that utilize non-conventional renewable energy sources using energy storage devices [4–14]. Such plants, for example, mini hydropower plants or offshore windmill farms, may be located quite far from consumption centers, which leads to a 'narrowing' of the SAS areas and has a significant impact on emergency control to ensure stability in post-emergency power plant modes [15]. This paper discusses mathematical models for the operational determination of the areas of static stability in electrical networks with DG plants, built on the basis of the limiting mode equations.

2 Problem Formulation

The electrical power systems steady-state modes are described by non-linear equations of the following type

$$\mathbf{F}(\mathbf{X}, \mathbf{Y}) = \mathbf{0} \tag{1}$$

where $\mathbf{F} = [f_1 f_2 \ldots f_n]^T$ is an n-dimensional vector function, corresponding to the power or currents balance equations in network nodes; $\mathbf{Y} = [y_1\ y_2\ \ldots\ y_m]^T$ is a given vector of controlled parameters (independent variables); $\mathbf{X}$ is a required vector of uncontrolled parameters (dependent variables).

The modes that are limiting in terms of static aperiodic stability can be considered as the EES modes corresponding to the points $\mathbf{X}_L$, $\mathbf{Y}_L$ from the parameter space $\mathbf{Z} = \mathbf{X} \cup \mathbf{Y}$, in which Eqs. (1) and the condition

$$a_0 = (-1)^n \det \frac{\partial \mathbf{W}}{\partial \mathbf{X}} = 0 \tag{2}$$

are satisfied. Here $\frac{\partial \mathbf{W}}{\partial \mathbf{X}}$ is the Jacobian for the steady-state equations (SSEs).

$$\mathbf{W}(\mathbf{X}, \mathbf{Y}) = \mathbf{0} \tag{3}$$

which are written down taking into account characteristics of the electrical energy system elements for low disturbances. The points $\mathbf{Y}_L$ form a discriminant hypersurface L_W in the space $\mathbf{Y}$ (Fig. 1).

The modes can be viewed as existence (transmitted power) limiting modes if they correspond to points the $\mathbf{X}_{LP}$, $\mathbf{Y}_{LP}$ of the parameter space $\mathbf{Z} = \mathbf{X} \cup \mathbf{Y}$, in which SSEs (1) and the relation

$$\det \frac{\partial \mathbf{F}}{\partial \mathbf{X}} = 0 \tag{4}$$

are fulfilled, where $\frac{\partial \mathbf{F}}{\partial \mathbf{X}}$ is the Jacobian for the SSEs (1).

The points that satisfy condition (2) generate a discriminant hypersurface L_F in the space $\mathbf{Y}$ (Fig. 1).

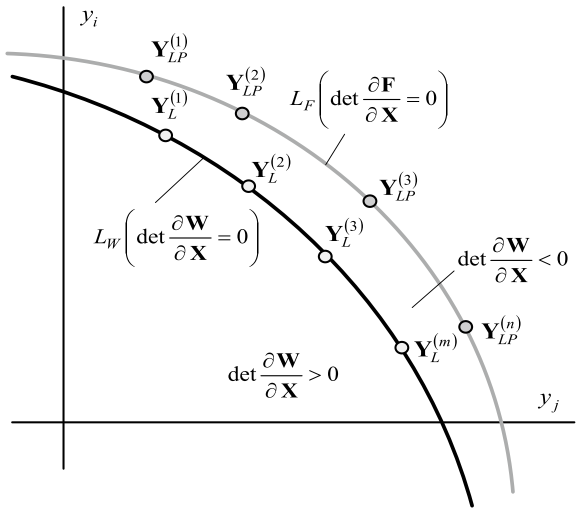


Fig. 1. Coordinate plane sections of the areas of modes stability and existence in the **Y** space

Generally, the Jacobians $\frac{\partial \mathbf{F}}{\partial \mathbf{X}}$, which are used to determine steady-state mode parameters, and the matrices $\frac{\partial \mathbf{W}}{\partial \mathbf{X}}$, used for stability analysis, do not coincide [3]. The stability and transmitted power limits are equal, if the characteristics of generators and loads used to calculate modes and study stability are the same. In this case, for the same forms of Eqs. (1) and (3), the matrices $\frac{\partial \mathbf{F}}{\partial \mathbf{X}}$ and $\frac{\partial \mathbf{W}}{\partial \mathbf{X}}$ are identical.

3 Limiting Modes Equations

An effective method for determining the limiting modes, which does not require multi-step computational procedures and can be applied for both coinciding and non-coinciding limits of the transmitted power and stability, may be implemented on the basis of the limiting modes equations (LMEs) [3]. This technique helps avoid the difficulties associated with solving ill-conditioned systems of linear equations.

The technique proposed is based on replacing condition (2) with the equivalent ratio that can be represented in two ways:

$$\mathbf{V} = \frac{\partial \mathbf{W}}{\partial \mathbf{X}}\mathbf{S} = 0 \tag{5}$$

$$\mathbf{V} = \left(\frac{\partial \mathbf{W}}{\partial \mathbf{X}}\right)^T \mathbf{R} = 0 \tag{6}$$

where $\mathbf{V}$ is an n-dimensional vector function; $\mathbf{S} = [s_1\ s_2\ s_n]^T$, $\mathbf{R} = [r_1\ r_2\ r_n]^T$ are eigenvectors of the matrices $\frac{\partial \mathbf{W}}{\partial \mathbf{X}}$, $\left(\frac{\partial \mathbf{W}}{\partial \mathbf{X}}\right)^T$ corresponding to the zero eigenvalue.

Since (5) and (6) define eigenvectors within constant factor, one of their components can be assumed to be arbitrary and different from zero. For instance, $r_n = s_n = 1$. Another way to complement Eqs. (5) and (6) is based on setting a length for vectors **R** and **S** (for example, we can take a unit length), i.e. we add equations $U(\mathbf{S}) = \mathbf{S}^T\mathbf{S} - 1 = 0$ or $U(\mathbf{R}) = \mathbf{R}^T\mathbf{R} - 1 = 0$. Elements of Jacobians are the functions that depend on parameters **X**. Consequently, unlike (2), conditions (5) and (6) provide an analytical description of the limit loads hypersurface L_W.

In the formulation stated above, determination of limiting the static stability loads is reduced to the joint solution of the following equations:

$$\left.\begin{aligned} &\mathbf{F}[\mathbf{X}, \mathbf{Y}(T)] = 0;\\ &\mathbf{V}[\mathbf{X}, \mathbf{S}, \mathbf{Y}(\mathrm{T})] = \frac{\partial \mathbf{W}}{\partial \mathbf{X}}\mathbf{S} = 0;\\ &U(\mathrm{S}) = \mathrm{S}^T\mathrm{S} - 1 = 0, \end{aligned}\right\} \tag{7}$$

where $\mathbf{Y}(T) = \mathbf{Y}_0 + T\Delta\mathbf{Y}$ is the trajectory of the vector $\mathbf{Y}$, $\mathbf{Y}_0$ is the value of the vector of controlled parameters in the initial mode; T is a scalar parameter.

When using a transposed matrix, the second vector equations in system (7) are replaced by ratio (6):

$$\left.\begin{aligned} &\mathbf{F}[\mathbf{X}, \mathbf{Y}(T)] = 0;\\ &\mathbf{V}[\mathbf{X}, \mathbf{R}, \mathbf{Y}(\mathrm{T})] = \left(\frac{\partial \mathbf{W}}{\partial \mathbf{X}}\right)^{\mathrm{T}}\mathbf{R} = 0;\\ &U(\mathbf{R}) = \mathbf{R}^T\mathbf{R} - 1 = 0. \end{aligned}\right\} \tag{8}$$

When the stability and transmitted power limits coincide, as well as when calculating the modes, the existence limiting systems of Eqs. (7), (8) are transformed to the following sets of equations:

(1) for a direct matrix

$$\left.\begin{aligned} &\mathbf{F}[\mathbf{X}, \mathbf{Y}(T)] = 0;\\ &\mathbf{V}[\mathbf{X}, \mathbf{S}, \mathbf{Y}(\mathrm{T})] = \frac{\partial \mathbf{F}}{\partial \mathbf{X}}\mathbf{S} = 0;\\ &U(\mathrm{S}) = \mathrm{S}^T\mathrm{S} - 1 = 0, \end{aligned}\right\} \tag{9}$$

(2) for a transposed matrix

$$\left.\begin{aligned} &\mathbf{F}[\mathbf{X}, \mathbf{Y}(T)] = 0;\\ &\mathbf{V}[\mathbf{X}, \mathbf{R}, \mathbf{Y}(\mathrm{T})] = \left(\frac{\partial \mathbf{F}}{\partial \mathbf{X}}\right)^{\mathrm{T}}\mathbf{R} = 0;\\ &U(\mathbf{R}) = \mathbf{R}^T\mathbf{R} - 1 = 0. \end{aligned}\right\} \tag{10}$$

To solve the LMEs, we can apply Newton's method, for each iteration of which the following system of linear equations is solved (for example, for the LME system written in the form (7)):

$$\begin{bmatrix} \frac{\partial \mathbf{F}}{\partial \mathbf{X}} & 0 & \frac{\partial \mathbf{F}}{\partial T} \\ \frac{\partial \mathbf{V}}{\partial \mathbf{X}} & \frac{\partial \mathbf{V}}{\partial \mathbf{S}} & \frac{\partial \mathbf{V}}{\partial T} \\ 0 & \frac{\partial U}{\partial \mathbf{S}} & \frac{\partial U}{\partial T} \end{bmatrix} \begin{bmatrix} \Delta X \\ \\ \Delta S \\ \\ \Delta T \end{bmatrix} = - \begin{bmatrix} \Delta \mathbf{F} \\ \\ \Delta \mathbf{V} \\ \\ \Delta U \end{bmatrix}$$

.

An essential property of the LMEs is non-singularity of the corresponding matrix at the points $\mathbf{X}_L$, $\mathbf{X}_{LP}$, i.e.

$$\det \frac{\partial \mathbf{H}}{\partial \mathbf{Z}} = \det \begin{bmatrix} \frac{\partial \mathbf{F}}{\partial \mathbf{X}} & 0 & \frac{\partial \mathbf{F}}{\partial T} \\ \frac{\partial \mathbf{V}}{\partial \mathbf{X}} & \frac{\partial \mathbf{V}}{\partial \mathbf{S}} & \frac{\partial \mathbf{V}}{\partial T} \\ 0 & \frac{\partial U}{\partial \mathbf{S}} & \frac{\partial U}{\partial T} \end{bmatrix} \neq 0,$$

where $\mathbf{H} = \{\mathbf{F}, \mathbf{V}, U\}$, $\mathbf{Z} = \{\mathbf{X}, \mathbf{S}, T\}$.

4 Simulation Results

Determination of the SAS areas based on the LMEs in the form (10) was carried out as applied to the network diagram [15], the situation plan and diagram of which are shown in Fig. 2. The DG plants rated capacities are assumed equal to 24 MW.

Calculations were performed for three options (Fig. 2):

1. A complete network diagram.
2. A jack between DG plants is open.
3. The line linking the DG1 plant with the EES substation is disconnected.

Figures 3 and Table 1 present simulation results. The results obtained allow us to conclude that an efficient technique for analyzing static aperiodic stability in an EES with DG plants can be implemented on the LMEs basis, which is applicable in design problems, as well as in operational and emergency control (OC and EC) problems. Non-singularity of the Jacobian of the LMEs at the solution point ensures the reliability of the results obtained, which is very important for solving OC and EC problems.

In addition, transient processes were simulated in MATLAB during a short-term connection of load with a power of $25 + j15$ MV·A at the EES substation for the following network configurations and values of the DG plants power:

1. for a complete network diagram (Fig. 2): $P_1 = 18$ MW; $P_2 = 18$ MW (steady state); $P_1 = 22$ MW; $P_2 = 18$ MW (unstable mode);
2. with the disconnected line that links the DG1 with the power source: $P_1 = 6$ MW; $P_2 = 6$ MW (steady state); $P_1 = 10$ MW; $P_2 = 8$ MW (unstable mode).

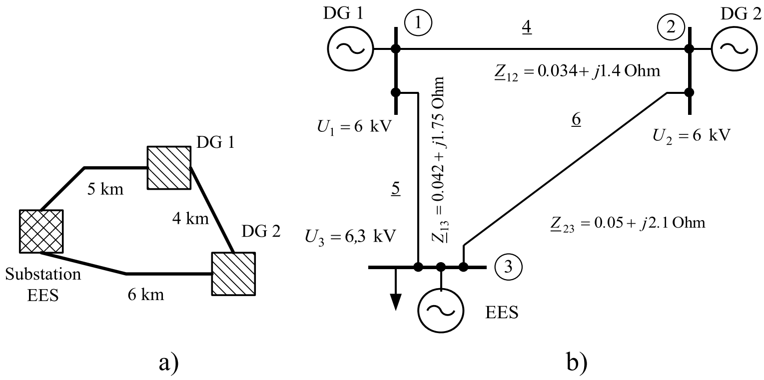


Fig. 2. The situation plan (**a**) and network diagram (**b**)

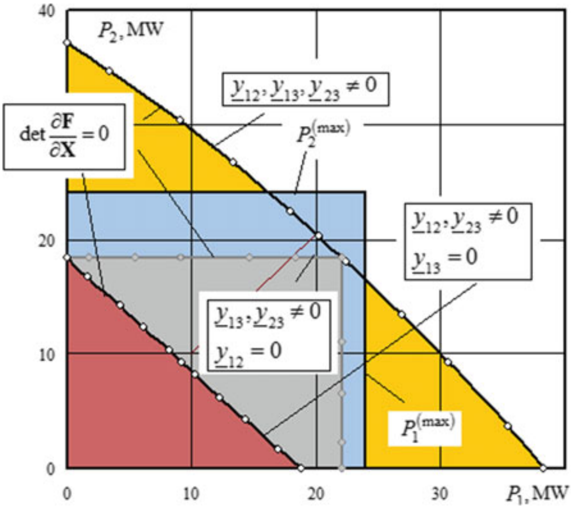


Fig. 3. SAS areas for different network structures

Figure 4 shows the complete diagram of the network model simulated in MATLAB. The model takes into account automatic voltage regulators (AVR) and automatic speed regulators (ASR) of the generator rotor rotation. Two mini hydropower plants with a nominal power of 24 MW each, operating on the basis of synchronous generators, are used as DG plants in the system under study. If the operating modes of the network have an additional load at the EES substations, they involve delivery of power from each generator to the receiving system (node 3 in Fig. 2). Disconnection of Line 1–3 means an emergency mode.

The synchronous generators of the DG plants were simulated by the standard block of the SymPowerSystems package of MATLAB - Synchronous Machine pu Fundamental.

We used the hydraulic turbine model (Fig. 4), whose diagram is shown in Fig. 5a. The model consists of a main servo motor, the block diagram of which is shown in

Table 1. Results of calculating the complete circuit modes

P_1, MW	P_2, MW	P_{ij}, MW	δ_1, deg	δ_2, deg	Q_1, Mvar	Q_2, Mvar
2	2	3.9	5.6	5.9	−0.97	−0.8
5	5	9.88	14.31	15.1	−0.5	−0.36
10	10	19.7	29.49	31	1.54	1.49
15	15	29.3	47.4	49.82	5.62	5.2
20	20	38.3	80.26	84.1	16.5	14.9

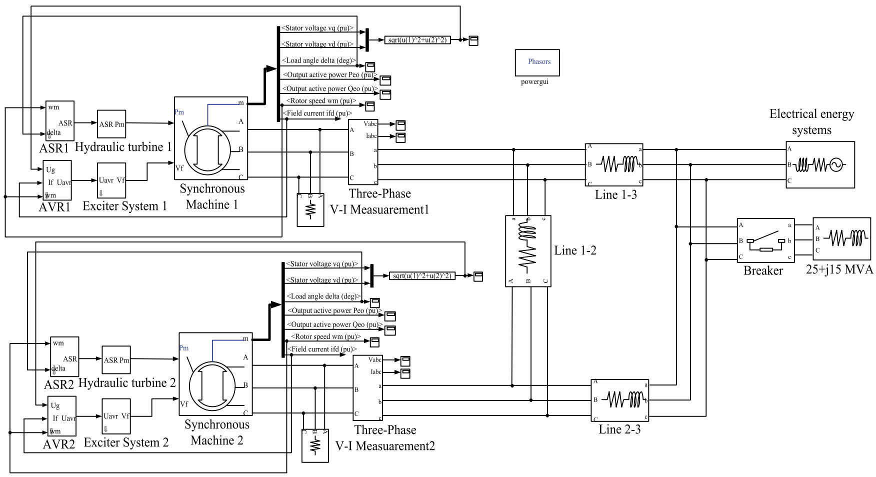


Fig. 4. Diagram of the network model in MATLAB

Fig. 5b. The hydraulic turbine was modeled by the following transfer function, taking into account water hammer:

$$W_{HT}(s) = \frac{1 - a \cdot T_{HT} s}{1 + 0.5 \cdot a \cdot T_{HT} s},$$

where T_{HT} is the time constant of the hydraulic turbine (in the simulation it was taken equal to 0.344 s); a is an opening position of the guide vane (takes values in the range $0 \div 1$); s is the Laplace operator.

At the first stage, for the purity of the experiment, generators of DG plants without AVR and ASR were modeled. The simulation results in the form of generator rotor speed of the DG1 plant are shown in Fig. 6. The results of computer modeling confirm that the technique proposed provides correct calculations of the EES stability areas the for the EES equipped with the DG plants. If the values of the mode parameters are located on the boundary of the SAS area and the EES is perturbed by connecting an additional load, the expected loss of the DG plants generators stability is observed (Fig. 6b).

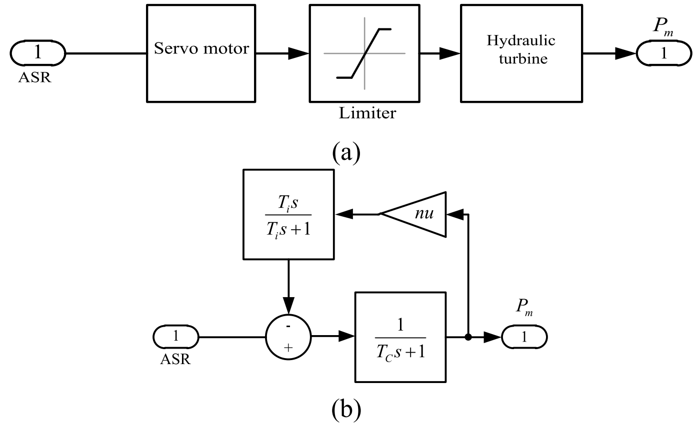
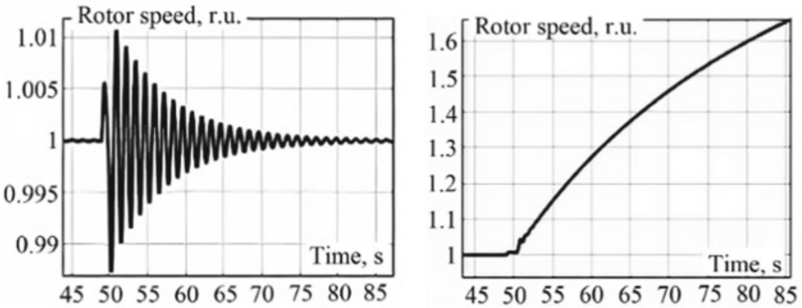


Fig. 5. Block diagram of the hydraulic turbine model (**a**) and the main servo motor (**b**) in MATLAB: $T_i = 0.1$ s, $nu = 10$ r.u., $T_C = 0.25$ s



(a) (b)

Fig. 6 Oscillograms of rotor speed of the DG1 plant generator at a short-term connection of an additional load in a network circuit with the disconnected Line 1–3: **a** $P_1 = 6$ MW, $P_2 = 6$ MW (stable mode); **b** $P_1 = 10$ MW, $P_2 = 8$ MW (unstable mode)

Transient processes were also simulated with additional loading of the DG plants generators for a network with the disconnected Line 1–3, which brings the EES mode beyond the stability area. The corresponding oscillograms of the DG1 plant generator parameters are provided in Fig. 7a. The use of prognostic AVR and ASR [16] allows us to expand the boundaries of the SAS area. Oscillograms of rotor speed and generator voltage, confirming these conclusions, are provided in Fig. 7b.

5 Conclusions

Based on the calculations performed and computer-aided modeling, the following conclusions can be formulated:

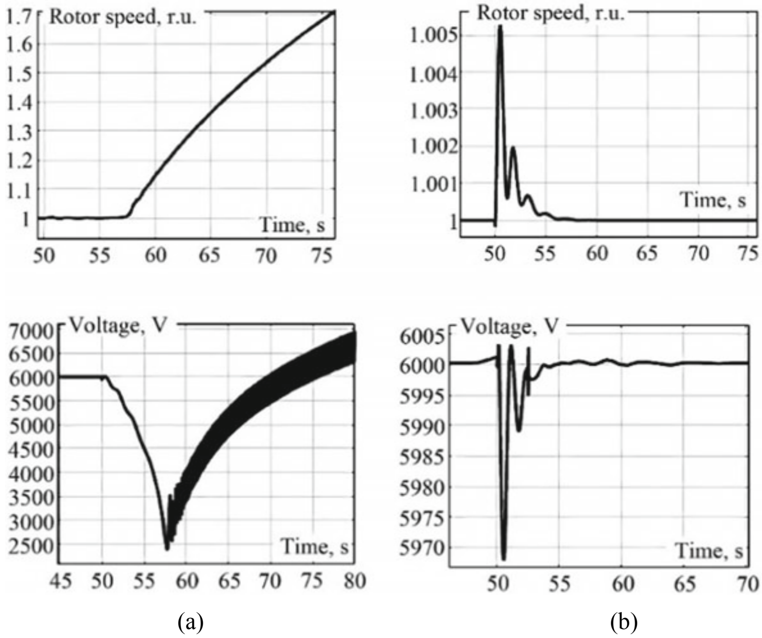


Fig. 7 Oscillograms of rotor speed and voltage of the DG1 plant generator with an increase in the load of generators from $P_1 = 6$ MW, $P_2 = 6$ MW to $P_1 = 12$ MW, $P_2 = 10$ MW in the network diagram with the disconnected Line 1–3: **a** without regulators; **b** using prognostic AVR and ASR

1. On the basis of the limiting modes equations, we proposed an effective technique for determining the EES stability areas with DG plants for various network structures.
2. We presented the results of constructing static aperiodic stability areas for an electrical network with distributed generation plants. The computer modeling results confirm that our technique provides correct calculations of the EES stability areas for the EES equipped with the DG plants. If the values of the mode parameters are located on the boundary of the stability area and the EES is perturbed by connecting an additional load, we can observe the expected loss of stability of the DG plants generators.
3. The use of predictive regulators of the DG plants makes it possible to expand the boundaries of the static aperiodic stability area for additional generators loading for a network with a disconnected communication line of the DG plant and the EES substation.

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Effectiveness of the Implementation of Information Technologies in Solving Problems of Transport and Logistics Sector

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Abstract. The process of transporting goods is one of the most important human needs, the efficiency of which is determined by the work of transport. Advances in information technology and management principles optimize traffic load on the road network, speed of delivery, quality of service, and operating costs. The use of information technology allows the elements of the transport system to promote effective communication. This study examines logistics processes in supply chain management, information technologies in management and the prospects for their use in the transport logistics segment, with special attention to the key factors affecting the efficiency of transportation, allowing data collection. These innovative tools for collecting traffic data open up new perspectives for assessing transport accessibility by providing high quality metrics that meet the requirements for use in transport planning. The main goal of this study is to provide an overview of information technologies applied to transport, allowing to work effectively in a competitive environment and improve the quality of service.

Keywords: Information technology · Transport system · Global positioning systems · Freight transport

1 Introduction

In the context of globalization, enterprises are increasingly faced with new economic components, which are determined by a combination of several fundamental factors: increased global competition covering the markets for goods, services, and other factors of economic growth, which entail changes in national and world freight and passenger flows, and increased requirements for the quality of transport services; the quality of professional staff, since transport is embarking on the path of innovative development with the transition to intelligent transport systems, using high-speed communication lines. During this period, significant restrictions on economic growth appeared in Russia, due to the insufficient development of the transport system. Today's economic, quantitative and qualitative indicators of the functioning of transport, especially its infrastructure, do not allow fully and effectively solving the problems of a growing economy [1, 2].

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In such an environment, the challenge for logistics is to support the economic growth of enterprises, as well as marketing and production activities as a result of increased international competition. Transport logistics allows you to optimize existing production processes and allocate available resources on their basis using management methods to increase the efficiency and competitiveness of enterprises.

The key element of the supply chain is the transport system, which brings together individual activities. Transport costs account for one third of the total and affect the efficiency of promoting goods and services in the logistics system. There are innovative techniques that combine transportation and distribution systems to improve efficiency in a global competitive environment. Transport logistics systems differ depending on the type of product, geographic coverage, components and finished products, but the common goal of different strategies is to deliver the required product to a specific location at a specified time, while minimizing inventory costs [3–6].

The use of information technology allows the elements of the transport system—rolling stock, road network, traffic lights, signs to promote effective communication, which is crucial for maintaining the operation of the transport complex as a whole.

This study is devoted to the use of information technology in the transport and logistics sector and is aimed at assessing the use of information technology in the transportation process of the Irkutsk region.

2 Materials and Methods

It is difficult to imagine the formation and organization of a chain of delivery of goods without regular exchange of information between participants in the transport process in real time, and without prompt response to changes in demand for transport services. It is impossible to provide high quality service and efficiency of transport operations without the use of information systems and software tools for analysis, planning and business decision support. The development of information systems and technologies makes it possible to automate operations in transport processes, which will allow transport logistics to become the dominant form of organizing the movement of goods in the technologically high competitive market of transport services [5, 7].

Prospects for the further implementation of information systems in the transport processes of the Irkutsk region are associated with the following tasks aimed at the balanced development of an efficient transport infrastructure [8]:

- integrated development of large transport hubs in the main directions of transportation with the introduction of modern intelligent technologies (sensors, detectors);
- creation of a unified balanced system of transport communications of the country based on the differentiated development of communication routes of all types of transport;
- increasing the capacity and speed parameters of the transport infrastructure to the level of the best world achievements, taking into account the use of transport planning and modeling;
- creation of an integrated system of logistics parks in the country as the basis for the formation of a modern distribution network;

- creation of a unified information environment for technological interaction of various types of transport, participants in the transport process, customs and other state control bodies.

Consider the types of transport information supported by freight intelligent transport systems according to empirical research:

1. Traffic and Infrastructure Information—allows to accurately assess traffic flow in real time and effectively use the road network. It also includes information on the location of road network objects, the status of roads (the quality of the road surface or temporary construction), the types of vehicles that can drive on the road of this category, restrictions and congestion, traffic accidents or other incidents associated with this type transport information.
2. Information about the location of vehicles and goods—allows to track goods in the transport network. Such information includes: notification of cargo arrival to the entity; data on loading and unloading operations; determination of the geographical position of the cargo, by means of a monitoring system for the location and condition of vehicles, location of cargo in warehouses, terminals and ports.
3. Information about the condition of the cargo—refers to the physical characteristics of the cargo during transportation, including at the time of storage in warehouses. Real-time information relating to the temperature level, pressure level, shocks, humidity or light level in a vehicle during transport are subcategories of this type of information.
4. Cargo positioning information is related to the placement and sequence of storing or sending cargo. This information is essential for reliable and efficient warehouse and handling operations.
5. Warehouse operations and inventory information—includes data regarding the number of cargo units in warehouses, customer orders, loading and unloading times for different categories of goods. The accuracy of the quantity and type of cargo are an important parameter for this type of information.
6. Information about the cargo—data on the types of goods sent, their attributes (such as model, class, size, color, weight, price and identification number), about the sender, about the recipient, about the number of goods shipped is an important factor for monitoring and managing transport operations. This information is used by transport organizations, terminals, shippers and consignees, as well as customs services in inspection procedures. Scanning and automatic cargo identification systems help maintain information and reduce operator errors.
7. Vehicle identification information—the type and class of vehicles, their registration numbers and other identification information, is used in various operations to manage vehicle resources. This information is also used to monitor the safety of transport operations [9–13].

Consider a number of technologies influencing the development of the supply chain using information technology [14].

1. Global Positioning Systems (GPS). Built-in GPS receivers in the on-board devices of vehicles receive signals from satellites to calculate the location, which is determined with an accuracy of ten meters. GPS is the main technology behind many car navigation systems.
2. Dedicated Short Range Communication (DSRC). DSRC is a short-to-medium-range wireless communication channel operating in the 5.8 or 5.9 GHz frequency band and specially designed for use in automobiles. It provides two-way wireless communication between the vehicle (using built-in tags or sensors) and roadside equipment. DSRC is a key technology for many intelligent transport systems, including between vehicles and infrastructure: integration, communication between vehicles, adaptive synchronization of traffic signals, electronic toll collection, collection of traffic congestion, electronic pricing on roads, provision of information. DSRC is a subset of radio frequency identification (RFID) technology.
3. Wireless networks. Similar to the technology commonly used for wireless Internet access, wireless networks allow rapid communication between vehicles and the road network, but have a range of only a few hundred meters.
4. Mobile telephony. Intelligent transport systems applications can transmit information in the third or fourth generation (3G or 4G) mobile network. The advantages of mobile networks include wide accessibility in cities and along arterial roads. Mobile telephony may not be suitable for some security-critical applications due to low speed.
5. Radio waves or infrared beacons. The Japanese Vehicle Information System (VICS) uses radio beacons on expressways and infrared beacons on highways to transmit traffic information in real time.
6. Recognition by roadside camera. Camera-based schemes can be used for zonal congestion charge systems on a road segment. Such systems use cameras placed on the roadway. The cameras use Automatic License Plate Recognition (ALPR) based on Optical Character Recognition (OCR) technology to identify vehicles. This information is transmitted digitally to servers that evaluate and charge drivers for the use of the carriageway in the congestion zone.
7. Sensors or devices. The so-called "probe vehicles" are used, which report their speed and position to the central traffic control tower, where the probe data is aggregated to generate and simulate traffic parameters. It also uses information from mobile phones as a mechanism to generate traffic data in real time using the subject's GPS location.

3 Results

Information and communication technologies are considered to be a tool to improve the efficiency of the supply chain. Their use leads to improved warehouse operations and customer service, including lower logistics costs. One of the important benefits of information and communication technologies is the increased safety and efficiency of freight transport as a result of improved information exchange between participants in supply chains. In addition, freight transport information and communication applications and services can support the integration of intermodal transport by supply chains.

The main functions of information and communication technologies in relation to freight transport are as follows:

- management of transport resources—the function is related to the management of freight units, rolling stock. This category includes information and communication technologies to improve the flow of information used for resource management systems, cargo terminal information systems and integrated route planning systems with online communication. The use of such systems results in shorter delivery times;
- terminal operations management—this function allows to control the cargo flow. It is supported through the use of systems for optimizing the operation of terminals, information and communication technologies of intermodal terminals and data exchange systems;
- tracking of cargo and vehicles—this function allows you to track and control the location of vehicles and cargo in the transport network. There are various information systems for monitoring and regulating the location, physical condition, position and safety of goods and vehicles.

Table 1 shows the main areas of application of information technology in logistics, depending on the type of activity [5, 12].

Table 1. Areas of application of information technology in logistics.

Kind of activity	Areas of application of information technology
Transport	Fleet management—tracking the rolling stock in real time, monitoring the technical condition, managing: the schedule of drivers, speed limits, fuel consumption, route network
Warehousing	Warehouse management
Customs clearance	Paperwork, payment of duties, inspection
Cargo management	Leasing of containers, cargo safety, loading and unloading operations

The experimental study is reduced to a survey of transport companies, logistics centers in the Irkutsk region about the methods used in the work. 274 respondents (transport companies) were interviewed regarding modern tools used in the transport sector (Fig. 1).

As a result, it was noted that the key benchmarks in the field of road transport are the improvement of the control system of the transportation process to track customers online at all stages of cargo delivery, including using artificial intelligence in planning and management, to build optimal routes.

Improving the safety and efficiency of road transport can be ensured by improving transportation technologies, developing technical solutions to optimize the requirements for equipping road transport with on-board devices that provide information transfer in order to monitor the safety of cargo transportation, as well as the introduction of automated monitoring and control systems transportation of goods.

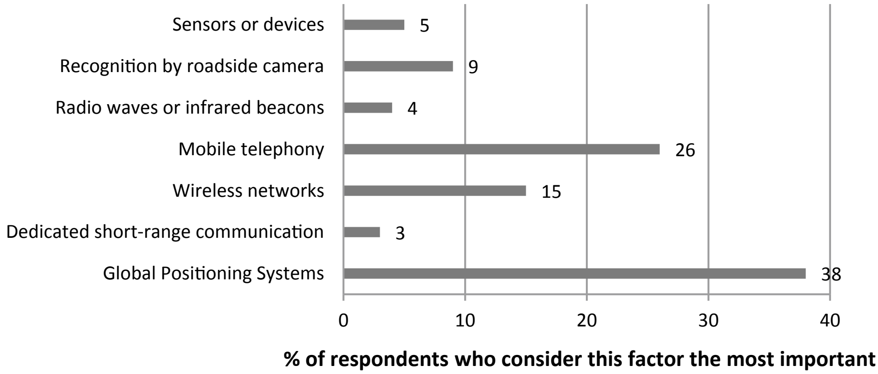

Fig. 1. Toolkit used at transport enterprises of the Irkutsk region, carrying out cargo transportation

4 Conclusions

Empirical studies show that the most common information technologies used to optimize the operation of freight transport are: global positioning systems, dedicated short-range communications, wireless networks, mobile telephony, radio waves or infrared beacons, recognition by roadside cameras, sensors or devices.

Commonly used types of information include traffic and infrastructure data, vehicle and cargo location, cargo condition, cargo location, warehouse operations and stocks, cargo and vehicle identification information.

The article describes the importance of intelligent transport systems for freight transport, as well as by means of which, they support various functions in transport operations.

It is necessary to understand that information technology presupposes the rapid development of new technologies and systems used in freight transportation. The complex application of such systems is due to the lack of standardized methods and processes for exchanging information, and requires that participants in the supply chain share both data and share the cost of the system's hardware and software. Research in this direction can optimize the work of transport enterprises, logistics centers, by introducing new technologies into the transportation process.

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Land Plots Clustering and Its Impact on the Agricultural Land Cadastral Valuation

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Abstract. The dependence of the built-up land value on the factor of the surrounding land value is beyond doubt. However, the final cost of the assessed land plot is significantly influenced by two more factors—the remoteness of the object from the district center as the main place of products sale and the influence of the population in the district center and in the district. The study purpose is to determine the influence of distance and population size factors on the cadastral value of agricultural land. When determining it, it is necessary to take into account the synergistic effect associated with the production use of facilities located on them, location, population. Due to this, the cost of such plots is much higher in comparison with the surrounding arable land, pastures, and hayfields. On the given example of the Bezenchuksky district lands, it can be seen that the cadastral value of the third type lands (taking into account these factors) ranged from 3.91 rubles/m^2 to 5.53 rubles/m^2.

Keywords: Clustering · Cadastral valuation · Agricultural land · Distance factor · Unit cost

1 Introduction

The dependence of the value of the built-up land on the factor of the value of the surrounding land is beyond doubt. However, the final cost of the assessed land plot is significantly influenced by two more factors—the remoteness of the object from the regional center as the main place of sale of products and the influence of the population in the regional center and in the region [1–5].

Distance factor. As you know, farms located in different objective conditions differ in profitability. There may be many reasons for this, but two of them are common: differences in natural conditions (rent for fertility in our case corresponds to the surrounding land) and distance to the market center (rent for position) [6–8].

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The patterns of the city's influence on the surrounding area are most clearly presented in the well-known scheme of I.G. Thünen, where the factor of the remoteness of the land plot from the city, located on an absolutely homogeneous plain, determines the intensity of agriculture. Thünen's model is based on the concept of rent by position as a particular case of economic rent. Thünen, proceeding from the ratio of costs and the price of grain, shows on specific calculations that the closer to the city the location of farmland, the more profitable it is to increase costs per unit area, since the price of grain rises so much that it pays for them. Accordingly, the grain yield decreases with distance from the city [9–14].

In our case, with equal economic costs of cultivating agricultural land, lands with lower transport costs will show higher profitability. At the same time, on-farm transportation is practically the same with equal agrotechnics, but off-farm transportation costs make a difference in the total costs. As a first approximation, this difference in costs can be entirely attributed to the distance to the regional center as the main place of sale of products [15–20].

At the same time, there is no need to create clusters by distance from the district or regional center, and a more accurate (non-discrete) accounting of this factor in the distance from a specific site to the sales center is used [21–25].

2 Methods and Materials

Inter-farm transportation—in essence, the products transportation to the place of sale or processing and other supply operations for the facility on the estimated land plot. Transportation costs in agriculture, of course, can vary significantly on a case-by-case basis, but many analysts set an upper limit on costs at 40%. In this case, the lower limit (with minimal inter-farm traffic) can be estimated at 14% [26–28]. For the purposes of further calculation, we take the average level of transport costs for inter-farm transportation in the amount of 25%. To take this factor into account, we will analyze the distances from the assessed sites of the third type of use to the corresponding regional centers throughout the Samara region.

The maximum distance from the border of the district to the regional center by road is taken at 65 km. Thus, we take for the Samara region an average level of transport costs of 25% with an average distance to the corresponding regional center of 33 km. For clarity, we will conventionally take the cost of the assessed farthest plot of land at 2 rubles/m^2.

The distance factor of 0.0078% (reflects an increase in costs per km) increases the land value when approaching the regional center. Thus, the final market value of the third type use land plot is determined by the formula:

$$CV_l = 1.2628 * CV_s * (1 + Li) \tag{1}$$

where CV_s—the market (cadastral) value of the surrounding land from the permitted use first type;

1.2628—Coefficient for Taking into Account the Synergistic Effect;

Li—the factor of the distance of the estimated site to the district center.

3 Results and Discussion

Table 1 shows an example of calculating the cadastral value of land plots of the third type of use in the Bezenchuksky district.

Table 1. An example of calculating the cost of land plots in Bezenchuksky district (by the first method).

Land plot number	Area, m^2	Distance to the district center, km	Unit cost of the surrounding undeveloped land, rubles/m^2	Distance factor	Unit cost of a built-up area, rubles/m^2	Land plot cost, r rubles (1 calculation method)
63:12:0,000,000:9090	152	8	2.24	0.4453	4.09	621.42
63:12:0,201,001:4	810	25	2.39	0.3125	3.96	3208.61
63:12:0,301,001:186	79,236	25	2.23	0.3125	3.70	292,860.83
63:12:0,301,001:187	203,852	25	2.23	0.3125	3.70	753,448.76
63:12:0,301,001:188	133,415	25	2.23	0.3125	3.70	493,109.54
63:12:0,301,001:189	62,738	25	2.23	0.3125	3.70	231,883.27
63:12:0,403,005:10	10	13	2.42	0.4063	4.30	42.98
63:12:0,403,005:60	140	13	2.42	0.4063	4.30	601.67
63:12:0,403,005:9	1113	13	2.42	0.4063	4.30	4783.25
63:12:0,603,003:67	401	5	2.47	0.4688	4.58	1837.12
63:12:0,604,002:6	615	8	2.29	0.4453	4.18	2570.41
63:12:0,605,003:9001	186	13	1.83	0.4063	3.25	604.47
63:12:0,808,001:1	10,911	20	2.18	0.3516	3.72	40,597.92
63:12:0,808,001:2	34,183	20	2.18	0.3516	3.72	127,188.96
63:12:0,809,002:29	10,344	26	2.02	0.3047	3.33	34,425.89
63:12:1,505,003:10	1597	5	1.95	0.4688	3.62	5776.13
63:12:1,505,003:9	1067	5	1.95	0.4688	3.62	3859.19
63:12:1,803,002:5	1045	26	2.32	0.3047	3.82	3994.38

The cadastral value unit indicators determination of the use type third group lands in the general case involves the actions following sequence:

- land plots grouping according to the lands characteristics assigned to the third group;
- the reference area determination within each group;
- the third group lands market value determination as the reference plot part;
- unit indicators calculation of these lands value.

The grouping is carried out at the constituent entity level of the Russian Federation (Samara region) and involves the following sequence of actions:

- the land plots cost factors composition determination;
- land plots description in the cost factor context;

- land plots unification into groups based on the characteristics similarity established in the cost factor context.

Location characteristics, distance from local centers, physical characteristics of capital buildings and structures, transport accessibility, etc. can act as factors in the land plots value.

The estimated lands are located in 27 administrative districts of the Samara region. Administrative districts are located at different distances from the Samara city, some administrative districts are located in close proximity to other large cities of the Samara region (for example: Samara, Togliatti, Kinel).

The remoteness of the administrative district main settlement (district center) from Samara, the population of the district and the district center, the investment attractiveness of the administrative district have a significant impact on the land value in the administrative district.

In calculating the cadastral value unit indicators of the use type third group land, all land plots were divided into 27 groups corresponding to the administrative districts.

For the reference site within each district, a site was selected located in close proximity to the main settlement of the given administrative district (district center).

The cost of each specific site is determined depending on the degree of the assessed land plot remoteness from the main settlement (district center).

We compared 27 administrative districts for the following factors:

- the distance from the Samara city to the main settlement of the administrative district;
- the population of the district;
- the main settlement population;
- the coefficient of the administrative district investment attractiveness.

Information on the above factors characterizing the administrative districts is given in Tables 2, 3.

Analyzing the numerical values of the distance from the administrative region to the city of Samara, the average distance of the administrative region was calculated, this value was 123.93 km. For the Volzhsky district, which is located in a ring around the city of Samara, the distance to the city of Samara is conventionally taken as 20 km.

Further, the index of the administrative district remoteness from Samara was calculated, which is determined by the formula:

$$\mathrm{I_{ud}} = \mathrm{D_d}/\mathrm{D_S} \tag{2}$$

where $\mathrm{I_{ud}}$—the index of the distance between the administrative region and Samara;

$\mathrm{D_d}$—average distance of the administrative region;

$\mathrm{D_S}$—the distance of the *i* district center from Samara.

Next, the population of the district was analyzed and the proportion of the population living in the administrative center was determined. For districts close to large cities (for example, the Stavropol district is close to the city of Togliatti), the proportion of the population living in the administrative center was taken as a unit. Thus, the importance

Table 2. Information about the factors characterizing the administrative districts

№	District name	The name of the main settlement	Distance from Samara, km	Population of the district P_d	Population of the main settlement P_{ms}	District investment attractiveness coefficient
1	Alekseevsky	Alekseevka	147	12,200	4600	0.422
2	Bezenchuksky	Bezenchuk	63	42,400	22,400	0.572
3	Bogatovsky	Bogatoe	92	15,700	6400	0.49
4	Bolsheglushitsky	Bolshaja Glushitsa	110	20,700	10,100	0.627
5	Bolshechernigovsky	Bolshaja Chernigovka	143	18,200	6300	0.548
6	Borsky	Borskoe	121	24,400	9200	0.419
7	Volzhsky	Samara (not included in the district)	10	73,100	1,164,900	0.901
8	Elkhovsky	Elkhovka	95	9900	3200	0.49
9	Isaklinsky	Isakli	155	14,000	4500	0.461
10	Kamyshlinsky	Kamyshla	178	11,400	4800	0.458
11	Kinelsky	Kinel (not included in the district)	41	31,500	30,900	0.856
12	Kinel-Cherkassky	Kinel-Cherkasy	111	47,900	18,500	0.597
13	Klyavlinsky	Klyavlino	215	14,900	6400	0.471
14	Koshkinsky	Koshki	140	25,800	8100	0.732
15	Krasnoarmeysky	Krasnoarmeyskoe	78	18,300	5400	0.451
16	Krasnoyarsky	Krasny Yar	40	51,900	7700	0.528
17	Neftegorsky	Neftegorsk	103	34,900	18,800	0.658
18	Pestravsky	Pestravka	110	17,300	6500	0.49
19	Pohvistnevsky	Pokhvistnevo	159	27,990	28,300	0.462
20	Privolzhsky	Privolzh'e	145	23,900	7500	0.411
21	Sergievsky	Sergievsk	135	44,600	8300	0.617
22	Stavropolsky	Togliatti (not included in the district)	90	45,300	719,500	0.826
23	Syzransky	Syzran (not included in the district)	137	25,600	179,000	0.576
24	Khvorostyansky	Khvorostyanka	130	14,800	4900	0.425
25	Chelno-Vershinsky	Chelno-Vershiny	185	17,300	6100	0.487
26	Shentalinsky	Shentala	204	17,100	6600	0.512
27	Shigonsky	Shigony	199	20,900	5300	0.473

of the main settlement by population was determined in relation to the population of the district.

$$Z_n = P_{ms}/P_d \tag{3}$$

where Z_n—the importance of the main settlement in terms of population relative to the population of the region;

P_{ms}—the population of the main settlement;

P_d—the population of the region.

The next characteristic influencing the cost is the ratio of the district main administrative center population and the Samara population. This parameter was named the importance of the main settlement in terms of population relative to the Samara city.

$$Z_{ns} = P_{ms}/P_S \tag{4}$$

where Z_{ns}—the importance of the main settlement by population relative to the Samara city;

P_{ms}—the population of the main settlement;

P_S—the population of the Samara city.

The last characteristic is the coefficient of investment attractiveness of the area, as defined in Table 3. Here are the values of factors affecting the cost.

Table 3. Values of factors affecting cost

№	District name	Distance index of the district	The significance of the main settlement by population relative to the population of the district	Significance of the main settlement by population relative to Samara	District investment attractiveness coefficient	Integral indicator
1	Alekseevsky	0.84	0.38	0.004	0.422	0.41
2	Bezenchuksky	1.97	0.53	0.019	0.572	0.77
3	Bogatovsky	1.35	0.41	0.005	0.49	0.56
4	Bolsheglushitsky	1.13	0.49	0.009	0.627	0.56
5	Bolshechernigovsky	0.87	0.35	0.005	0.548	0.44
6	Borsky	1.02	0.38	0.008	0.419	0.46
7	Volzhsky	6.20	1.00	1.000	0.901	2.27
8	Elkhovsky	1.30	0.32	0.003	0.49	0.53
9	Isaklinsky	0.80	0.32	0.004	0.461	0.40
10	Kamyshlinsky	0.70	0.42	0.004	0.458	0.39
11	Kinelsky	3.02	1.00	0.027	0.856	1.23
12	Kinel-Cherkassky	1.12	0.39	0.016	0.597	0.53
13	Klyavlinsky	0.58	0.43	0.005	0.471	0.37

(*continued*)

Table 3. (*continued*)

№	District name	Distance index of the district	The significance of the main settlement by population relative to the population of the district	Significance of the main settlement by population relative to Samara	District investment attractiveness coefficient	Integral indicator
14	Koshkinsky	0.89	0.31	0.007	0.732	0.48
15	Krasnoarmeysky	1.59	0.30	0.005	0.451	0.58
16	Krasnoyarsky	3.10	0.15	0.007	0.528	0.95
17	Neftegorsky	1.20	0.54	0.016	0.658	0.60
18	Pestravsky	1.13	0.38	0.006	0.49	0.50
19	Pohvistnevsky	0.78	1.00	0.024	0.462	0.57
20	Privolzhsky	0.85	0.31	0.006	0.411	0.40
21	Sergievsky	0.92	0.19	0.007	0.617	0.43
22	Stavropolsky	1.38	1.00	0.618	0.826	0.96
23	Syzransky	0.90	1.00	0.154	0.576	0.66
24	Khvorostyansky	0.95	0.33	0.004	0.425	0.43
25	Chelno-Vershinsky	0.67	0.35	0.005	0.487	0.38
26	Shentalinsky	0.61	0.39	0.006	0.512	0.38
27	Shigonsky	0.62	0.25	0.005	0.473	0.34

To determine the integrated cost indicator, characterizing each of the 27 districts of the Samara region, equal weighting factors were assigned to all factors.

Analysis of the agricultural land market showed that there is very little information on offers for the sale of land plots. It is impossible to collect complete information on the value of land in each administrative region.

For example, in the Sergievsky district, land plots are presented for sale that are formally agricultural, but actually located in the settlement.

Such lands are offered for sale, taking into account the possibility of their transfer and actual use for other non-agricultural purposes. And the cost of such plots is an order of magnitude higher than the cost of real agricultural land.

Information about the analogous objects was obtained from the Information System "Center".

Having calculated the cost of the reference plot in the Volzhsky district, and using the integrated cost indicator (Table 3), conclusions can be drawn about the cost of the reference plots in other administrative districts.

The selected land plots are located at different distances from the city of Samara. Therefore, an adjustment was made in Table 4, taking into account the effect of remoteness from Samara.

Table 4. Adjustments to the value of analogue objects and calculation of the weighted average cost of a land plot

№	Land area, m^2	District, address	Land cost, rubles / m^2	Distance from Samara, km	Correction factor	Adjusted value of the land plot, rubles/m^2	Adjusted cost of analogue, rubles
1	500 000	Volzhsky, Kalinka	10.00	15	0.932291	10.73	5 363 128
2	1 919 900	Volzhsky, Stroykeramika	10.42	15	0.932291	11.17	21 452 514
3	66 000	Volzhsky, Chernorechye	12.12	25	0.875	13.85	914 286
4	60,000	Volzhsky,	15.00	10	0.953125	15.74	944 262
5	6000	Volzhsky, Chernorechye	25.00	25	0.875	28.57	171 429
6	60,000	Volzhsky, Chernorechye	26.67	25	0.875	30.48	1 828 571
7	330,000	Samarsky	35.00	20	0.901041	38.84	12 818 497
8	100,000	Spiridonovka	40.00	40	0.796875	50.20	5 019 608
9	110,000	Dubovy Umet	40.91	20	0.901041	45.40	4 994 220
10	500,000	Lopatino	45.00	10	0.953125	47.21	23 606 557
Amount	3 651 900						77 113 072
Weighted average value, rubles/m^2							21.12
Weighted average value, taking into account the bargaining discount (15.3%), rubles/m^2							17.89

The calculated value of the reference plot, taking into account the area of land offered for sale, is the weighted average cost. The weighted average value of the value of the land plot is 21.12 rubles/m^2, excluding the bargaining discount.

A bargaining discount was accepted at 15.3%. This is the minimum value of the bargaining discount for agricultural land [20].

Thus, the cost of 1 m^2 of a reference plot in the Volzhsky district of the Samara region, located in close proximity to the main settlement of this administrative district (district center) is 17.89 rubles. Using the integrated indicator defined in Table 3, it is possible to determine the cost of 1 m^2 of a reference land plot in each of the districts. The unit cost of reference land plots in each of the administrative districts is presented in Table 5. The reference plot is located in close proximity to the administrative center of the district.

Table 5. Unit cost of reference land plots by administrative districts in the Samara region

№	District name	Integrated indicator	Unit cost of a reference land plot, rubles/m^2
1	Alekseevsky	0.4115	3.24
2	Bezenchuksky	0.7717	6.07
3	Bogatovsky	0.5625	4.42
4	Bolsheglushitsky	0.5625	4.42
5	Bolshechernigovsky	0.4415	3.47
6	Borsky	0.4570	3.59
7	Volzhsky	2.2743	17.89
8	Elkhovsky	0.5301	4.17
9	Isaklinsky	0.3965	3.12
10	Kamyshlinsky	0.3948	3.11
11	Kinelsky	1.2263	9.64
12	Kinel-Cherkassky	0.5289	4.16
13	Klyavlinsky	0.3706	2.91
14	Koshkinsky	0.4845	3.81
15	Krasnoarmeysky	0.5849	4.60
16	Krasnoyarsky	0.9453	7.43
17	Neftegorsky	0.6040	4.75
18	Pestravsky	0.4995	3.93
19	Pohvistnevsky	0.5664	4.45
20	Privolzhsky	0.3965	3.12
21	Sergievsky	0.4320	3.40
22	Stavropolsky	0.9552	7.51
23	Syzransky	0.6586	5.18
24	Khvorostyansky	0.4284	3.37
25	Chelno-Vershinsky	0.3787	2.98
26	Shentalinsky	0.3778	2.97
27	Shigonsky	0.3385	2.66

The unit cost of a reference land plot is determined by the formula:

$$UC_i = 17.89/2.2743 * II_i \tag{5}$$

where UC_i—the unit cost of the reference land plot of the *i* district;

17.89—the cost of a reference land plot in the Volzhsky district;
2.2743—an integrated indicator in the Volzhsky district;

II_i—an integrated indicator of the *i* district.

To calculate the cost of each specific land plot, the distance factor was taken into account. The essence of the calculation lies in the fact that areas remote from the regional center are valued less because of the increasing transport costs than those close to the regional center.

An example of calculating the value of land plots in Bezenchuksky district is shown in Table 6.

Table 6. Calculation of the cost of land plots in Bezenchuksky district (second method)

Land plot number	Area, m^2	Distance to the district center, km	Unit cost of the reference plot, rubles/m^2	Correction factor for distance from the district center	Unit cost of a specific site, rubles/m^2	Cost of the appraisal object, rubles (2 calculation method)
63:12:0,000,000:9090	152	8	6.07	0.963542	5.847	888.74
63:12:0,201,001:4	810	25	6.07	0.875000	5.310	4 300.86
63:12:0,301,001:186	79,236	25	6.07	0.875000	5.310	420 719.31
63:12:0,301,001:187	203,852	25	6.07	0.875000	5.310	1 082 392.75
63:12:0,301,001:188	133,415	25	6.07	0.875000	5.310	708 393.49
63:12:0,301,001:189	62,738	25	6.07	0.875000	5.310	333 119.89
63:12:0,403,005:10	10	13	6.07	0.937500	5.689	56.89
63:12:0,403,005:60	140	13	6.07	0.937500	5.689	796.45
63:12:0,403,005:9	1113	13	6.07	0.937500	5.689	6 331.82
63:12:0,603,003:67	401	5	6.07	0.979167	5.942	2 382.66
63:12:0,604,002:6	615	8	6.07	0.963542	5.847	3 595.90
63:12:0,605,003:9001	186	13	6.07	0.937500	5.689	1 058.15
63:12:0,808,001:1	10,911	20	6.07	0.901042	5.468	59 658.36
63:12:0,808,001:2	34,183	20	6.07	0.901042	5.468	186 903.27
63:12:0,809,002:29	10,344	26	6.07	0.869792	5.278	54 596.60
63:12:1,505,003:10	1597	5	6.07	0.979167	5.942	9 489.06
63:12:1,505,003:9	1067	5	6.07	0.979167	5.942	6 339.91
63:12:1,803,002:5	1045	26	6.07	0.869792	5.278	5 515.61

The calculation of the cost of land plots of the third type of permitted use was carried out by two methods. Therefore, a final conclusion on cost requires agreement between these results.

Depending on the proximity of the estimated site to the administrative center of the district in which it is located, it is necessary to differentiate the weight coefficients. Taking into account the influence of the administrative center on the value of land, the weighting factors for the calculation methods described above were assigned as follows (Table 7).

Table 7. Weights for the first and second calculation methods.

Distance to the regional center, km	Weighting factor for 2 calculation method	Weighting factor for 1 calculation method
1–10	0.7	0.3
11–20	0.5	0.5
21–66	0.3	0.7

Using the example of land plots in Bezenchuksky district, the final cadastral value of plots of the third type of permitted use was calculated. The results are shown in Table 8.

Table 8. The final table of the permitted use third type plots cadastral value.

Land plot number	Area, m^2	Cost of the appraisal object, rubles (1 calculation method), rub	Weight coefficient	Land plot cost, rubles (2 calculation method)	Weight coefficient	Cadastral value of the land plot, rubles	Unit cadastral value of the land plot, rubles/m^2
63:12:0,000,000:9090	152	621.42	0.3	888.74	0.7	808.55	5.32
63:12:0,201,001:4	810	3 208.61	0.7	4 300.86	0.3	3 536.28	4.37
63:12:0,301,001:186	79,236	292 860.83	0.7	420 719.31	0.3	331 218.37	4.18
63:12:0,301,001:187	203,852	753 448.76	0.7	1 082,392.75	0.3	852 131.96	4.18
63:12:0,301,001:188	133,415	493 109.54	0.7	708 393.49	0.3	557 694.73	4.18
63:12:0,301,001:189	62,738	231 883.27	0.7	333 119.89	0.3	262 254.26	4.18
63:12:0,403,005:10	10	42.98	0.5	56.89	0.5	49.93	4.99
63:12:0,403,005:60	140	601.67	0.5	796.45	0.5	699.06	4.99
63:12:0,403,005:9	1113	4 783.25	0.5	6 331.82	0.5	5 557.53	4.99
63:12:0,603,003:67	401	1 837.12	0.3	2 382.66	0.7	2 219.00	5.53
63:12:0,604,002:6	615	2 570.41	0.3	3 595.90	0.7	3 288.25	5.35
63:12:0,605,003:9001	186	604.47	0.5	1 058.15	0.5	831.31	4.47
63:12:0,808,001:1	10,911	40 597.92	0.5	59 658.36	0.5	50 128.14	4.59
63:12:0,808,001:2	34,183	127 188.96	0.5	186 903.27	0.5	157 046.12	4.59
63:12:0,809,002:29	10,344	34 425.89	0.7	54 596.60	0.3	40 477.10	3.91
63:12:1,505,003:10	1597	5 776.13	0.3	9 489.06	0.7	8 375.18	5.24
63:12:1,505,003:9	1067	3 859.19	0.3	6 339.91	0.7	5 595.69	5.24
63:12:1,803,002:5	1045	3 994.38	0.7	5 515.61	0.3	4 450.75	4.26

4 Conclusion

Evaluation of agricultural land plots with buildings and structures located on them has its own characteristics. When determining it, it is necessary to take into account the synergistic effect associated with the facilities production use located on them, location, population. Due to this the cost of such plots is much higher in comparison with the surrounding arable land, pastures, and hayfields. On the given example of the Bezenchuksky district lands, it can be seen that the cadastral value of the third type lands (taking into account these factors) ranged from 3.91 rubles/m^2 to 5.53 rubles/m^2.

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Installation and Results for Determining the Velocities of an Aerosol Cloud

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Abstract. Sneezing and coughing of a patient are especially dangerous when, together with a jet of air moving at a high speed, droplets of liquid containing viruses fly out. There is a lack of experimental data to create model, describing these processes and calculate the concentration of aerosol particles. The paper describes an installation for assessing the time-varying distribution of velocities and changes in the shape of the aerosol cloud that occurs during coughing and sneezing. The proposed experimental method allows obtaining data on the distribution of relative velocity in a single act of air release. This data is then calibrated against absolute velocity measurements with a low sensitivity sensor installed near the source. The purpose of these studies is to determine the direction and velocity of the cloud carrying the droplets with the virus, as well as the time of its passage past potential recipients. Based on these data, it will be possible to estimate the received dose of infection and the dependence of this dose on the distance between the source and a person near it.

Keywords: Aerosol · Model · Sensor · Concentration · Velocity · Experiment · Virus · Temperature · Flow

1 Introduction

A person who is sick with a dangerous virus is a "pulsating" source that changes its power, creating an aerosol cloud moving at high speed when coughing and especially when sneezing, which has the temperature and density of exhaled air. The construction of a physical model of these processes is a rather difficult task. So, in particular, due to the finite time of the process, the well-developed theory of jet flows cannot be applied. The fact is that in this case, the relatively low speed and low temperature difference make it difficult to apply its conclusions to this one, since in addition to physical processes, there are specific biological processes. Although there are already many works on a similar topic [1–7], mainly describing the processes of the spread of infection on the basis of mathematical models of the processes, additional experimental studies seem to be very important. Medical research also provides too little information to accurately

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estimate the spread and shape of "artificial" aerosol clouds that carry the threat of the spread of infection. This kind of knowledge will help overcome many prejudices and develop practical recommendations for coping strategies in a global pandemic [8, 9]. The ultimate goal of the paper is a practical study of the process of transmission of infection by airborne droplets, because, according to many scientists, it is this path that is the most likely way of infection. Of course, such studies should be carried out with large groups of subjects in order to obtain reliable statistical data. And only such results will be able to provide sufficiently accurate recommendations for the behavior of people in the difficult conditions of the global spread of infection.

2 Possible Research Methods for "Artificial" Clouds

The parameters of movement and changes in the shape of the aerosol cloud can be experimentally studied by the following methods:

- measuring the distribution of velocities using microelectronic mechanical systems (MEMS) of increased sensitivity.
- measuring the temperature distribution in the exhaled cloud using thermal imaging equipment [10, 11].
- temperature measurements of the aerosol cloud structure using a network of microthermometers [12];
- mechanical 3-D measurements of the cloud velocity distribution by microanemometers of increased sensitivity [13].

The mainstream movement of microelectronic technology has led to the creation of unique microelectromechanical sensors. However, the low sensitivity of modern sensors does not allow them to be used for the specific task at hand. Most likely, similar tasks were not of practical interest in the past. But now, already in the near future, with their obvious relevance, they will naturally take their rightful place. But such developments will require additional funds and a fairly long time.

Thermal imaging equipment for measuring the spatial distribution of air temperature has a very high cost and is available only to selected high-tech laboratories. Moreover, the velocity distribution required for the "infection model" is obtained only indirectly on the basis of temperature measurements. This also applies to direct temperature measurements with microsensors.

Thus, there was only one possibility to begin the study—to develop a special network of numerous mechanical micro-anemometers of increased sensitivity.

3 Description of the Experimental Installation

Based on the foregoing, the authors proposed a method for measuring the relative velocity of air flow elements using the installation presented in this paper. At the same time, due to the variability of the volume and velocity of the aerosol cloud, a scheme was developed that makes it possible to obtain a two-dimensional distribution of the relative velocity in two planes located at different distances from the source. To create a picture of the dependence of the relative velocity on the distance, a number of experiments were carried out with these planes located at a selected number of distances from the source of aerosol clouds. Then, the absolute velocity calibration of the obtained relative velocity distribution was carried out using a low sensitivity anemometer located at a close distance from the cloud source.

As an anemometric sensor of high sensitivity, small triangular paper flags were used, suspended on horizontal silk threads, which were stretched on two rectangular frames (Fig. 1). The picture of the frames was taken on a white background. In reality, there was free space behind the frames. The frames were installed one after another on the same line with the subject, while on the far frame the flags had a greater length, and, therefore, less sensitivity. To determine the relative sensitivity of the flags, several larger flags were suspended in the center of the installation with small flags.

The movement and deflection of the flags were recorded by four video cameras placed along the perimeter of the installation at the same height. General view of the installation (Fig. 2).

Cameras were installed on the left and right sides of each of the panels (the figure shows only two cameras on the left side), which made it possible to partially compensate for the projective decrease in the visible size of the flags.

The video filming data was then transferred to a computer, for which a specific video processing program was created by one of the authors of the article.

4 Description of the Experimental Installation Software

With the help of this program, at the first step, the projective distortion of each sensor was calculated.

At the second step, the following was calculated for each flag:

1. projective restoration of position in a stationary state;
2. determination of the maximum deviation of the flag;
3. calculation of the relative maximum velocity of the flags located on the panel nearest to the subject;
4. calculation of the relative sensitivity of sensors of different sizes located side by side on the first panel;
5. calculation of the total response time of the sensor to an episodic impact;
6. calculation of the relative air velocity on the second panel (item 2, item 3 and item 5) on the basis of the data on the relative sensitivity of the sensors (item 4).

5 Substantiation of the Method for Calculating the Cloud Velocity from the Sensor Deflection

We have made a theoretical substantiation of the method for determining the relative velocity of air carrying aerosol particles by the magnitude of the deviations of the sensors (flags) from the vertical position. In the case when the gas flow is laminar and the

Fig. 1. Experimental installation.

deflection of the flag occurs under the action of the force of the falling air pressure, the deflection of the suspended flag from the vertical does not depend on its shape.

It was believed that the sensor response was caused by two reasons:

- the action of the pressure of the falling air flow;
- the difference in pressure on the front and back surfaces of the accelerometer sensor.

In this case, the impulse of the force acting on the flags did not dependS directly on the area of their surface.

It is usually considered that the force acting on a flat plate [14–18] is determined by the formula: $F = CS\rho v^2/2$, where the coefficient C depends on the shape of the body, which, of course, includes the area of the frontal section, and, in turn, determines the

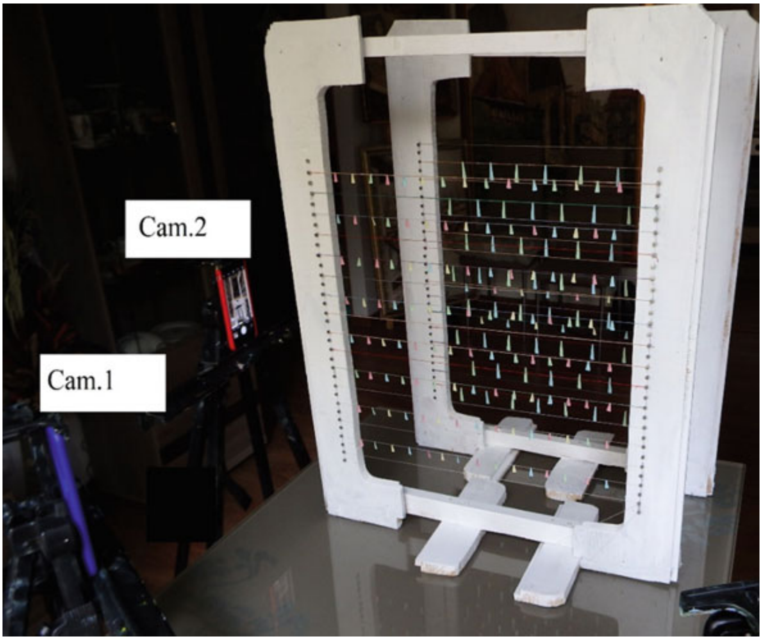

Fig. 2. General view of the installation.

structure of the flow behind the object. Theoretically, this coefficient can be approximately calculated only in special cases. As a rule, for different streamlined objects, it is determined experimentally [19, 20, 9].

Vortices are formed behind the flag, while the pressure behind the flag decreases, which causes additional deflection of the flag under the influence of the pressure difference. A large flag causes more flow turbulence than a small flag at the same incident flow rates. The empirical value of the coefficient was determined by the comparative deviation of neighboring (i.e. located in flows with different speeds) sensors.

The use of sensors of different surface areas, but of a similar shape (and, hence, sensitivity) made it possible to obtain data on the decrease in the relative velocity of the aerosol cloud when it is removed from the source.

After absolute calibration of the relative distribution of the artificial cloud velocities by the method of three-dimensional integration, the change in the volume of the cloud with time, the change in concentration with time, the dependence of the propagation time on the distance to the recipient, the duration of the passage of the cloud in the recipient's zone, and the approximate total dose of aerosol drops obtained by it are obtained.

6 Data from the First Cycle of Experiments

6.1 Preliminary Experiments with a Coughing Subject

The first experiments with a coughing subject gave paradoxical results. It was found that when coughing, the aerosol cloud does not spread along the horizontal axis extending from the center of the mouth of a sitting person. The experiment showed that the central axis of the cloud's motion is usually tilted downward at an angle of 10–40°. The angular distribution of the cloud velocity during coughing is subject to strong variations and depends on the shape of the mouth and, possibly, the position of the tongue in the larynx. These results are of practical importance. When coughing, if a person wants to protect others, he should first cover the lower part of his mouth, preventing the active movement of the cloud. Reliable measurements of the angular distribution of cloud velocity should be carried out with a large group of subjects. The average angular distribution of the velocity of the cloud emerging during coughing corresponds to approximately 30–50°

During the experiment, the position of a person or a device simulating a cough or sneezing remained constant. The position of the sensors changed. This made it possible to determine the area of air movement.

Calculations show that the cloud of exhaled air is quickly released from saliva droplets. So, droplets of 50 microns in size settle from a height of 2 m in a few seconds. Smaller droplets settle more slowly, but they contain fewer viruses. When creating a mathematical model of droplet motion, the following were taken into account: gravity, buoyancy and viscosity. The difficulty is that the drop participates in two independent movements—it is carried away by the air flow due to the action of the viscosity force, and it falls down under the action of the above three forces. The solution is further complicated by the fact that the droplet diameter changes due to evaporation. Therefore, a rigorous assessment of its motion must take this fact into account.

6.2 Preliminary Experiments with a Sneezing Test Subject

Due to the high speed of the cloud during sneezing, the first panel had to be spaced at a distance of at least 0.5–1 m. When sneezing, the air stream, as a rule, has a relatively symmetrical shape, close to cone-shaped, and is almost reproduced from one experiment to another. Axle tilt is generally less than 20°. The angular distribution of the cloud velocity ranges from 35 to 50°. A preliminary estimate of the propagation time over a distance of about 1 m is 0.2 s.

Thus, it is already advisable to cover the mouth when sneezing. Note that the sneezing of a person infected with the virus poses a danger to others even in open space if the latter are at a distance of closer than 4–5 m and do not have protective equipment.

In subsequent experiments, a more accurate determination of the velocity and angular distribution of the flow of an artificial aerosol cloud is assumed, on the basis of which the accuracy of determining the velocity of cloud propagation and changes in the concentration of aerosol with distance will be increased.

7 Conclusions

- A fairly simple installation has been developed to measure the angular distribution of the relative velocity of an artificial aerosol cloud and the change in the relative velocity with distance from the source of infection.
- A technique for measuring the propagation velocity of an artificial air flow and a method for absolute calibration of the relative velocity distribution have been developed. The results of the first studies were obtained, where the sources of clouds

were people with artificially stimulated sneezing. Based on the measurement of the velocities, the cloud propagation time is 0.2 s.
- Based on a preliminary cycle of experiments, practical recommendations have already been developed, intended to reduce the likelihood of the spread of a dangerous infection.

In further studies, it is assumed to conduct a theoretical analysis of the angular distribution of the concentration of water microdroplets in an air cloud and changes in the concentration of drops depending on the distance between the source and the recipient, the duration of the passage of the cloud in the recipient's zone and the dose of aerosol particles received by it.

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Geographic Information Systems in Forecasting the Winter Wheat Yield

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Abstract. The paper presents the results of field studies to identify a correlation between the vegetation index (NDVI), obtained on the basis of satellite images using the Agrosignal platform and biometric indicators of the condition of winter wheat plants. Studies have shown that in the forest-steppe zone of the Volga region there is direct strong relationship between the vegetation index of plants (NDVI) and their biomass ($r = 0.889$), also with the number of productive stems of winter wheat plants ($r = 0.833$), leaf surface index ($r = 0.766$) and grain yield of winter wheat ($r = 0.722$). We have obtained adequate regression equations, which, in the regional conditions of the Volga forest-steppe, will give an opportunity, with the use of multispectral aerial photography, to monitor the condition and development of winter wheat crops with accurate forecast of grain yield.

Keywords: Geographic information systems · Winter wheat · Vegetation index · Correlation

1 Introduction

In Russia, in comparison with many other countries, labor productivity in agriculture remains low, which is often explained by the use of ineffective practices of cultivating crops and outdated approaches, as well as the lack of global digital transformation. According to a number of authors, it is necessary to introduce digital technologies (to make wider use of the possibilities of digital technologies) to increase productivity and production efficiency in agriculture [1, 2]. Precision farming systems are widely used in many parts of the world,—the use of navigation devices, all kinds of sensors, vegetation indices, etc. [3].

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The use of remote sensing in a diverse spectral range for predicting yield based on vegetation indices has been studied quite widely [1–4], in addition, models are also built using data such as the land surface temperature (LST) [5], the influx of photosynthetically active radiation (PAR) [6, 7], plant biomass [8], evapotranspiration [9, 10] and other indicators.

However, not all models are reliable, and the accuracy of yield forecasts is not high, which is explained, first of all, by the differentiation of soil and climatic conditions in different zones. According to various data, the error in predicting the yield of grain crops according to vegetation indices reaches 40%. Therefore, it is of practical interest to create models and relationships of normalized difference vegetation indices (NDVI) for individual crops and even varieties to obtain accurate information by monitoring the development and condition of crops, which will make it possible to predict their yield adequately.

The results of studies to assess the relationship between the NDVI index, indicators characterizing plant development, including crop yields, as well as the development of various models and recommendations for their use in practice using remote sensing, are presented in numerous works. The latest of them were carried out by Storchak with co-authors [11], Komarov [12], Eroshenko et al. [13], Panesha and Tsalova [14], Trofimenko with co-authors [15], Teryokhin [16], Gulyanov et al., Zermas, Sultana, and others. Storchak [11] and co-authors, as a result of studying winter wheat crops in the Stavropol Territory, came to the conclusion that elements of the winter wheat cultivation technology—variety, predecessor, mineral nutrition, seeding time and rate, have a great influence on the optical and biological properties of its seedlings. It was found that the relationship between yield and NDV index is estimated by the correlation coefficient equal to 0.62. Similar data are presented in the works of Gulyanov [17], who, analyzing the results of studies in the Orenburg region, came to the conclusion that the deviations of the actual yield of winter wheat from those predicted on the basis of the NDVI of sowing in the ear formation phase are insignificant and they can be referred to quite acceptable ones in such forecasts.

Eroshenko and co-authors [13] found that there was a relationship between the area of the photosynthetic surface and the NDVI of winter wheat crops, which is assessed by a correlation coefficient of 0.61–0.68. In the works by Panesha and Tsalova [14] data were presented on a strong correlation between the yield of winter wheat by NDV indices, chlorophyll photosynthetic potential, vegetative photosynthetic potential in the conditions of the Republic of Adygea.

In recent years, studies have been carried out to identify the relationships between the Normalized Difference Vegetation Index and productivity of other crops. The vegetation index can serve as a management tool in the precision farming system [12]. The heterogeneity of the spatial distribution of the NDVI for each array of the field demonstrates the uneven growth and development of the vegetation cover of perennial grasses. The value of the NDVI makes it possible to carry out the required technological operations promptly (top dressing, mowing, etc.) in those areas of the field that need them. It has been established that, on the basis of satellite images, it is possible to carry out a timely forecast of the harvesting of perennial grasses, which gives an opportunity to obtain a high quality yield.

There are other possibilities for using vegetation indices. For example, Teryokhin proposed a technique for the automated identification of fallow lands among arable land [16], on the basis of the analysis of seasonal values of the NDVI. Taking into account the experimental information collected from agricultural land in the Belgorod region, equations have been calculated and evaluated that help in an automated mode to assign a specific agricultural land to arable land or fallow land.

In addition, studies were carried out to analyze the possibilities of using remote sensing methods for the assessment of the biological diversity of plant communities. In the conditions of the steppe landscapes of the Donetsk ridge in the Ukraine, Trofimenko et al. [15] found a reliable correlation ($r = 0.900$) between the biodiversity of steppe landscapes and the dynamics of the normalized difference vegetation index. There are studies to study the patterns of seasonal changes in the NDVI of crops depending on the exposure of the slopes on which they are located [18]. Despite the numerous data giving an opportunity to establish relationships between vegetation indices, studies in the field of establishing relationships between plant development parameters and NDVI values in specific conditions are very important. We assume that there are close relationships between the NDVI and the number of shoots in the period the end of tillering—shooting, plant biomass, leaf surface index, and yield, which can be used for forecasting and planning production processes. It is also necessary to establish a relationship between the MSI index and the moisture content of winter wheat grain, which gives grounds for predicting the harvesting terms of each field.

Goal of the study: Monitoring the development and condition of winter wheat with predicting the yield by geobotanical interpretation of multispectral aerial photography data in the regional conditions of the Volga forest-steppe, which will answer the following questions:

- to study the dynamics of the NDVI depending on the accumulated biomass of winter wheat plants;
- to establish a relationship between the NDVI and the number of productive stems in the tillering phase of winter wheat;
- to determine the relationship between the NDVI and the leaf area index and grain yield of winter wheat.

2 Materials and Methods

The study was carried out using a special method in agronomy—field research. The data obtained were processed using the correlation analysis method. The object of research was the parameters of winter wheat sowing, the study of the condition of plants in the fields was carried out according to the phases of plant development during the route survey. The studied fields are located in agricultural enterprises (organizations).

In some fields during the survey, the following observations, counts and analyzes were carried out:

- determination of plant biomass, selection and weighing of plant mass from 10–20 plots (depending on the size of the field) measuring 0.5 * × 0.5 m (0.25 m2). The field was surveyed diagonally, the mass was converted to 1 m2 with the determination of the dry matter content;

- calculation of plant density and productive bushiness, selection was carried out from 10–20 plots (depending on the size of the field) measuring 0.5 * × 0.5 m (0.25 m2), the field was examined diagonally;
- measurement of the leaf surface area by mass;
- determination of weed infestation of crops by the quantitative-weight method, in addition, the species composition of weeds in crops is studied;
- registration of the yield by the method of overall threshing;
- vegetation indices (NDVI) obtained as a result of satellite images on the platform of the online system for monitoring and accounting agricultural production Agrosignal (https://agrosignal.com).

The data obtained were subjected to correlation and regression analysis to establish the relationship between the vegetation indices and plant development indicators and the yield of winter wheat. The sample consisted of 22 fields located in the Ulyanovsk region of the Russian Federation, the study was carried out in 2020.

3 Results

Agricultural plants serve as an indicator of growing conditions, showing high responsiveness to agro-technological cultivation methods, which is reflected in the varying degrees of their growth and development at certain stages of organogenesis. This, in turn, has a significant effect on the optical and biological properties of sown crops and, as a result, on remote sensing data. The normalized difference vegetation index is one of the technologically reliable parameters for assessing the general condition of crops, including winter wheat that can be obtained as a result of satellite images.

The results of a survey of winter wheat crops by a set of indicators showed that the plant biomass varied from 4.03 to 9.89 kg/m^2 and had a direct relationship with the number of plants and productive stems. The leaf surface index varied from 1.96 to 2.83 units, grain yield from 1.36 to 7.98 t/ha, and the maximum value of the NDVI from 0.64 to 0.91 units.

At the early stages of plant development in grain crops during the period of insignificant plant biomass per unit area, the determining factor reflected in the NDVI index (x) is the number of shoots (stems) (Y) (Table 1). The compiled correlation model)/ shows that a direct strong relationship (0.889) is found between the noted features, which is characterized by the regression equation:

$$Y = 1848{,}7x - 689{,}6 \tag{1}$$

The bushiness of plants reflects the density of the grain crop stand. Thus, the sown crops of winter wheat with the NDVI of 0.54 had about 307 stems per 1 m^2, which is extremely insufficient to obtain high indicators of crop productivity. On the contrary, the crops with an index 0.86 had a dense stand at the level of 1032 pcs/m^2. Obtaining low values of the index at the early stages of crop development serves as a certain signal to carry out activities aimed at realizing the genetic potential of the crop. The presented

Table 1. Regression and correlation relationships between indicators of the winter wheat yield structure (Y) with the normalized differentiated vegetation index—NDVI (X, units).

N	Indicator	Assessment period	Span of values		Correlation coefficient	Relationship character
			$Y_{1,2,3}$	X		
1	Number of productive stems, pcs./m^2	End of tillering—shooting	307–1032	0,54–0,86	0,889	Direct, strong
2	Dry biomass of plants, kg/m^2	Ear formation	1,01–2,47	0,86–0,91	0,833	Direct, strong
3	Leaf surface index, m^2/m^2	Ear formation	1,96–2,83	0,86–0,91	0,766	Direct, strong
4	Grain yield, t/ha	Full maturity	1,36–7,98	0,64–0,91	0,722	Direct, strong

model shows that with an increase in the value of the NDVI by 0.1 units, there is an increase in the number of stems by about 185 per square meter.

The counts carried out during the maximum biomass accumulation period (winter wheat ear formation) showed that the dry aboveground weight of plants from 1 m2 varied from 1.01 kg to 2.47 kg. Undoubtedly, this indicator is a sign that significantly differs between varieties, however, by means of correlation analysis, we established a relationship between the accumulation of aboveground biomass of winter wheat (excluding biomass of weeds) during the ear formation period (Y1) and the values of the NDVI (x), while the correlation coefficient was $r = 0.833$. The relationship is characterized as direct and strong and it is described by the regression equation:

$$Y_1 = 25{,}028x - 20{,}603 \tag{2}$$

Despite the fact that the value of the NDVI in determining the biomass of plants in the ear formation phase varied slightly (0.86–0.91), the difference in the accumulation of dry biomass by the experimental fields was significant (up to 2.4 times).

The main factor that determines the intensity of plant photosynthesis is the leaf area (index). Our studies have shown that there is a direct strong relationship ($r = 0.766$) between the NDVI (x) and the winter wheat leaf area index (Y2), the regression equation is as follows:

$$Y_2 = 13{,}556x - 9{,}5894 \tag{3}$$

Crops of winter wheat with the NDVI of 0.91 had the highest assimilation leaf area (2.83 m^2/m^2). A high value of the NDVI indicates the optimal development of crops, because the better the condition of the plants, the greater the assimilation area of the leaves they have. All the studied winter wheat crops formed the optimal leaf area, however, the best indicators were observed among highly productive crops.

Our studies are consistent with the results obtained by Eroshenko et al. [17], who found the existence of a close relationship between the parameters of the assimilation surface of leaves and the NDVI in winter wheat crops (r = 0.61–0.68). Because the leaf area index of a plant reflects the photosynthetic productivity of crops, therefore, the results obtained can be used to develop methods for monitoring the physiological state during the growing season and assessing the productivity of agricultural crops according to remote sensing data.

The data on the relationship between the NDVI indicator (x) and the yield of the main cereal crops (Y3) are of theoretical and practical interest. Such relationships are widely used in production, but they require specification in certain regional conditions. Based on the data obtained, we have established a relationship that is characterized as direct and strong (r = 0.722) and is expressed by the regression equation:

$$Y_3 = 20{,}192 - 12{,}384 \quad (4)$$

Variation of the NDVI in the phase of full ripeness of winter wheat was more significant (0.64–0.91). Sown crops, having NDVI values at the level of 0.86–0.91 units throughout the growing season, provided an increase of up to 8 t/ha of grain. In this case, it is possible to assert that agrotechnical and protective measures were fully implemented in crops grown, which gave an opportunity to obtain high indicators of winter wheat productivity. Plants formed a dense, highly leafy stand. On the contrary, crops with an index of 0.64 units gave no more than 1.4 t/ha of grain. According to the revealed relationship, an increase in the index value by 0.1 units provided an additional harvest of 2 tons of grain per hectare. The conclusions are valid with the value of the NDVI in the range of 0.64–0.91 units.

4 Discussion

Thus, we have developed mathematical models to use the results of multispectral aerial photography in monitoring the condition and development of winter wheat of various varieties to make prompt decisions and predict the yield of winter wheat in the forest-steppe zone of the Volga region. Multichannel aerial photography of the area will allow accurate monitoring of the state of development of winter wheat plants to take quick decisions on adjusting the cultivation technology and predicting its yield.

5 Conclusions

Studies have shown that positive relationships were found between the NDVI and the development indicators of winter wheat plants, which are characterized by the following correlation coefficients: the number of shoots in the end of the tillering phase—shooting—r = 0.889, plant biomass in the ear formation phase r = 0.833, the leaf surface index of—r = 0.766, the winter wheat yield—r = 0.722.

The obtained regression equations will give an opportunity, on the basis of multispectral aerial photography, to monitor the condition and development of winter wheat with predicting the yield in the regional conditions of the Volga forest-steppe.

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Mathematical Modeling in Forecasting Reproduction Processes in Agriculture

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Abstract. The article developed the author's method for assessing the forecasting of reproduction processes in agriculture of the Russian Federation. For this, an index analysis of thirteen indicators was carried out, grouped into three groups of production factors: labor, land, capital. The integral indicators characterizing their changes and the saturated rates of reproduction processes in the agriculture of the Russian Federation have been calculated. Then, using the means of mathematical modeling, a multifactorial mathematical model was built and tested in real time, which makes it possible to obtain a high-quality predicted result. Based on the forecasts obtained, it is possible to state the need to adjust certain indicators that actively influence the rates of reproduction processes, which is a mathematical justification for making managerial decisions in the development of strategies and programs in order to ensure sustainable development of agriculture in the Russian Federation.

Keywords: Forecasting · Agriculture · Reproduction processes · Assessment methodology · Integral indicator · Mathematical modeling · Sustainable development

1 Introduction

At the beginning of the XXI century, the new realities of the economy revealed an urgent need for modern technologies for studying the reproduction process, both in the national economy as a whole and in agriculture, since the pre-reform methods are hopelessly outdated.

Given the shortcomings of publications on this issue, for example, in the works of Albeaik [1], Lou [2], Tahamipour [3], is not accepted in attention is paid to the approach for accounting indicators with different units of measurement. In the works of Brunton [4], Bongiorno [5], Minina [6], there are no mathematical models for studying economic processes. And in the articles by Hruschka [7], Tacchella [8], Brummitt [9], Tyapkina

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[10], Stavtsev [11] in the presence of statistical information, there is no mathematical apparatus for research and the possibility of obtaining forecasts.

Analyzing the results of our earlier studies, and having a developed technology for assessing the impact of socio-economic factors on the reproduction of personal potential in agriculture [12, 13], we have developed an algorithm for predicting reproduction processes in agriculture.

In contrast to the presented publications, in this work it is proposed to use a mathematical apparatus for the study of reproduction processes and, on the basis of forecasts obtained from the developed mathematical models, to carry out effective management of agriculture in order to ensure its sustainable development.

We believe that this topic will be of interest to foreign scientists in connection with a special research technology in solving applied problems, which has no analogues in the world.

2 Methods

At the initial stage, a sample of the most significant criteria is formed for assessing the reproductive processes that are the objects of this study. Since reproduction includes four main factors of production: labor, land, capital, entrepreneurial ability, further research will be based on a grouping of indicators reflecting the state of these factors. Without the constant renewal of each of them reproduction is impossible.

In an enlarged form, the sample includes a variety of indicators, but to simplify and efficient calculations, based on the correlation analysis, thirteen indicators have been identified that have a significant impact on the sustainable development of the industry. The selected factors are provided with the available information on the website of the Federal State Statistics Service [14] and are reduced to an index value (in% to the previous year) in Tables 1, 2, 3 for the possibility of taking them into account when calculating the integral indicator.

The index analysis method allows you to aggregate a wide range of quantitative indicators for assessing reproductive processes that have different units of measurement and are not comparable with each other without standardizing values. So, Table 1 reflects the index values of indicators characterizing the agricultural production of the Russian Federation in 2010–2019 (work).

Based on the information in Table 1, according to formula 1, an integral indicator is calculated that characterizes the agricultural production of the Russian Federation in 2010–2019 (labor)(II_{labor}), (in points):

$$II_{labor} = \sqrt[3]{I_{apc} * I_{gymc} * I_{plp}} \tag{1}$$

where I_{apc}—agricultural production change index, %;

I_{gymc}—index of changes in the gross yield of major agricultural crops, %.

I_{plp}—index of change in production of basic livestock products, %;

To summarize the indicators characterizing the second factor of production—land, we will form Table 2.

Table 1. Dynamics of changes in indicators characterizing agricultural production in the Russian Federation in 2010–2019 (labor), in% of the previous year.

Indicators	Years									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Index of change in agricultural production	88.5	126.0	102.4	113.5	113.9	119.6	106.6	92.8	104.7	110.4
Index of change in gross yield of major agricultural crops	78.2	148.6	82.2	119.4	111.0	101.4	108.8	101.6	87.5	105.3
Index of change in production of basic livestock products	99.8	100.5	101.9	98.8	101.9	101.4	100.7	100.2	101.8	102.2
Integral indicator characterizing agricultural production (labor), points	88.4	123.5	95.0	110.2	108.8	107.1	105.3	98.1	97.7	105.9

Table 2. Dynamics of changes in indicators characterizing land resources used in agriculture of the Russian Federation in 2010–2019 (land), in% of the previous year.

Indicators	Years									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Index of change in sown areas of agricultural crops	99.0	102.0	99.5	102.4	100.5	101.0	100.9	100.0	99.5	100.4
Index of change in area of pure steam	102.4	95.2	100.0	89.3	99.2	96.0	100.8	98.3	101.7	96.7
Index of change in the application of mineral fertilizers	97.4	105.3	95.0	100.0	100.0	105.3	115.0	108,7	100.0	108.0
Index of change in the use of organic fertilizers	100.7	98.7	103.0	102.8	110.6	104.2	101.6	102.5	103.0	102.8
An integral indicator characterizing land resources (land), points	99.9	100.2	99.3	98.4	102.5	101.6	104.4	102.3	101.0	101.9

Table 3. Dynamics of changes in indicators characterizing the material and technical base of agriculture in the Russian Federation in 2010–2019 (capital), in% of the previous year.

Indicators	Years									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Index of change in livestock and poultry (at the end of the year), million heads	97.6	105.0	104.8	99.2	110.4	101.0	100.8	99.7	97.4	100.8
Index of change in the fleet of main types of equipment in agricultural organizations, thousand units	102.8	94.6	94.6	94.2	95.5	94.6	96.2	97.1	97.7	97.7
Index of change in the balanced financial result (profit / loss), billion rubles	86.7	130.7	114.4	68.5	232.8	146.8	89.7	78.1	146.2	111.9
Index of change in investments in fixed capital of agriculture (excluding forestry), billion rubles,	83.2	140.4	107.6	105.6	107.4	97.2	119.8	102.7	98.7	100.7
Index of change in commissioning of capacities, incl. for: livestock and poultry farming, million seats	90.9	120.0	67.2	205.1	55.3	96.7	306.6	32.9	47.5	277.2
Crop production, thousand tons of one-time storage	71.4	180.0	178.4	32.1	185.8	137.9	65.5	189.0	60.2	169.1
Integral indicator characterizing the material and technical base (capital), points	88.2	125.7	106.5	87.4	118.1	110.5	113.1	88.6	85.6	131.6

The data in Table 2 are used to calculate the integral indicator characterizing land resources (land) (II_{land}), according to formula 2 (in points):

$$II_{land} = \sqrt[4]{I_{sa} * I_{aps} * I_{amf} * I_{uof}} \tag{2}$$

whereI_{sa}—index of change in sown areas of agricultural crops, %;

I_{aps}—index of change in area of pure steam, %;

I_{amf}—index of change in the application of mineral fertilizers, %.

I_{uof}—index of change in the use of organic fertilizers, %.

To summarize the indicators characterizing the third factor of production—capital, we will form Table 3, reflecting the material and technical base of agriculture in the Russian Federation in 2010–2019.

The data in Table 3 are used to calculate the integral indicator characterizing the material and technical base of agriculture in the Russian Federation (capital) ($II_{capital}$), according to formula 3 (in points):

$$II_{capital} = \sqrt[6]{I_{lp} * I_{fe} * I_{bfr} * I_{ifc} * I_{ccpl} * I_{cccp}} \tag{3}$$

where I_{lp}—index of change in livestock and poultry, %;

I_{fe}—index of change in the fleet of main types of equipment in agricultural organizations, %;

I_{bfr}—index of change in the balanced financial result, %.

I_{ifc}—index of change in investments in fixed capital of agriculture, %.

I_{cclp}—index of change in commissioning of capacities for livestock and poultry farming, %.

I_{cccp}—index of change in commissioning of capacities for crop production, %.

Further, the values of formulas 1–3 are substituted into formula 4 to calculate the integral indicator characterizing the reproductive processes in agriculture of the Russian Federation ($II_{R.P.A.}$), (in points):

$$II_{R.P.A.} = \frac{II_{labor} + II_{land} + II_{capital}}{3} \tag{4}$$

where II_{labor}—is an integral indicator characterizing agricultural production (labor), points;

II_{land}—an integral indicator characterizing land resources (land), points;

$II_{capital}$—an integral indicator characterizing the material and technical base of agriculture (capital), points.

The values of the integral indicator characterizing the reproduction processes in the agriculture of the Russian Federation ($II_{R.P.A.}$) are entered in Table 4.

Based on the classification of reproduction rates in agriculture, proposed by Ivanova T.V. [12] and on the calculations carried out, the designations of the rates of reproduction processes in branch are introduced: in the analyzed period, they ranged from 92.2 points (narrowed polarized reproduction) in 2010 to 116.5 points (minimally extended) in 2011.

Table 4. Integral indicator characterizing the reproduction processes in agriculture of the Russian Federation in 2010–2019, in points.

Indicators										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Integral indicator characterizing reproduction processes in agriculture	92.2	116.5	100.3	98.7	109.8	106.4	107.6	96.3	94.8	113.1

3 Results

At the next stage, in order to further detail the problem under study, it is proposed to use mathematical modeling tools to predict reproduction processes in agriculture in order to ensure sustainable development of the Russian economy. The capabilities of the current state of mathematics and computer technology allow, on the basis of mathematical models, to obtain high-quality reliable forecasts, as evidenced by publications in the field of economics [12, 13] and technology [15, 16].

Let's compose a multivariate mathematical model of the dependence of the data in Table 4 on the index indicators of Tables 1, 2, 3. For the data in Table 4, we will introduce the designation, and the index indicators of Tables 1, 2, 3 will be designated respectively. In this case, the structure of the multivariate mathematical model will be as follows:

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 \tag{5}$$

Based on the matrix of interfactor correlation, established using office computer software, Excel,

$$R_{x_1x_2} = 0,0534; R_{x_1x_3} = 0,6009; R_{x_2x_3} = 0,3587$$

we can state the correlation of the first and third factors. Eliminating the first factor, we obtain a corrected version of the multivariate model

$$Y = a_0 + a_2x_2 + a_3x_3 \tag{6}$$

whose coefficients are:

$$a_0 = 57,04706; a_2 = -0,01980; a_3 = 0,45983 \tag{7}$$

The calculated multivariate regression equation has a multiple coefficient of determination $R^2 = 0,9052$. Using Fisher's statistical test: at the level of significance $\alpha = 0,005$, as well as, $F_{cr}(2; 7; 0,05)$ and $F_{obser} = 33,579$, by accepting a competing hypothesis $H_1 : R^2 \neq 0$, we confirm the significance of the multivariate regression Eq. (2). The geometric illustration of the initial information, the values of Table 4 and the constructed multivariate model (2) is shown in Fig. 1.

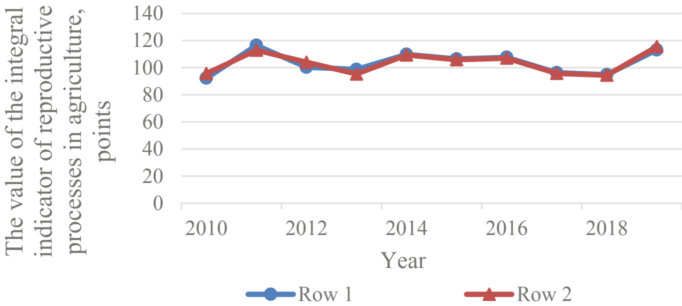

Fig. 1. Graphic interpretation of the initial information—row 1 and built multifactor model—row 2.

Mathematical model (2) tested on data from 2010 to 2018. In this case, the coefficients of model (2) have the values$a_0 = 56,68659$; $a_2 = -0,05303$; $a_3 = 0,49871$. The confidence interval of the predicted value of the integral indicator of reproduction processes in agriculture was calculated $\mathrm{II}_{\mathrm{R.P.A.}} : Y_{2019}$

$$105,8291 \leq Y_{2019} \leq 127,9965. \tag{8}$$

As the data in Table 4 show, the obtained confidence interval covers the real value of the indicator for 2019. To obtain a forecast for 2020 of the integral indicator of reproductive processes in agriculture, it is necessary to calculate the predicted values of the factors of the constructed mathematical model (2) and x_3. Considering the values of these factors as time series, point forecasts for 2020 were obtained $x_2 = 105,0922$ and $x_3 = 119,1747$. Then, based on the mathematical model (2), for the obtained predicted values of factors x_2 and x_3 we obtain the confidence interval of the predicted value of the integral indicator of reproduction processes in the agriculture of Russia:

$$99,4050 \leq Y_{2020} \leq 120,1274. \tag{9}$$

When analyzing the model, it should be noted that the increase in the material and technical support of agriculture is more important than new areas.

4 Discussion

The obtained range of the confidence interval of the predicted value $\mathrm{II}_{\mathrm{R.P.A.}}$ for 2020 is less than the range of indicators for 2019, which indicates the low efficiency of measures implemented within the framework of the “Priority national project “Development of the agro-industrial complex”, the federal “State program for the development of agriculture and regulation of markets for agricultural products, raw materials and food for 2013–2020” and other sub-industry programs related to the regulation of reproduction processes in agriculture of the Russian Federation.

The analysis of $\mathrm{II}_{\mathrm{labor}}$ revealed that in 2019 change in indices: the gross harvest of basic crops amounted to 124.7% compared to 2010, the gross harvest of basic crops—134.7%, the production of basic livestock products—102.4%. Accordingly, the second parameter has a greater impact on the integral indicator characterizing agricultural production (labor).

The analysis of II_{land} indicates that in 2019 compared to 2010, the maximum change in the indices in this group occurred with the indicator reflecting the application of mineral fertilizers—an increase of 110.9% was noted, and the minimum change in the index of the change in the area of pure fallows—a decrease of 94.4%.

The group $II_{capital}$ demonstrates that for the analyzed period the cumulative change in indices had the following values: livestock and poultry—103.3%; the park of the main types of equipment in agricultural organizations—95.0; balanced financial result—129.1; investments in fixed assets of agriculture—121.0; the commissioning of capacities, including for livestock and poultry—304.9% and crop production—236.8%, respectively. Consequently, the last two parameters had the greatest impact on the integral indicator characterizing the material and technical base of agriculture in the Russian Federation.

5 Conclusions

Thus, the developed algorithm is a unique tool for determining the rates of reproduction processes in agriculture in the Russian Federation. It is a universal and accurate forecasting tool for the next period and has great potential for further research, since it can be used to assess not only the impact of certain parameters on the reproduction process, but also the impact of any external factors in order to ensure sustainable development of the country, federal districts and regions. Also, the methodology is one of the grounds for legislative and executive authorities in the development of socio-economic projects and programs.

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Method for Optimizing Speed and High-Speed Routes with Semi-Automatic Blocking

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Abstract. Currently, active work is underway to develop systems to ensure the safety of train traffic on the tracks, if these conditions are met during automatic blocking, then, when switching to semi-automatic blocking, it is not known at what speed to approach the crossing and the station. Using such methods as balise do not determine exactly how fast the train should move, especially when obstacles arise and the route needs to be optimized and prepared. A method based on RFID points is proposed. In the article, the developed method of optimization preparation of routes with semi-automatic blocking on high-speed lines is considered. Presented are: a scheme for preparing a route of mixed high-speed traffic lines at stations in conditions are semi-automatic blocking; the graph of the position change of the active closing point confirmation of the crossing. As a result, the proposed method for optimizing the preparation of the route for semi-automatic blocking showed that it is possible to reduce non-productive time losses under conditions of timely provision trains with routes, taking into account the sectional train speed determined by the active RFID point.

Keywords: High-speed line · High-speed train · Route · Mixed traffic · Electric interlocking · Semi-automatic blocking

1 Introduction

The organization of high-speed traffic (HST) is currently selected in different countries, taking into account the peculiarities of the application of movement, structures and methods [1]. At present, the structure of mixed high-speed traffic (HST) has been selected on the existing railway lines. The operation of the electrical interlocking system (EI) is carried out by the scheduled preparation of routes at stations in all areas, where the "high-speed movement" mode is introduced, at semi-automatic blocking on railway tracks, depending on the characteristics of the track, its scheduled time, the "high-speed movement" mode is introduced, where the route preparation time increases or remains unchanged.

The ways to solve this problem are to propose a mathematical model of train movement and calculations, where the margin of time for preparing routes at stations with semi-automatic blocking can be solved by entering an active identification point [2–4].

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High-speed train movements began to be organized on the railways, where stretches with a microprocessor-based semi-automatic blocking system (PAB) [5, 6] based on an axle counting system are being modernized. For the preparation of routes when departing or receiving to a station, especially in high-speed sections, preparation is carried out with a large investment of time, this, in turn, interrupts the technological work carried out at the station [7, 8].

2 Main Part

Currently, RFID technology is increasingly being used in railway transport. RFID technology consists in the marking of rolling stock, thereby helps to protect against counterfeiting, create databases on spare parts, track the life of spare parts and rolling stock, plan purchases and is the basis for electronic document management.

Research is proposed, associated with experiments and RFID implementations to automate control of rolling stock movement on railway tracks, stations, in the metro. Devices are being developed to track movements of containers, equipped with locking and sealing devices with built-in passive RFID marks. Are being developed sensors for by receiving information from the carriages at the expense of counting computations, located near the tracks.

Modeling movement of trains on a section with track circuits with mixed movement of trains on high-speed lines showed, that in some cases there is a waste of time waiting for freight trains to clear a section of the track, which leads to costs associated with the operation, therefore, work is carried out to eliminate these shortcomings.

In article, as the research of modeling the movement of trains at stations with mixed lines of high-speed railways with linking by an automatic blocking system (AB) shows [9, 10], it has shown that the preparation of routes by category removes all restrictions associated with the route of preparation. Consequently, the operation of station electrical interlocking (EC) systems, with the preparation route, depends on systems the section of track between stations, if the section of track is equipped with a semi-automatic blocking system, the distance and track profile between stations do not have a clear distribution, and the schedule for preparing routes 10 min before the arrival of the train increases several times. At this raises the question of how to determine the cooking time without a scheduled route at stations, if the line between station A and station B is equipped with a semi-automatic blocking system (SAB) (Fig. 1) [2, 11].

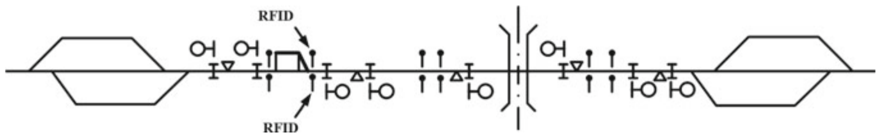

Fig. 1. Route preparation scheme.

Given the conditions the conditions that when a train leaves for a track section with a PAB semi-automatic blocking system, the route of movement to the neighboring station captures in advance the maximum speed (Vmax) of the route:

- stations (the whole route);
- track section (whole).

When receiving and sending a high-speed route from a neighboring station, the route is established with the consent of the station attendant (DSP) of the dispatched station. In case of a malfunction and an emergency situation of the route, according to the rules of technical operation (PTE), the stopping point of the route must be:

- at the exit traffic lights of the station;
- at the entrance traffic light.

In the event that the route is changed with the conditions for solving the high-speed line (HSR), the cancellation occurs within 6 min, taking into account the absence of the braking distance of the train, and if the train approaches the pre-entry traffic light, the driver will know that the route ahead of him is cut off and the entrance traffic light is closed—and this indicates that the braking distance (Lf) at Vmax is not provided. To ensure the movement of trains in such a situation, a point is introduced beyond Lf from the entrance traffic light, this is an active RFID (Radio Frequency Identification) point – label (identification) lengthening of the approach sections, taking into account the transfer of the pre-entrance traffic light, which determines the length of the section path and the response time of the driver or train device of the automatic driving system and the time of data transmission over the radio channel to confirm the reception route (Fig. 2). The mark RFID itself represent is a radio frequency system, consisting of transmitting devices and receivers, consisting of transmitting devices and receivers working at a frequency of 2.5 GHz. Train detection occurs by determining the passage of the train through control sections, RFID devices of radio frequency identification by means of fixing marks of railway carriages and locomotives, which are determined at the control points along the paths. The identification distance of the train occurs from a distance of 2–10 m, which determines the speed of movement of the train and its direction, management intersections of road transport with a railway line, as well as any integration with other systems, for example, with the help of additional elements and sensors, the acceleration and temperature of the wheel are determined, based on the data obtained, information about mechanical damage can be obtained, which is transmitted to the control room to prevent damage to infrastructure elements.

Most road-rail intersections are equipped with track chains. The notification of the approaching train is transmitted along the rail lines. The rail chain at the crossing is separated by insulating joints. The disadvantage of the system is the frequent breakdown of the insulating joints in the automatic crossing signaling, lack of information about the approach to the move, speed of approach to the crossing, not fulfilling the conditions approaching to a high speed of 250 km/h, premature closure of the level crossing. Therefore, a method with a semi-automatic blocking has been proposed.

In accordance with the requirement for the rules of technical operation for the organization of train traffic on sections with semi-automatic blocking, the distance between the input, route, output traffic lights must be at least the length of the braking distance, determined for this section with full service braking at the maximum realizable speed, and in the presence of track devices of automatic locomotive signaling, this distance, in

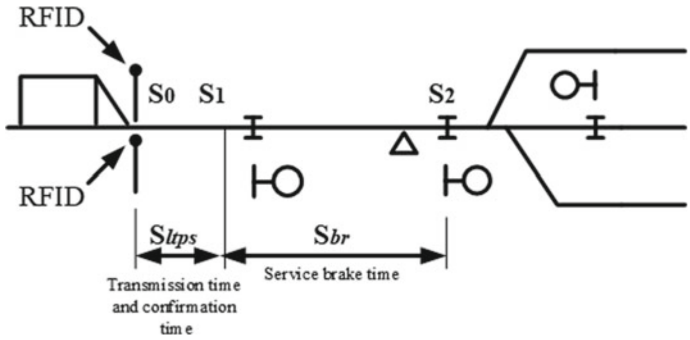

Fig. 2. Scheme of the preparation of route proposed type for preparation of a pass through the station on the lines of high-speed traffic with semi-automatic blocking.

addition, there should be no less than the stopping distance during emergency braking, taking into account the distance traveled by the train during the time required for the effect of automatic locomotive signaling devices on the train's braking system.

To ensure safety, it is proposed to use a radio channel and a radio frequency identification active point RFID with semi-automatic blocking (SAB). Since the active tags of the tracked vehicle can travel at speeds up to 220 km/h, this approach can be used to track high-speed trains.

On the other hand, when driving at a speed of 250 km/h and above, the braking distance must be taken into account, especially when approaching a railway crossing, where, due to the carelessness of motorists and haste, building up occurs on the railway tracks, which can lead to human casualties.

Therefore, you must take into account the braking distance before crossing in Fig. 3.

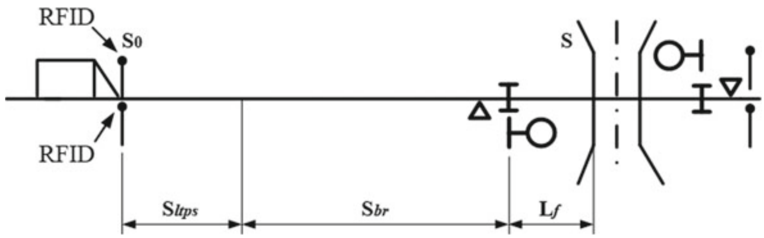

Fig. 3. Scheme route preparation for the proposed type of pass route through the crossing on high-speed lines at semi-automatic blocking.

The active point for routes is determined based on the braking distance and the response time of the driver or train device of the automatic driving system, which allows you to increase:

- maximum train speed;
- track profile;
- the braking distance of the train.

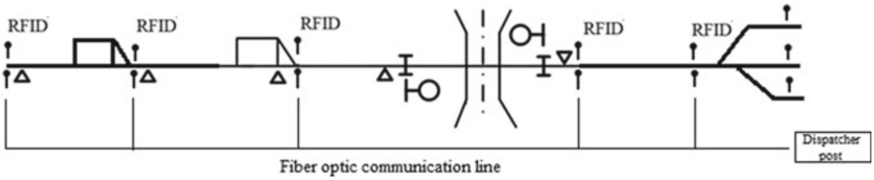

Fig. 4. Scheme showing the methodology for calculating the current coordinate of the train from the RFID point.

$$S_0 - S_2 \geq S_{br}(V_{max}) + (S_0 - S_1)(V_{max}) = S_{br}(V_{max}) + S_{ltps}(V_{max}) \quad (1)$$

where: $S_{br}(V_{Ma\kappa c})$ is the length of the service braking at the maximum speed of the train on a given section;

$S_{ltps}(V_{Ma\kappa c})$ is length of the traversed path of the section during the reaction time of the driver or the train device of the automatic driving system, taking into account the time of setting the route and the time of data transmission over the radio channel at the maximum speed of the train in this section;

S_0 is the place of the active point;

S_2 is the place of the entrance traffic light;

If inequality (1) is not fulfilled, the train following the route will not have time to stop in front of the entrance traffic light and enter the section where the route is cut, which violates the safety of train traffic.

As can be seen from (2), the minimum interval from the active point to the place of the entrance traffic light must be at least the aggregate of the response time of the driver or train device of the automatic driving system, and the time of data transmission over the radio channel and the passage of the train of the corresponding stopping distance or braking time:

$$T_u(S_0) = F_{min} + T_s[S_{br}(V_{max})] + T_d \quad (2)$$

The length between the active point and the obstruction light at crossings is determined using the formula (3).

$$S_0 - S_2 = S_{br}(V_{max}) + S_{lpts}(V_{max}) + L_f. \quad (3)$$

where L_f—length of the path from the crossing to the traffic light.

The minimum interval from the active point to the obstruction traffic light is determined using the formula (4).

$$T_u(S_0) = F_{min} + T_b[S_{br}(V_{max})] + T_d + T_{lprs}\left[L_f(V_{max})\right]. \quad (4)$$

3 Result and Discussion

For ensure the timely establishment of routes on the tracks and stations with mixed traffic with semi-automatic blocking with RFID, the length of the approach section must be calculated with considering the freedom of the next railway section. Mathematical modeling of the processes movement of trains on the tracks and stations, and traction calculations trains of various categories showed, In the calculations, that the times when preparing routes on mixed traffic lines can be reduced in comparison with the existing scheduled approach. In the calculations, the method of calculating the current coordinate of the train from the RFID point was used. The results obtained showed, that the anticipation of the preparation of routes should be carried out taking into account the categories of trains.

This integration RFID with axle counting on semi-automatic blocking has shown an advantage for the railway network. The ability to quickly and easily connect to the control system when approaching the railroad crossing fence allows you to accurately determine the further movements of the locomotive on mixed lines (Fig. 5). As revealed from the study and shown in the graph, for more stable operation and movement of trains on mixed lines at different speeds, the installation of an active point will reduce the time difference between the idle time of auto transport, as well as the passage of trains along the section and stations in a mixed type of traffic on high-speed highways.

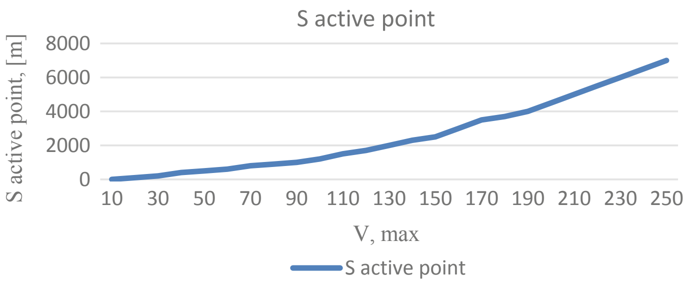

Fig. 5. The graph of the change in the position of the active point confirmation of the closure movement at crossings.

Thus, the proposed method, based on the results analysis of the operation EC system on the lines of mixed traffic, showed the optimization of the preparation of the route with semi-automatic blocking, which made it possible to reduce unproductive loss of time under the conditions of timely provision of trains with routes, possibly, if we take into account, that the section speed of the train on the section is determined by the RFID active point. In this case, the introduction of the “high-speed traffic” regime is reduced and the efficient use of the capacity of stations is achieved with the SAB system on the tracks.

4 Conclusion

The research presented in the article shows what is critical for the future development of axle counters, and RFID has the ability to easily transfer data through flexible interfaces. Research have shown that the model of application of the new system with axle counters can also find its application with radio communication channels and satellite navigation. Therefore, when working on improving methods for measuring and transmitting information, special attention is paid to such information as the length and speed of the train, heating of axle boxes, breakdowns of rolling stock, individual components of the train and infrastructure. Optimization of axle counter and RFID systems can provide complete information, from which the analysis of the data of the beginning and the end of the train became distinguishable, which in turn solves another problem of the integrity of the train entering the station, and this is related to traffic safety. Currently, research is being carried out with a new type of rail circuit system without insulating joints and an active point using RFID technology, where the determination of the location and speed of the train can bring a significant result, and raise the safety of movement of trains on the tracks to a higher level.

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Operational Control of Power Distribution Systems of Aircraft During Maintenance

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Abstract. Electrical power distribution system is one of vital components of aircraft systems which requires attention for flight safety. Practically operation of every element, unit, and modules of aircraft system is dependent on smoothly functioning of the electrical power distribution system. Therefore the most strict requirements are made to meet high stability and reliability. The article is devoted to the analysis of the problem of operational control of power distribution systems of modern aircraft during maintenance. Special attention is paid to the use of disparate, unrelated complexes for monitoring and assessing the state of power distribution systems. Based on this, the necessity of introducing into practice control procedures of an intellectual approach based on modern information technologies is substantiated. In addition, special emphasis is placed on the problems associated with the complication of controlled equipment, the features of detecting arc faults and target requirements for the efficiency of aircraft power distribution systems are also considered.

Keywords: Electrical power distribution · Control · Aircraft

1 Introduction

The power distribution system is an integral and essential component of all aircrafts. Generators or alternators are used within this system, depending on the aircraft type and specification. They are usually driven by a motor, but can also be activated by an auxiliary power unit, hydraulic motor or ram air turbine (RAT). The generator output is usually 115–120 V/400 Hz AC, 14 or 28 V DC. Electricity from a generator can be used unchanged or directed through transformers, rectifiers or inverters to change the voltage or type of current [1–3].

At the same time, it is necessary to pay attention to the fact that at present, the electrical power distribution systems (EDS) of modern aircraft are developing at a rapid pace and involve, for example, replacing traditional mechanical breaker systems with intelligently controlled solid-state switches, which are able to ensure reliability and security of a new generation of systems. In addition, certified and operated EDSs provide for the deployment of Electronic Circuit Breaker Units (ECBU) throughout the aircraft to reduce wiring stress, help detect arc faults, and replace multiple switches and other mechanical points of potential failure [4].

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In addition, in order to meet the increasing demands of consumers, new modular solutions for architectures of ± 270 V DC are actively used in practice with the possibility of a smooth transition from engine start to power generation. Manufacturers are also expanding the use of silicon carbide (SiC) material, which provides twice the power density of current technologies in order to achieve significant improvements in the efficiency and integrity of EDS.

2 Methods

It is obvious that the described innovations and breakthrough technological solutions necessitate the implementation of very stringent requirements for the reliability and safety of t EDS for both the primary and secondary levels of power distribution. There is no doubt that the architecture of the control and monitoring of EDS must be improved and have sufficient flexibility to meet the high reliability requirements of all aircraft systems, since all its constituent elements and assemblies are permanently exposed to harsh environmental conditions in terms of operating temperatures, pressures and heights.

In this context, special attention is paid to the problems of operational control of ERS and the need to solve them in the context of introduction of intelligent technologies for aircraft control through the use of new generation information and measurement systems; automation equipment operating in real time and allowing one to solve problems of controlling the aircraft electric power facilities; relay protection and emergency automation tools, as well as methods for monitoring and diagnosing the state of EDS technological equipment.

These tasks constitute an important scientific and practical problem, the solution of which is the subject of this paper.

The results of studying the issues of energy efficiency of EDS, as well as some aspects of modeling the modes of their operation are reflected in the works of domestic and foreign scientists: I.V. Zhezhelenko, P.D. Lezhnyuk, A.S. Yandulsky, V.V. Kulik, S.P. Denisyuk, Indranil Saaki, Jian Sun, et al.

Such scientists as Balan A.S., Budzko I.A., Vorotnitsky V.E., Zhelezko Yu.S., Kazantsev V.M., Levin M.S. were engaged in the problem of reducing losses in the distribution of electricity on aircraft of various types.

The analysis of the composition and purpose of the onboard equipment used to control EDS, carried out by Tashakor, Nima, Wang, Xinying, Hsu, Brian, Jiang, Jun, indicates that their effective use largely depends on the functionality of automated control systems and their effective load in the form of, as a rule, multifunctional test equipment.

However, despite a significant amount of research in the field of designing systems for the onboard generation and distribution of electricity, special scientific works devoted to the generalization of experience and highlighting the features of the use of modern control devices that would contain certain technical requirements are not enough today. In addition, the versatility of the tasks of monitoring and diagnosing the state of EDS causes fundamental difficulties in formalizing the goals and criteria for assessing the effectiveness of control and measuring procedures.

Thus, taking into account the above, the purpose of the paper is to analyze the problems of operational control of the power distribution systems of modern aircraft in the process of maintenance, as well as to substantiate promising ways to solve them.

The study of the current situation with the operational control of EDS allows us to state that in most cases, the approach used in practice comes down to diagnosing individual power electrical equipment or to the introduction of disparate monitoring systems for electrical, measuring and protective devices. This situation, according to the author, causes the emergence of a general, global problem of the implementation of control procedures for EDS, which does not allow ensuring high requirements for the reliability of diagnostic information. The essence of this problem lies in the fact that the use of disparate systems, as a rule, leads to insufficient information from primary sensors and an unreasonable rise in the cost of the diagnostic system as a whole due to the need to duplicate control data and their measurement means.

It seems that it is possible to solve this problem through the use of an intelligent monitoring and diagnostics system for EDS, which allows for a reliable, process-based and multidimensional assessment of the technical condition of equipment using new methods and evaluation criteria that increase the efficiency and quality of the organization of maintenance and repair of electrical equipment.

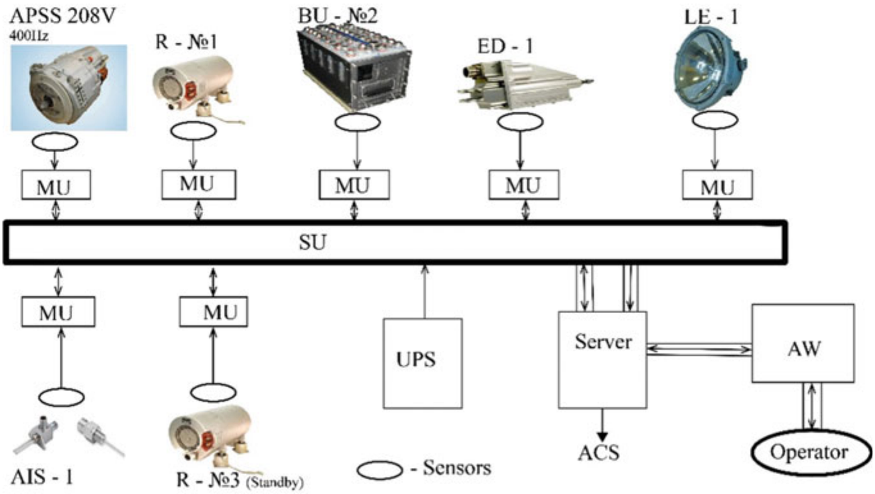
Longstanding experience in the field of continuous diagnostics, which is used by leading operating organizations and manufacturers of electrical equipment, indicates that an integrated approach to monitoring and control allows obtaining the following advantages [5]:

- eliminating duplication of primary sensors and, accordingly, reducing their total number by about 40%;
- reducing the total number of input channels of secondary measuring instruments by about 30–50%;
- increasing the reliability of diagnostics by using additional information received from other subsystems;
- increasing the convenience and efficiency of diagnostics due to the possibility of using a single server with an integrated software shell for issuing information to personnel with the possibility of integrating it into the repair and maintenance planning systems of the upper level (Fig. 1).

At the next stage of the study, we will consider in more detail the specific problems of operational control of the aircraft EDS.

One of the problems in the implementation of operational diagnostics and assessment of the state of EDS is associated with the fact that modern voltage regulators have become technologically and programmatically much more complex and, accordingly, more sensitive, which leads to the fact that they tend to generate false signals and readings. These semiconductor controllers, along with warning systems in the cockpit and aircraft mechanics, provide, on the one hand, faster, but on the other hand, not necessarily high-quality and reliable information.

To correct the failures of the voltage regulator, it is advisable to check its input and output voltage. The input voltage should be approximately the same as the bus voltage. A drop of more than 0.5 V indicates a problem in front of the regulator. If the drop



MU – monitoring unit;
APSS - aircraft power supply system;
R – rectifier;
BU – battery unit;
ED – electric drives;
LE – lighting equipment;
AIS – anti-icing systems;
UPS – uninterrupted power supply
ACS – automatic power distribution control system
AW – automated workstation
SU – switching unit

Fig. 1. Block diagram of the integrated system of continuous monitoring of the aircraft EDS.

between the input and output of the regulator exceeds 1.5 V, it is possible to assume that the regulator has a grounding problem or an internal malfunction.

3 Results and Discussion

Special attention should be paid to identifying, detecting, monitoring and, accordingly, timely response to arc faults, as well as mitigating their consequences.

Traditional control methods based on mechanical switches of one form or another, which are equipped with an overcurrent shutdown function, have unconditionally high performance and reliability. However, even with design features that allow minimization of breaking time, it can last from 30 to 50 ms at high currents, which is actually an unacceptably long period of time when an arc fault can cause serious failure of systems, assemblies and components of the aircraft.

More progressive and modern control systems use arcless semiconductor switching or arcless hybrid switching to mitigate these problems. Instead of opening the gap between the contacts, a solid-state switch uses transistors to regulate the current. This breaking can happen very quickly—in just microseconds—minimizing damage from large arc faults.

However, solid state switching for faster elimination of the arc has several significant disadvantages:

First, the cost. High-performance transistors are quite expensive, especially modern high-temperature, low on-resistance crystals made of silicon carbide. Besides, at least hi-tech electronics are required to apply bias voltage and drive the gate. These factors add up to the initial cost of a solid-state device over a comparable electromechanical device.

Secondly, the on and off resistance of solid-state devices is inferior to electromechanical ones. Connecting more transistors in parallel will improve the on-resistance, but decrease the off-resistance (increasing leakage). On- resistance and switching losses can be significant; they also require external cooling to prevent the transistors from reaching their maximum junction temperatures (Tj,max). Transistors operating near or above Tj,max are likely to fail. The generated heat must be efficiently dissipated, which requires the use of expensive packaging materials, and this further increases costs.

According to the author, an effective solution to these problems can be electronic circuit breakers, which have a unique ability to be conveniently located throughout the aircraft. These switches are smaller and lighter than their traditional counterparts and create a more evenly distributed system. This distributed system allows fewer wires to be used throughout the aircraft and also assists in arc fault detection, replacement of many switches, relays, controllers and contactors.

The advantages of electronic circuit breakers in the performance/reliability context are as follows:

- increase in the reliability of EDS up to 20 times in comparison with traditional circuit breakers;
- certification and experience of use in many power systems;
- data on current and voltage are reported automatically [6].

In terms of size and weight advantages, they allow for an overall reduction in wire weight of 30%, and also reduce the weight and volume of the wire.

In addition, each electronic circuit breaker has both I2t protection and fast response function to prevent nuisance tripping, as well as environmental qualification (RTCA/DO-160E) and software qualification (RTCA/DO-178A). Special emphasis should be placed on the fact that the intelligent system of these switches integrates and automates control functions with fewer panels, which significantly reduces the workload of the pilots.

Summing up, we note that, taking into account the above complexities and problems, both general and specific ones, as well as the fact that EDS will only get more complicated over time, in order to improve and optimize the operational control of their functioning, it is advisable to use adaptive EDS diagnostics and control systems, demonstrating high efficiency in conditions when the model of the object of diagnostics and control is set "inaccurately" and the operating conditions are not fully maintained [7].

In this case, the target requirements for the indicator of technical efficiency of EDS—$TE = \{C_\Sigma(t), K_\Gamma(t), W(t)\}$ can be expressed using predicates:

$$\begin{gathered} \Theta_{K_G} = \left\{K_\mathrm{G}(t_n) \geq \widehat{K}_\mathrm{G}\right\} \\ \Theta_w = \left\{W(t_n) \geq \widehat{W}\right\} \\ \Theta_C = \{C_\Sigma(t_n)/t_n \leq (1 - a_n)C_\Sigma(t_{n-1})/t_{n-1}\} \end{gathered} \tag{1}$$

where, 0 < a_n < 1.

where TE—technical efficiency;

C_Σ—total costs for control, diagnostics, forecasting, management, maintenance and repair of EDS;

K—coefficient characterizing the reliability of EDS during operation;

W(t)—determines the degree of effectiveness of the use of EDS for its intended purpose when using various control algorithms for its operation modes.

The functional characterizing the value of the EDS efficiency (reliability, power-to-weight ratio, etc.), which depends on the chosen strategy of operational control and management of the operating modes of electrical equipment $\sigma = \{f_1, f_1, \ldots, f_n\}$, can be represented as follows:

$$R_n = \frac{1}{n}\sum_{k=1}^{n} \chi_k \tag{2}$$

where χ_k—predicate truth indicator.

The functional for assessing the efficiency of EDS R_n is a convolution of the vector criterion TE, which characterizes the technical and economic efficiency of the functioning of the monitoring and diagnostic circuit. The control strategy σopt will be optimal if it provides a maximum of the lower boundary during the continuous operation of EDS:

$$\rho = sup \lim_{\sigma \in \Sigma n \to \infty} R_n(\sigma) \tag{3}$$

This limit exists due to the limited value $0 \leq R_n \leq 1$, which depends on the rated power of the aircraft power supply system, its technical condition, the influence of external and internal disturbances. The value of ρ characterizes the guaranteed possibility of meeting the target requirements in the case of an unlimited duration of operation. The resulting criterion is a generalized criterion for optimal control over the EDS operating modes, depending on its current technical state.

4 Conclusion

Thus, summarizing the above, we note that the problems of operational control of the power distribution systems of modern aircraft during maintenance are associated with automation, complication, increased requirements and power of aircraft electrical power supply systems. These problems will be resolved by the introduction of intelligent systems for diagnostics, monitoring and assessment, which will allow a comprehensive approach to the monitoring and control system, excluding duplication of information, using parallel control sensors and, accordingly, reducing the cost of the system as a whole.

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Selenium Compounds in the Waste Water

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Abstract. The article discusses the importance of ensuring chemical safety when using selenium compounds in the implementation of environmental safety in the framework of ensuring a general safety culture. The analysis of literary sources for an extensive period of time is carried out. The field of application of selenium in industry and its main properties are indicated. Information about the danger of selenium for human physiology and the consequences of selenium poisoning is given. The issues related to the analysis of selenium content in waters, soil and atmosphere are considered as elements of environmental monitoring. It is noted that in most cases analysts are dealing with very low selenium concentrations. It is indicated that various valence forms of selenium have different toxicities, and therefore it is proposed to use methods for determining the MPC level of selenium in one form or another in a given analyzed medium. Analyzed electrochemical methods for the determination of selenium and some organoselenium substances in natural objects. The features of anodic stripping voltammetry on a gold-graphite electrode as the most promising method for detecting selenium are considered. It was revealed that ensuring chemical safety in the framework of digitalization and the implementation of the concept of a culture of safety in transport is an important task.

Keywords: Machines and mechanisms of chemical protection · Labor protection · Transport industry · Selenium · Cyclic voltammetry · Environmental friendliness · Electrochemical methods of analysis · Sustainable development

1 Introduction

Modernization of existing and development of new technologies for wastewater treatment contributes to the solution of an urgent problem—better processing of industrial waste and reduction of environmental damage caused by industrial waste.

Optimization of production processes at enterprises can provide a significant reduction in the cost of basic products. This is due to the fact that the production shops of enterprises are the main consumers of energy resources, including fresh water. They are also responsible for wastewater treatment.

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Wastewater treatment of enterprises is a topical environmental problem in industry.

The field of application of organoselenium heterocycles is multifaceted and the prospect of their use as drugs, radioprotectors, components of optical recording means, photographic elements, photographic materials, initiators of photo-polymerization, electrophotography, photoconductive materials in measuring technology, materials for fast-reacting passive laser gates is very interesting [1].

The importance of studying the electrochemical determination of selenium-containing heterocycles and elemental selenium is due to the fact that selenium is a biologically active element that is part of most hormones and enzymes and enhances lipid peroxidation, the improper development of which threatens gross irreversible damage to cell membranes.

Selenium deficiency in the diet inevitably causes functional disorders associated with selenium deficiency, is the cause of more than 20 serious diseases: exudative diathesis, toxic dystrophy, diabetes, Graves' disease, ulcerative colitis, cataracts [2], cancer [3].

In work [3], the anti-staphylococcal and antifungal effects of the most active 4-H-selenopyrans and selenopyrilium chloride on clinical strains were found.

In China, along with areas with endemic selenium deficiency, there are areas with a high selenium content, which has a pronounced toxic effect [4], since small amounts of selenium and its derivatives cause irritation of the respiratory tract, lingering runny nose and headaches, and skin rash.

2 Materials and Methods

The most poisonous are hydrogen selenide, selenium dioxide, selenium halides and selenium compounds with heavy elements.

In cases where selenium dioxide poisoning occurs, finger cramps are observed, and sometimes general body cramps. Acute selenium poisoning is caused by its content in the air in concentrations of a few hundredths of a milligram per liter. The permissible concentration of selenium dioxide should not exceed 0.0003 mg/l.

Selenium is a toxic element, the determination of which in various objects is of considerable interest and a known difficulty.

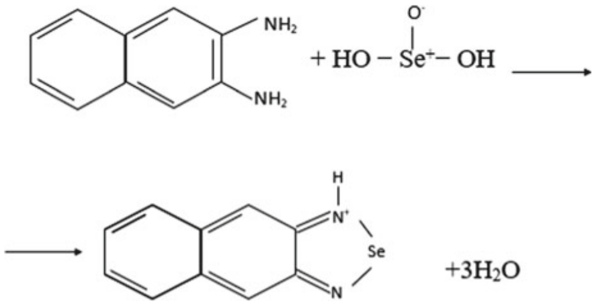
Many ecological problems cannot be solved without reliable data on the qualitative and quantitative analysis of soils, fertilizers, natural and waste waters, and air for selenium content.

In most cases, analysts are dealing with very low selenium concentrations. So, for example, in soils, selenium is present in ultramicro quantities (ranging from 10^{-8} to 10^{-3}%). With its high chemical activity, selenium forms more than 170 known solid compounds, 3 liquid (Se_2Cl_2, SeF_4, CSe_2) and 2 gaseous (H_2Se, SeF_6). The bulk of solid selenides are intermetallic compounds. There are also many organic selenium compounds, and their nomenclature is expanding from year to year. Various methods of analysis are used from all currently available groups. Spectroscopic methods based on the interaction of selenium or its compounds with electromagnetic radiation include:

- photometry or fluorimetry of selenium complexes with 3,3 '-diamino-benzidine, o-phenylenediamine, as well as measurement of the color of colloidal solutions of selenium [5];

- methods of luminescence, promising for the determination of trace elements and organic substances.
- From chromatographic methods based on sorption processes:
- partition chromatography on paper or thin layer, used for the separation and identification of selenium;
- gas–liquid chromatography as the most promising method for the analysis of complex mixtures of organic compounds.

From the known methods for the determination of selenium, the most convenient and sensitive is the fluorometric method using 2,3-diaminonaphthalene (DAN). The detection limit for selenium using this method is $8 * 10^{-10} - 1 * 10^{-8}\%$. The fluorometric method includes three main stages: wet combustion of samples with an oxidizing mixture (nitric and perchloric acids) at high temperatures, reduction of Se (VI) to Se (IV) with hydrochloric acid upon heating, and condensation of selenous acid with DAN as a result which produces 4,5-pyazselenol, the fluorescence intensity of which is proportional to the selenium concentration in the sample. The reaction between 2,3-diaminonaphthalene and selenous acid in an acidic medium can be represented by the equation:



The maximum reaction rate is observed at pH from 1 to 2. Studies show that the formed selenodiazole complex fluoresces (λ max 525 nm) at an excitation wavelength of 364 nm.

This method is used to determine selenium in water, in biological materials, in blood plasma and serum, in food products and in other objects.

Due to the different toxicity of certain valence forms of selenium, the solution to the problem involves the use of methods that provide the possibility of determining at the MPC level of selenium in one form or another in a given analyzed medium. These tasks are key for the use of electrochemical methods of analysis. The advantages of electrochemical methods over others include the following:

- Wide ranges of determined concentrations—from tens to $n.10^{-8}\%$, correctness and high reproducibility of the results (the relative standard deviation of the results of the analysis of solutions of low concentrations in most cases is less than 0.3).
- The ability to carry out multi-element analysis, in contrast, for example, to traditional methods of absorption spectroscopy. The separation of most interfering components

in electrochemical methods is also usually not required. Essential for practical application is the simplicity of the hardware and methodological design and the low cost of the analysis.

In most cases, the analysis does not require the concentration of the determined elements, since the minimum determined concentrations are often at the MPC level and below, the separation of most interfering components in electrochemical methods is also usually not required.

Electrochemical methods are technologically advanced, relatively easily adaptable to changing conditions: very often the transition to the determination of another element is reduced only to a change in the composition of the background electrolyte, electrode or potential.

Let us consider the possibility of using these methods, based on the behavior of substances at the electrodes and in the near-electrode space, for the detection of trace amounts of selenium.

With regard to this element, these are, first of all:

- direct potentiometry;
- potentiometric titration;
- voltametric methods of analysis.

A simple express method of potentiometric titration of selenium (IV) ions with a solution of 2-mercaptobenzoic acid with an indicator platinum electrode [6] is described, the determination error was 0.01–0.018%.

In 1999, a new membrane ion-selective electrode sensitive to selenite ions was proposed [7]. The membrane included a selenium complex with 1,2-phenylenediamine as an electrode-active substance, polyvinyl chloride as a membrane matrix, and dibutyl phthalate as a plasticizer. At the same time, a new ion-selective electrode with a solid membrane containing AgSe and Cu2Se (Fig. 1) was proposed. The concentration range of the linear response extends from 10–5 to 10–2 mol/L, the slope is 28 mV per order of concentration. The method of restorative inversion chronopotentiometry with a flow-through system [8] has been successfully applied in the determination of selenium in biological materials. In voltammetry, various adsorption, catalytic and other effects are often used that accompany or precede electrode processes.

Stripping voltammetry is applicable to the determination of extremely low concentrations, down to n 10^{-11} mol/l.

For example, an inversion voltametric method for determining selenite ions in aqueous solutions has been proposed [9]. By the method of anodic IV after concentrating selenium on a gold electrode at an accumulation potential of—0.4 V, its concentration was determined at the level of 5–100 mg/ml.

The possibility of using a DC IV with a cathodic potential sweep to determine the content of selenium (IV) in the presence of 1,3-diaminonaphthalene in a dilute hydrochloric acid medium has been revealed. It is known [10] that selenium is deposited on an indifferent electrode only in the presence of other depolarizers (Cu, Pd, Pb, Bi, Ag).

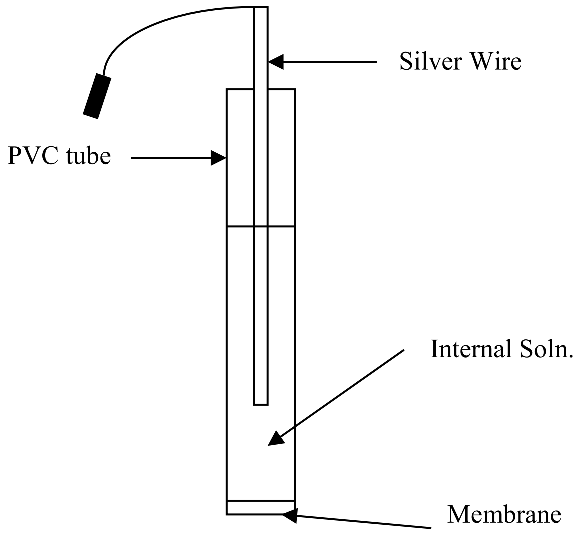


Fig. 1. Membrane electrode.

In many works on the use of stripping voltammetry for the determination of selenium, it is associated with the use of a stationary mercury electrode of the "hanging drop" type [11–13]. It follows from these works that selenium accumulates on a stationary mercury electrode in the form of HgSe (or selenides of other metals, if they are specially introduced into the solution). The precipitates, as a rule, are dissolved during the cathodic potential sweep, as a result of which the selenides are reduced, for example, according to the reaction:

$$HgSe + 2\,H^+ + 2\,e- = H_2Se + Hg$$

The method of adsorption cathodic IV was used to determine selenium in seawater [14]. With the help of cyclic voltammetry, it was found that in the stage of preliminary accumulation, Cu2Se adsorption occurs on the surface of the mercury electrode. The optimal conditions for determination are pH = 1.6 and the concentration of copper (II) 40 μmol/l. To eliminate the interfering effect of organic natural surfactants, the sample is irradiated with a UV lamp. With such irradiation and pH = 8, selenium (VI) is reduced to electrochemically active Se (IV). It was found that the determination of selenium by this method does not interfere (nanomolar): Mo (VI), Ba 500; As (III) 250; Ni, Zn, V (V), Al 200; Zr, Sb, U (VI), W (VI), Gr (VI) 100; Co, Ge 50; Pb, Zn, Bi 10; Fe (III) and Sn (IV)−1000.

On a stationary mercury electrode modified with iron (III), the determination of selenium (IV) in solid natural objects was rather efficiently carried out by the methods of cathodic constant-current and differential-pulse IV [15]. The presence of copper or ruthenium increases the sensitivity of the analysis. It is believed that the following reaction takes place at the stage of electron accumulation:

$$H_2SeO_3 + 2\,Cu^{2+} + 4\,H^+ + 8\,e- = Cu_2Se + 3H_2O,$$

and during cathodic scanning, copper selenide is reduced:

$$Cu_2Se + 2\,H^+ + 2\,e- = H_2Se + 2\,Cu(Hg)$$

In similar works on the analysis of river waters, the minimum detectable concentration of selenium is given on the order of 0.1 μg/д [16].

An interesting method is catalytic cathodic IV in the presence of rhodium [17]. The accumulation mechanism is represented by the reaction:

$$3\,H_2SeO_3 + 2\,Rh^{3+} + 12\,H^+ + 18\,e- = Rh_2Se + 9H_2O$$

The peak observed at –0.97 V and corresponding to the reduction of rhodium selenide was 10–50 times higher than for copper and mercury selenides, and many times higher than for silver selenide. The estimate of the minimum detectable concentration of selenium is given at the level of 2.4.10–12 mol/l.

3 Results

Since the determination of total selenium does not provide sufficient information on its toxicity and bioactivity, a separate determination of selenium (IV) and selenium (VI) on the EDS is described [18], since selenium (VI) is not electrochemically active, but it can be chemically reduced to selenium (IV).

The selenium content in the atmosphere was also determined by the method of differential pulse cathodic IV under similar conditions. NGOC was 0.05 ng / ml [19].

Determination of selenium in biological samples is relevant in the light of the increased interest of medical scientists and toxicologists to the problem of selenium deficiency. A simple method for preparing biological samples for the subsequent determination of Se (IV) by differential pulse cathodic stripping voltammetry using a 40% solution of threemethylbenzylammoniummethoxide in methanol has been described [20]. One of the solutions to the problem of analyzing environmental objects is the work according to the method of cathodic differential-pulse IV [21], performed on the SRE against the background of 0.1 M HCl containing 1 mg / L of copper (II).

The overwhelming majority of works on the use of stripping voltammetry for the determination of selenium are associated with the use of a stationary mercury electrode, on which the peak of cathodic dissolution of mercury selenide serves as an analytical signal. This electrode has an obvious disadvantage due to the toxicity of mercury. Therefore, there is an increase in the number of works on the use of solid electrodes (graphite, platinum, gold, etc.).

Therefore, it is promising from the point of view of efficiency, safety, as well as rapidity and versatility to study the voltametric behavior of selenium (IV) on various solid electrodes.

Analysis of the literature data showed that the electrochemical production of organometallic compounds is used more widely than the synthesis of non-organometallic compounds [22–25].

The possibility of determining selenium in organoselenium compounds (after mineralization) using ZGE with a pre-applied film is shown on a sample of DAFS (1,5-diphenyl-3-selenium-pentanedione-1,5). DAFS is used as a feed additive for animals.

Quite satisfactory results were obtained (the purity of the preparation was checked by gas chromatography-mass spectroscopy). At the same time, it turned out that compounds of this structure (DAFS and its analogs with various substituents in the ring) are electroactive on the ZGE and, apparently, can be determined without carrying out mineralization, which requires additional research.

4 Conclusion

Ensuring chemical safety in the framework of digitalization and the implementation of the concept of a safety culture [26] in transport is an important task.

On solid electrodes, it is possible to obtain both cathodic and anodic selenium inversion signals. Analytically, anodic stripping voltammetry on a gold-graphite electrode is more convenient.

Comparison of the modes of functioning of the ZGE for the determination of selenium allows us to recommend both the one and the other method of its preparation. At the same time, the signal reproducibility in the "in situ" mode is better, but the range of linearity of the calibration curve is wider in the case of an electrode with a pre-applied gold film.

The alternating current recording mode provides significant advantages in the cathodic version on a mercury film electrode. In the anodic voltammetry of selenium on the ZGE, its use does not lead to a gain in sensitivity.

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Analysis of the Technological Efficiency of Soybean Production in the Russian Federation

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Abstract. The article presents the results of the rating assessment of the technological efficiency of soybean production in the context of the subjects of the Russian Federation, which are in the top 10 in terms of soybean production over the past five years. For the purpose of designing the level of possible innovative and technological development, a model was developed and implemented in the Excel spreadsheet environment, with the help of which the projected increase in technological efficiency was calculated due to the introduction of innovative technologies for the technological and technical development of soybean production. The implementation of measures aimed at introducing innovative approaches to soybean production, and as a result, achieving the projected technological efficiency index, will ensure the projected increase in yield. At the same time, in general, the policy of the regions aimed at innovative and technological development of agricultural production will allow, all other things being equal, in relation to 2020, to obtain an additional volume of gross soybean harvest in all regions that are in the top 10 in the total volume of 437.2 thousand tons.

Keywords: Innovation · Technological development · Efficiency · Rating assessment · Project forecast · Soy production · Russian Federation

1 Introduction

Efficiency is a complex economic category that reflects the interaction of natural, organizational, economic and social conditions of the functioning of a business entity. The problem of efficiency is very complex, since it should reflect the effectiveness of the diverse activities of people in the process of their production of material goods [1].

In economic science, the concept of «Production efficiency» appeared in the late 20 s of the twentieth century. The formation of the theory of the efficiency of social production took place simultaneously with the formation of the theory of the effectiveness of capital investments [2]. One of the first to try to solve the problem was engineering, technical and financial workers. This is due to the fact that the problem is at the knocking of many sciences.

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Modern scientists are of the opinion that when studying the efficiency of agricultural production, it is necessary to proceed from the understanding that it is a complex multi-purpose open system consisting of functional and organizational subsystems. In turn, one of the functional subsystems is the technological subsystem, the result of which is expressed through technological efficiency.

To manage the effective technical and economic development of production systems, it is necessary to additionally include in the system of balanced indicators the coefficient of the level of technological efficiency of production and the investment and innovation lever [3].

The definition of the essence and content of technological effectiveness is the subject of research by many economists.

Specialists of the Higher School of Economics give the following definition of technological efficiency: «technological efficiency is a characteristic of production that determines in physical terms the optimal (best of all possible) combination of production factors used for the production of a certain given level of output» [4].

In the encyclopedia of economics, technological efficiency is defined as a method of production in which the maximum possible output of products is achieved with a minimum amount of attracted production resources [5].

As noted by Rezinkov et al. Smykov, technological efficiency reflects the degree of resource use in the production process and characterizes the level of development of a scientifically based system of agricultural production, while operating with natural indicators [6].

According to scientists of the All-Russian Institute of Agricultural Economics, technological efficiency characterizes the use of production resources (performance of work, provision of services) and is widely used to assess the process of production, processing, transportation and storage of agricultural products and food. At the same time, it is noted that to assess the efficiency of the crop industry as a whole, the indicator of gross output in current and comparable prices is used. The main indicator of technological efficiency in crop production is the crop yield per unit area. Technological efficiency reflects the degree of development of agricultural systems and is determined by comparing the actual data with the corresponding normative indicators, which use the level of production corresponding to the rational level of intensity for average weather conditions [7].

The methodological approach to assessing the technological efficiency of the placement of agricultural crops in the territories within the region involves calculating the Technological Efficiency Index (TEI) by dividing the yield of this crop in a certain area of the region in relation to the average yield of this crop in the region [8].

To assess the effectiveness of agricultural enterprises at the level of the country, region, agricultural area in modern conditions, the rating evaluation mechanism is increasingly used. Ratings are currently an important provider of business information in all areas of life. The use of the rating assessment methodology of agricultural enterprises makes it possible to assess the competitive position of enterprises in the market, to choose the most relevant investment mechanisms [9].

In order to determine the level of technological development of soybean production in the Russian Federation, it is proposed to conduct a rating assessment of technological efficiency using the methodological approach of calculating the Technological Efficiency Index for the main cultivated crops in the country.

2 Materials and Methods

The dynamics of the level of technological development of soybean production in Russia was studied using officially published statistical indicators. The empirical basis of the study was the data of the Federal State Statistics Service of the Russian Federation. In the course of the research, a set of scientific research methods was used: statistical, comparison method, rating evaluation method, growth rate analysis.

3 Results

In the Russian Federation, the main soybean production is concentrated in two federal districts—the Central Federal District and the Far Eastern Federal District. The share of these federal districts in total production as of 2020 was 47.4% and 33.3%, respectively (Fig. 1).

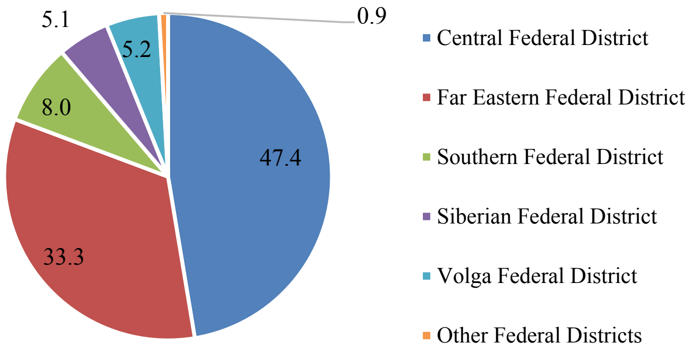

Fig. 1. The share of federal districts in the total soybean production of the Russian Federation in 2020, %.

For more than a decade, the largest number of soybean acreage in the structure of the total acreage of the Russian Federation has been located on the territory of the Far Eastern Federal District. As of 2020, the region's share was 43.5% (Fig. 2).

The Amur Region traditionally leads the top-10 regions of the Russian Federation in soybean production, with an indicator of 23% of the total soybean production in the country. From the Far Eastern Federal District, with a participation share of 7.9% of the total soybean production, Primorsky Krai entered the top-10 in the overall rating of regions, it occupies the 4th place.

It is noted that 6 subjects included in the top-10 soybean producers in the Russian Federation are part of the Central Federal District, which allowed in 2020, taking into account the total production volume, to bring this district to the first place with a specific weight in the total production volume of 47.4% (Fig. 3).

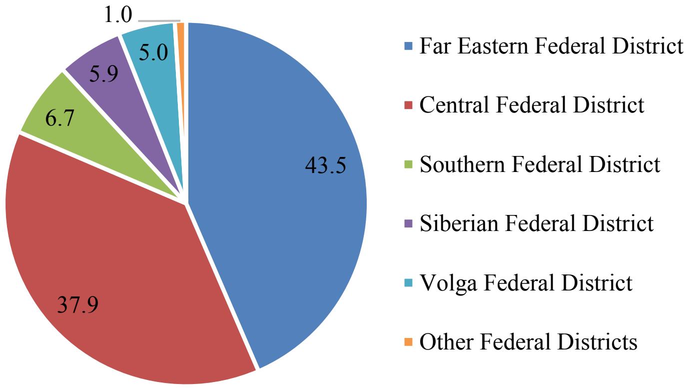

Fig. 2. Structure of soybean acreage by federal districts of the Russian Federation as of 2020, %.

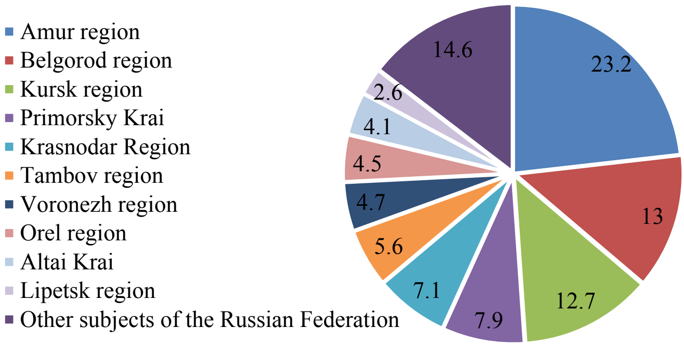

Fig. 3. The share of the Russian Federation's top-10 regions in total soybean production, %.

The rating assessment of the technological efficiency of soybean production was carried out in the context of the subjects of the Russian Federation that are in the top 10 in terms of soybean production over the past five years. At the same time, the TEI for each subject is calculated from 2016 to 2020, taking into account the regional characteristics of cultivation (Table 1). The analysis revealed that the Belgorod region has been the leader for the last 3 years. During the analyzed period, the region rose from 3rd to 1st place, which indicates a high level of technical and technological development of the region.

For the purpose of rating the level of technological development of the regions for the analyzed period, the weighted average TEI of soybean production for 2016–2020 was calculated (Table 2).

The top-5 leaders in terms of technological development are: the Belgorod Region, the Kursk Region, the Krasnodar Territory, the Altai Territory, and the Primorsky Territory.

At the same time, the data obtained on the current state of technological efficiency of soybean production indicate that there is a reserve for increasing production in the

Table 1. Rating assessment of technological efficiency of the subjects of the Russian Federation included in the top-10 in total soybean production.

Subjects Russian Federation	2016 year		2017 year		2018 year		2019 year		2020 year	
	TEI	Rating	TEI	Rating	TEI	Rating	TEI	Rating	TEI	Rating
Russian Federation	1		1		1		1		1	
Amur region	0.9823	6	1.0153	5	1.0000	6	1.0476	4	1.0000	6
Belgorod region	1.1393	3	1.0608	4	1.2713	1	1.0990	1	1.1330	1
Kursk region	1.0796	4	1.1486	2	1.1117	3	1.0833	2	1.1064	3
Primorsky Krai	1.1504	2	1.0153	5	1.0635	4	1.0476	4	1.1069	2
Krasnodar Region	1.0404	5	1.2357	1	1.1864	2	1.0168	6	1.0272	4
Tambov region	0.8507	8	0.9527	7	0.8404	8	0.9375	7	0.9255	9
Voronezh region	0.7413	10	0.8446	10	0.8777	7	0.9375	7	0.6862	10
Orel region	0.9055	7	0.9189	8	0.8404	8	0.8698	10	0.9894	7
Altai Krai	1.1656	1	1.0942	3	1.0472	5	1.0804	3	1.0077	5
Lipetsk region	0.8458	9	0.8919	9	0.7287	10	0.8750	9	0.9309	8

top-10 regions due to the introduction of innovative technologies for technological and technical development of agriculture (Table 3).

In order to design the possible technological development of the top-10 regions, a model was developed and implemented in the Excel spreadsheet environment, which was used to calculate the projected growth in technological efficiency in relation to 2020.

The analysis showed that in relation to the leading region, there is a potential for TEI growth in the Voronezh Region by 0.44 points, in the Tambov and Lipetsk regions by 0.2 points, in the Orel Region by 0.14 points, in the Amur Region by 0.13 points, in the Altai Territory by 0.12 points, in the Krasnodar Territory by 0.11 points, in the Primorsky Territory and the Kursk Region by 0.02 points.

The implementation of measures aimed at introducing innovative approaches to agriculture, and as a result, achieving the projected TEI, will ensure the projected increase in yield from 1.72 to 2.77 c/ha.

In general, the policy of the regions aimed at the technological development of agricultural production will allow, all other things being equal, in relation to 2020, to

Table 2. Rating assessment of the technological efficiency of soybean production according to the weighted average ITE for the period from 2016 to 2020.

Subjects Russian Federation	Total TEI for 2016–2020	Weighted average TEI for 2016–2020	Weighted average TEI rating for 2016–2020
Amur region	5.04519	1.00904	6
Belgorod region	5.70333	1.14067	1
Kursk region	5.52967	1.10593	2
Primorsky Krai	5.38369	1.07674	5
Krasnodar Region	5.50645	1.10129	3
Tambov region	4.50691	0.90138	8
Voronezh region	4.08722	0.81744	10
Orel region	4.52397	0.90479	7
Altai Krai	5.39499	1.07900	4
Lipetsk region	4.27224	0.85445	9

Table 3. Projected assessment of the technological efficiency of soybean production in the top-10 regions in relation to the level of 2020.

Subjects Russian Federation	Projected growth TEI	Projected yield growth	Projected increase in gross revenue
Amur region	0.1330	1.74	147.3
Kursk region	0.0266	2.77	72.9
Primorsky Krai	0.0261	1.93	53.4
Krasnodar Region	0.1058	2.51	41.3
Tambov region	0.2074	2.31	32.0
Voronezh region	0.4468	1.72	26.9
Orel region	0.1436	2.47	25.6
Altai Krai	0.1253	1.74	22.9
Lipetsk region	0.2021	2.33	15.0

obtain an additional volume of the gross soybean harvest of all regions in the top 10 in the total volume of 437.2 thousand tons.

4 Discussion

The problem of protein deficiency in the Russian Federation is becoming more and more urgent and requires urgent measures to solve it. World experience shows that this problem can be solved by increasing the gross production of crops with a high content of protein and fat—legumes, rapeseed, sunflower. Among them, the first place in the world in terms of gross production is occupied by soybeans [10].

Thousands of dishes are made from soybeans and products based on them in the cuisine of various countries of the world, and in eastern countries soy has been one of the main food products for more than one thousand years. The Western community belatedly in more than one hundred years and only after numerous and long-term scientific research, at the end of the twentieth century, recognized the key role of soy in improving the quality and longevity of life and assigned soy products a special status—the so-called "health point". According to the 1999 FDA recommendation, the gist of this status is that "25 g of soy protein per day, as part of a low-fat, low-cholesterol diet, lowers the risk of cardiovascular disease." That is, every person has the opportunity to protect themselves from heart attack and stroke in such a simple way—by introducing soy products in a certain amount into their diet (replacing about a third of the protein consumed with soy) [11].

At the same time, Russian soy is the best soy in the world, because it is not genetically modified, natural, and there is practically no such soy anywhere in the world except Russia [12]. This indicates the need and special relevance of the development and implementation of additional innovative solutions aimed at increasing the level of technological efficiency of soybean production in the constituent entities of the Russian Federation.

5 Conclusions

Thus, the conducted studies of the technological efficiency of soybean production revealed the potential for the development of Russian soybean production by means of implementing the directions of innovative technological and technical development.

In modern conditions, the development of agriculture is determined by the level of introduction of innovative technologies and the efficiency of production. Any innovation in agriculture is highly dependent on the climatic conditions of the regions, and this applies both to the cost of the innovation process and the timing of its implementation—therefore, investments in innovative projects in the agricultural sector are more risky than in other sectors of the economy. To date, experts consider the most potentially effective innovations to be those that can be implemented in various areas of agriculture in the short and medium term [13]. Among them, there are innovations that have prospects for implementation in the Russian soybean industry, including: bioinsecticides and pollinators; precision seeding technologies; Craft Scanner sensors for monitoring the depth of tillage.

The introduction of innovative projects, including public–private partnership projects [14], should become a priority for the development of Russian soybean production in the near and medium term, which will increase the ITE, save material, financial and human resources, and increase the volume of exports and domestic consumption.

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Intellectualization of Logistic Interaction of Economic Entities of Transport and Logistics Chains

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Abstract. Based on a critical analysis of existing approaches to organization and functioning of transport and logistics chains, the aim of the study was formulated: to develop a new concept of transportation process management, taking into account market nature of labour, organization, high uncertainty and noisy input data for modeling and decision-making, subjectivity in assessing the capabilities of economic entities and results of their activities. The concept is based on two key aspects: intellectualization and digitalization of the interaction of economic entities of transport and logistics chains, implemented on the basis of specially created digital platform. Three methods of intellectualization of the synthesized system are defined and commented on. Tools (models, algorithm) have been developed to coordinate the interests of economic entities of the same and different levels of the system management, ensuring the development of a new corporate culture of interaction between participants in the transportation process. The choice of the type has been made and the logic of the functioning of the digital platform containing the digital twin of the transport and logistics chain and the decision-making block has been developed. Conditions and problems of the system development are analyzed, the resulting economic, production and organizational effects are justified.

Keywords: Transport and logistics chains · Intellectualization of logistic interaction of economic entities · Queuing theory · Theory of active systems · Expert analysis · Neuro-fuzzy modeling · Superintelligence · Digital platforms

1 Introduction

Logistics interaction of economic entities (EE) is carried out within the framework of transport and logistics chains (TLC), synthesized for freight transportation. A typical example of the complex interaction of such TLCs is the transport system of the South of Russia (TSSR) that combines the activities of various types of transport in the Southern region of Russia in conditions of unstable development of transport services market [1].

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The main problems of TSSR include: disproportions in the rate and scale of development between modes of transport; low technical level and unsatisfactory state of the production base; exhaustion of the capacity of a significant part of railway lines and federal highways; suboptimal network configuration; uneven development of ports and related infrastructure; low safety of transport activity that negatively affects the competitiveness of TSSR in the global transport services market [1].

Recently, various studies have been carried out aimed at solving some of the above problems [2, 3].

2 Materials and Methods

The traditional approach of TLC management is based on modeling such interaction by means of queuing theory (QT) [4]. In this case, the entire process of freight delivery is divided into a set of separate operations performed by so-called service channels connected to each other in series and/or in parallel. The basic parameters of the channels are the intensities of the input λ and output μ flows. On their basis other parameters of the system are calculated: the average service time of the request (loading and unloading of the wagon; diagnostics of the car, uncoupling, and train set; train uncoupling and coupling, etc.), the waiting time of the request in the queue, the queue length, the system exchange rate (channel capacity resource), etc.

As an example, Fig. 1 shows a fragment of such a division in a certain TLC, containing a sequential connection of three links: wagons loading, trains set, trains moving along the section. At the same time in link 2 parallel service is carried out by several channels (the sorting system simultaneously forms several—n trains).

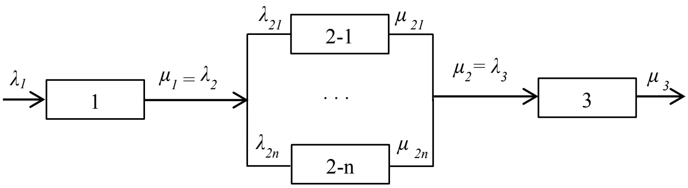

Fig. 1. Fragment of TLC.

The successful application of this mathematical apparatus depends significantly on the fulfillment of the basic conditions of the method. As a rule, the simplest (Poisson) flows are used as models of input and output flows of channels [4]. They have the following properties: ordinariness (simultaneous appearance of requests is excluded), absence of aftereffect (the probabilities of the appearance of requests at different times are independent of one another), stationarity (the statistical parameters of channels and the system as a whole do not depend on time). Obviously, this approach has a number of significant drawbacks:

1. It is focused on the systemic organization of labour (assumes the presence of strict ties between economic entities (EE), the unconditional fulfillment of their tasks, the

absence of their own goals and interests). This approach does not take into account the market nature of the development of transport complexes at the present stage. Decisions are made at the Center and the possibilities of the EE in this regard are limited. But in reality, TLCs are formed with the participation of EE of various departmental identity, with different forms of ownership, with different resources and goals. That is, they are formed under conditions of multi-agent transport and technological processes. This actualizes the task of coordinating the interests of the EE of one (stations, ports, storage systems, etc.) and different levels of management (for example, JSC Russian Railways (or regional authorities) and EE TLC).

2. The conditions for the input and output flows are not met. Indeed, several trains can be simultaneously ready for sorting on the hump (departure to the site) (the condition of ordinariness is violated), the parameters of the transport process significantly depend on the days of the week, the time of the year, sanctions, economic crises (there is no stationarity), delays in the TLC at some point increase its density in the following moments (aftereffect is present in the system). In this regard, QT can be used for limited time periods, ensuring by its smallness the stationarity of the processes under the study using approximate models (real traffic flows are approximated by the simplest flows).
3. It requires knowledge of the parameters of the production process (the totality of λ and μ) at all its stages. This is a difficult task taking into account the independence of the EE. On request, this data may be distorted to meet the interests of production.
4. The QT tools take into account only the production indicators of the process under the study: processing capacity of links, time characteristics. In this case, the socio-economic criteria of the process are not taken into account: the quality of freight delivery, economic indicators (profitability, revenue, …), process safety.

Considering the above it is proposed to develop a new concept for the organization of the TLC, that includes four innovative aspects:

- Development of a special mathematical tool for making coordinated decisions of the EE participating in logistic interaction.
- New principle of TLC formation based on accounting of economic indicators of TLC of EEs.
- Intellectualization of TLC activities.
- Creation of a digital platform (DP) of TLC on the basis of which the above mentioned innovations are implemented.

3 Results

1. Mathematical tools (supported by the DP) of decision-making by economic entities involved in logistics interaction should, on the one hand, take into account the private interests of individual EE, and on the other hand, ensure the interests of the transport complex as a whole. This requires the development of methods for reconciling the conflicting interests of the EEs.

The theory of active systems (TAS) [5, 6] can serve as a theoretical basis for reconciling the conflicting interests of EE of one and different levels of management. Let us consider the basic element of the procedure for coordinating the interests of two EE of two management levels: the customer and the contractor.

We assume that the contractor is characterized by variable parameters: x as the volume of products issued (services provided) and some economic indicator y (revenue, profitability, income, etc.). With an increase in x, the criterion parameter y first increases (since the resources of the EE are used more fully), but then it begins to decrease (the resource is exhausted, losses from equipment and technological process failures occur). That is, there is some value $x = x_o$ at which the function y reaches its maximum. It is shown in TAS [5] that at a point x_o the function y can be approximated with a sufficient degree of accuracy by a quadratic function (Fig. 2, curve 1):

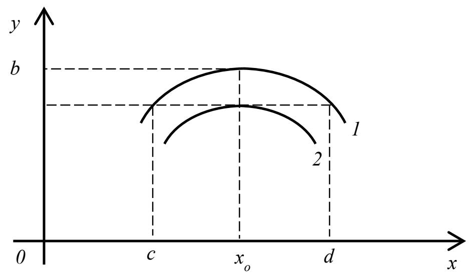

Fig. 2. Geometric illustration of the agreed decisions area formation.

$$y = a_0 + a_1 x + a_2 x^2 \text{or } y = -m(x - x_o)^2 + b \tag{1}$$

The value x_o is preferable for the contractor, but may not suit the customer. He may require either more or less quantity of products (services) x. In [6], it is proposed to introduce a penalty coefficient $0 \leq k \leq 1$, and to pay for the service according to the dependence if the plan is not fulfilled:

$$y = -m(x - x_o)^2 + kb. \tag{2}$$

In Fig. 2 this is curve 2. Then, when the plan set by the customer is fulfilled, the contractor is rewarded according to the algorithm prescribed by curve 1, and if it is not fulfilled—by curve 2. Region [c, d] in Fig. 2 is the area of agreed decisions. Indeed, if the Center establishes a plan within the segment [c, d], then it is profitable for the EE to fulfill it, since the values of the incentive in this interval are greater than the value b—the maximum possible incentive if the plan is not fulfilled.

2. Formation of the TLC on the basis of economic indicators of the EEs of TLC.
   The TLC is considered in the form presented as in the particular example in Fig. 1, but instead of production criteria determined by the parameters λ and μ, we will use economic criteria (1). The following procedure is suggested:

- Each EE calculates the type of dependence for itself (1), which reflects its effectiveness depending on the volume of services provided. That is, it knows the value of xo, which is desirable to receive as a task from the management top level.
- EE performing parallel servicing (link 2 in Fig. 1) inform the Center of their desired values x_{oi}, from which the total demand of the corresponding TLC link is formed: $x = \sum 1^n x_{oi}$. Now our TLC consists only of series-connected links. For each such link the Center knows the value of the desired order x_m, m = 1, 2, … – TLC serial link number (Fig. 3).

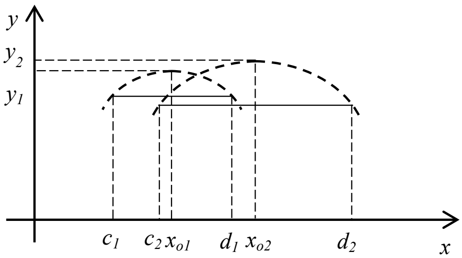

Fig. 3. Modelling of the EEs economic interests.

- The Center compares its need for services with the capabilities of the TLC links. Not all of these numbers, in general, coincide. That is, both the Center and the EEs-contractors will not work in the optimal mode. A compromise is needed. The mechanism for its achieving is shown in Fig. 3 for an example of two EEs. A dotted line represents the corresponding curves (1) in Fig. 3, since they are not known to the Center (but known to the corresponding EEs). It (Center) introduces a penalty coefficient k. This will form the areas of coordinated decisions: $[c_1, d_1]$ for the first EE and $[c_2, d_2]$ for the second one. EE informs the acceptable value limits, respectively d_1 and c_2. We check:

(a) Whether the region $[c_2, d_1]$ has been formed, that is, we check the condition $c_2 < d_1$. If not, we assign a new penalty coefficient that expands the areas of agreed decisions. If the area $[c_2, d_1]$ is large enough, then the coefficient k can be increased to reduce it. In this case, EE will receive the best economic indicators.

(b) Whether this area includes the value of the volume of services requiring processing of the TLC. Moreover, it is desirable for this value to enter the area $[c_2, d_1]$ with some «margin». In the process of work, unpredictable deviations are possible and it is necessary to have a resource to compensate for them. If not, then we again correct (decrease) k.

Thus, the DP organizes an iterative procedure between its agents, the Center and the EE-contractors, for coordinating interests (a kind of civilized bargaining is formed, in which all interested parties participate: both the Center and the EE).

3. Intellectualization of TLC activity requires systematization of approaches and methods for modeling the experience and intuition of the reference operator, expert analysis of the problem, development of methods of computerized data analysis and is carried out by the implementation of three procedures:

   - Translation of the natural intelligence of developers and users of the system. This task can be accomplished in various ways. By modeling the activities of experienced operators (through the construction of regression dependencies, classification systems), and including these models in the decision support systems (DSS) of the TLC, we increase the speed and exclude involvement, inexperience, emotionality within the framework of the technological process of freight movement [7, 8]. In more complex cases, one should resort to expert analysis of the problems that arise. To conduct a collective examination, the parameters and logics of the expert group work are determined: the number of experts, the degree of their importance, and the mechanism for drawing a general decision based on private statements [7, 8].
   - Generation of computer intelligence, Methods of computerized data analysis can be represented by the Method of Group Arguments Accounting (MGAA), developed by A.G. Ivakhnenko [9] and neuro-fuzzy models [10, 11]. In the first case, using MGAA, we obtain analytical regression-type relations between the studied TLC parameters (the same curves in Figs. 2 and 3 or the parameters of the freight transportation process: speed, travel time, etc.). In the second case, designed for processes with greater uncertainty, the machine makes a decision in the image and likeness of the human brain.
   - Generation of superintelligence (otherwise, swarm intelligence) of the corresponding multi-agent system [12]. Swarm intelligence (SI) describes the collective behaviour of relatively independent agents of a decentralized self-organizing system.
     Each agent «follows very simple rules and, despite the fact that there is no centralized system for managing the behaviour of agents that would indicate to each of them what to do, local and, to some extent, random interactions lead to the emergence of intelligent group behaviour uncontrolled by individual agents» [12]. In general, superintelligence is formed by a multi-agent system that has self-organizing behaviour, which, in total, shows some reasonable behaviour.

4. The creation of a TLC DP requires the development and selection of EEs interaction schemes. Various classifications of existing DP can be given. In the context of this study, we will consider two types of DP structures: market-oriented and centrally managed. In the first case, the owner of the platform provides it for agents (sellers and buyers of products: goods and / or services), without interfering in the purchase and sale process, controlling only the legality of transactions. Examples of such DPs are: Avito, Uber, etc. In the second case, the platform owner has his own interest (except

for platform usage fees) and acts as an agent of a higher level of management. Taking into account the specifics of the process under the study, the use of the second approach should be recommended. Indeed, TLCs perform socially significant functions and regional leaders, Unified Network Technological Process, and JSC "Russian Railways" can act as Management Centers. Figure 4 shows such a scheme of interaction between the Center and the EEs.

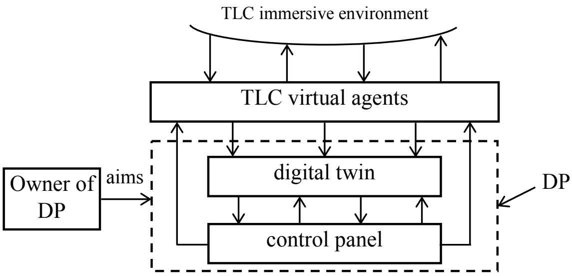

Fig. 4. The structure of EEs interaction on DP of TLC.

4 Discussion

The presented development forms a number of positive effects:

1. The agreed solution of the most important national economic tasks for freight transportation is regulated. At the same time, a unified discipline of the transportation process is preserved, and market mechanisms of interaction between EE of one and different management levels are implemented.
2. The proposed approach provides the intelligent functioning of the TLC based on three types of intelligence:

   - natural intelligence of developers, transport specialists translated into the integrated intelligence of the synthesized system;
   - generated computer intelligence (through MGAA algorithms and neuro-fuzzy models);
   - the superintelligence of the system arising from the multi-agent interaction of EE.

3. Two important roles of mathematical methods in practical problems are realized

   - The first (traditional): optimization of interaction and results of joint activities at different levels of management (individual EEs and the system as a whole).
   - The second (new function of mathematical modeling) is the formation of a socially significant corporate culture of EE interaction within the TLC participants, excluding involvement, manipulation, and non-professionalism.

- While developing and implementing the declared concept of TLC management, a number of problems arise:
  The formation of a new culture of interaction requires resources, efforts and time. Particular attention should be paid to the development of the necessary intellectual potential: training of qualified personnel, the development of the DP, software for modeling and decision-making procedures. Large-scale implementation of the proposed technology will require government's participation: improvement of educational programs, personnel training systems and development of public–private partnership.
  New transport process management mechanisms will require the improvement of regulations that ensure the introduction of the developed decision-making procedures and freight promotion technologies. In particular, the most important areas under reform include:
- Financial and economic (for example, it is necessary to introduce blockchain technologies).
- Safety of transportation process. The new concept changes the structure of responsibility. For example, who bears the responsibility for an improper made computer decision: the software developer, the provider of erroneous data, the process manager?
- We also need to take measures to protect intellectual property (DP, algorithms, programs).

4. Information support of decision-making processes and procedures in the new concept of TLC management requires accelerated development and content of databases (presented, for example, in the form of OLAP cubes), knowledge bases, the development of big data processing technologies (Big Data), Data mining technologies.
   The solution of these problems is facilitated by the conditions prevailing in Russia for the transition to a new technological framework. In particular:

- The Government Decree on the introduction of the «Digital Economy of the Russian Federation» defines the terms, financial resources, and responsible persons for the development of relevant projects [13]. The Intelligent TLC Management System may be one of them.
- The Decree of the President of the Russian Federation «On the development of artificial intelligence in the Russian Federation» [14] defines the tasks and mechanisms of the transition of the Russian society to intelligent technologies in all spheres of public and economic life of the country, including transport.
- Similar documents and measures for the digitalization and intellectualization of railway transport have been taken in JSC «Russian Railways».
- It should be noted that JSC «Russian Railways», long before the announcement of the state programs of digitalization and intellectualization [13, 15], adopted and successfully implemented the Unified intelligent management and automation system of production processes in railway transport (IMSRT) [15]. This system is already being tested at the country's landfills and can serve as the basis for the development and implementation of the Intelligent TLC Management System that implements the models and mechanisms proposed above.

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Automating MySQL Database Complexity Estimation Based on Quantitative Metrics

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Abstract. The article examines the problems of automating assessment of the level of database complexity using quantitative metrics based on the developed application. The main approaches and methods of researching the quality of databases are analyzed. An algorithm for assessing the complexity of a physical database scheme based on metric characteristics: the number of tables, keys, attributes, is presented. As a result of the best solutions review, several directions in the development of software for analyzing database metrics were identified. The necessity of creating a program with the ability to customize the weight coefficients using a matrix of paired comparisons is substantiated, which allows one to get rid of subjectivity and adjust the calculation of the assessment for specific tasks. The main functionality of the developed application, settings and management of the database complexity level estimation are described. A distinctive feature of the developed software package is automatic connection to MySQL, analysis of additional metric characteristics that are absent in similar solutions, calculation of the resulting estimate using matrices of paired comparisons. Integration with other database management systems, the creation of a database manager, which enables to load a dump through the program and delete unnecessary databases, is considered as prospects for the development of the presented approach to automating the assessment of the databases complexity; as well as the introduction of statistics calculation, on the basis of which to create a statistical setting of the coefficients.

Keywords: Database quality · Database complexity · Database metrics

1 Introduction

The software development process is a set of interrelated steps to achieve a quality software product. Processes in the life cycle of a software tool have two main categories: main and auxiliary. The main ones include those processes that are implemented under the control of organizations that initiate or carry out development, that is: task, delivery, development, operation and support. Auxiliary processes ensure successful implementation and quality of software product execution.

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Evaluation of the development quality refers to auxiliary processes and can occur both at the stage of testing and use [1, 2]. The evaluation can be subject to various software characteristics, for example, the quality of the stored data of statistical methods [3] can be evaluated, thus, the identification of a poor-quality product at an early stage of the life cycle allows one to eliminate bugs as quickly as possible with minimal loss of resources.

Database (hereinafter referred to as DB) is an ordered set of structured information or data. A well-organized database helps to save not only disk space, but also query execution time. That is why the optimization of the entire software package depends on the database [4].

The tables included in the database possess their own characteristics that can be measured quantitatively, and the automation of this process will ensure the accuracy and reliability of such measurements. Based on the results of calculating these characteristics, the developer gets the opportunity to comprehensively assess the complexity of the entire database, which would allow assessing the efforts and amount of work performed by the developer, as well as choosing the best physical scheme from several alternatives. A separate application of such tools can be effective in the field of education for teaching approaches to assessing the complexity of the designed databases [5].

The database is the core of the information system. It is an organized structure for storing, changing and processing related information. Like any software product, a database has its own life cycle (hereinafter—life cycle):

1. Preliminary planning.
2. Requirements definition.
3. Conceptual design.
4. Logical design.
5. Physical design.
6. Selecting the target DBMS.
7. Application development.
8. Database creation.
9. Database testing.
10. Operation and maintenance.

Creating a high-quality database is one of the most important tasks in optimizing the development and operation of the entire software package. Thus, developers face the task of assessing the database for its complexity. The database should not only contain all the necessary information, but at the same time be the simple. That is why when choosing from several concepts, each of which fully corresponds to the functional characteristics, it is worth making a choice towards the least complex and loaded.

Database scheme quality control is impossible without numerical metrics, and metrics are useful mechanisms for improving the quality of software products. Such approaches are usually based on network research methods that allow analyzing the quality of the database based on the topology of links [6], as well as the stability of operations when working with the database based on the parameterization of various classes of queries [7], estimating the time of queries [8], the quality of the stored data [9], etc.

It should be noted that although traditionally indicators of the "quality" of a database are the normalization evaluation of the database scheme or individual metric indicators, the total complexity indicator, consisting of a related set of metrics and necessary to build an objective view of the database, is most often not considered.

2 Methods and Materials

In the course of information sources review of the subject area [7–10], an algorithm was identified for assessing the complexity of the physical database schema based on metric characteristics: the number of tables, keys, attributes, but there was no ready-made software product. At the same time, the methods of object-oriented programming in integration with a database management system (hereinafter referred to as the DBMS) made it possible to implement this technique.

Let the database contain n tables. Then, for the i-th table of the physical scheme of the database, the value of the complexity weight W_i is determined by formula (1).

$$W_i = \sum_{j=1}^{k} \alpha_j \cdot M_j \tag{1}$$

where

M_j metric characteristics of the table;
α_j weighting factor of the metric;
k number of metrics.

The following are distinguished as metric characteristics:

- *M1*number of table attributes;
- *M2*the number of attributes in the primary key;
- *M3*number of outer keys;
- *M4*number of indices;
- *M5*number of field constraints.

The complexity of the physical database scheme is calculated as the sum of the complexity of its tables by formula (2).

$$\mathrm{C} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{W}_{\mathrm{i}} \tag{2}$$

where

C database complexity.
W_i the complexity of the i-th table;

n the number of tables in the database.

Based on the analysis of the subject area and indirect similar solutions, the general functionality of the application was determined:

- creating a connection to MySQL;
- getting a list of databases;
- getting a list of database tables;
- formation of a conceptual database graph;
- visualization of the conceptual graph of the database;
- obtaining metric characteristics of the table;
- obtaining metric characteristics of the database;
- calculation of the table complexity;
- calculation of the database complexity;
- generating a report on the complexity calculation;
- saving the results of complexity calculation;
- setting the weight coefficients of metric characteristics;
- customization of visualization of the conceptual graph (color palette and font size).

A distinctive feature of the program is the ability to customize the weighting coefficients using a matrix of paired comparisons, which allows one to get rid of subjectivity and adjust the calculation of the estimate for specific needs.

The following structural units should be presented in the application:

- module for working with the database;
- module for calculating the database complexity;
- module for calculating the table complexity;
- module for calculation results' visualization;
- module for setting weight coefficients;
- module for configuring parameters for connecting to a DBMS;
- application personalization module;
- module for working with the history of the calculation of complexity.

3 Realization

In order to implement the application, the following technology stack was used:

- programming language Kotlin (version 1.3);
- framework JavaFX 8;
- integrated development environment: IntelliJ IDEA Community;
- visual layout tool: Scene Builder 2.0;
- application development kit: JDK 8u231;
- DBMS MySQL (version 5.5);
- adapter for connecting to the database: MySQL Connector / J 5.1.48.

When the application starts, a window opens with the parameters for connecting to the MySQL server. You must specify the server URL (for example, “localhost” or IP address), port (if required), and the MySQL username and password. The first two items are saved in the system upon successful authorization. The window layout is shown in Fig. 5.

To create a conceptual graph, the user needs to select a database. Each database table on the graph is represented by a rounded rectangle with a caption. Tables linked by foreign keys are connected by lines. When you move the mouse over the table view, it is highlighted in a different color. When pressed, a window for calculating the complexity of the table opens. An example of constructing a conceptual graph is shown in Fig. 1.

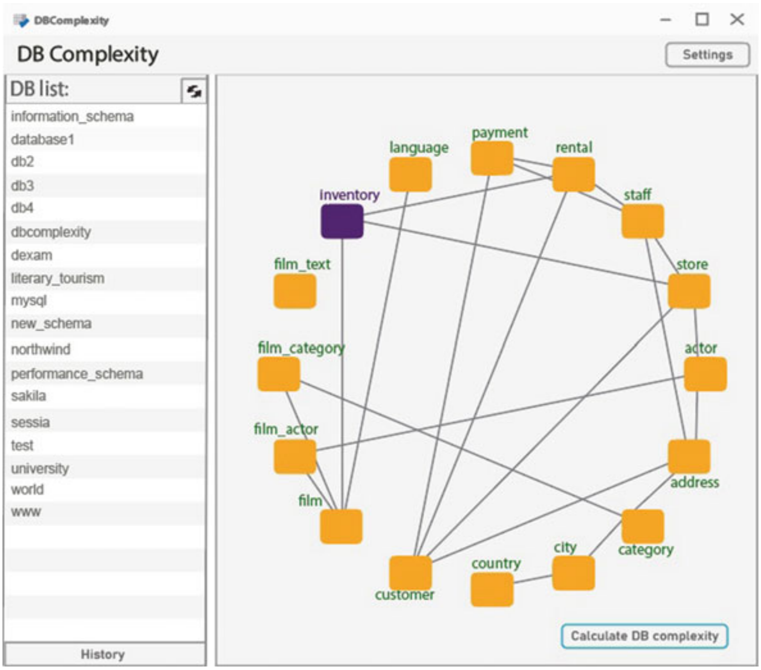

Fig. 1. Conceptual graph of the database “Sakila”

The system has the ability to customize the color palette and font size of the conceptual graph with the ability to set default values.

To set up the weighting factors, one must specify the weighting factors of the following metrics:

- the number of table attributes;
- the number of attributes in the primary key;
- the number of foreign keys;
- number of indices;
- the number of field restrictions.

One can select the type of indices (unique/non-unique) and the type of field constraints (auto_increment, unique, not_null, default). It is possible to reset the parameters to their default values (all weight coefficients are equal to 1, all types of indices and field restrictions are taken into account). The weight coefficient settings window is shown in Fig. 2.

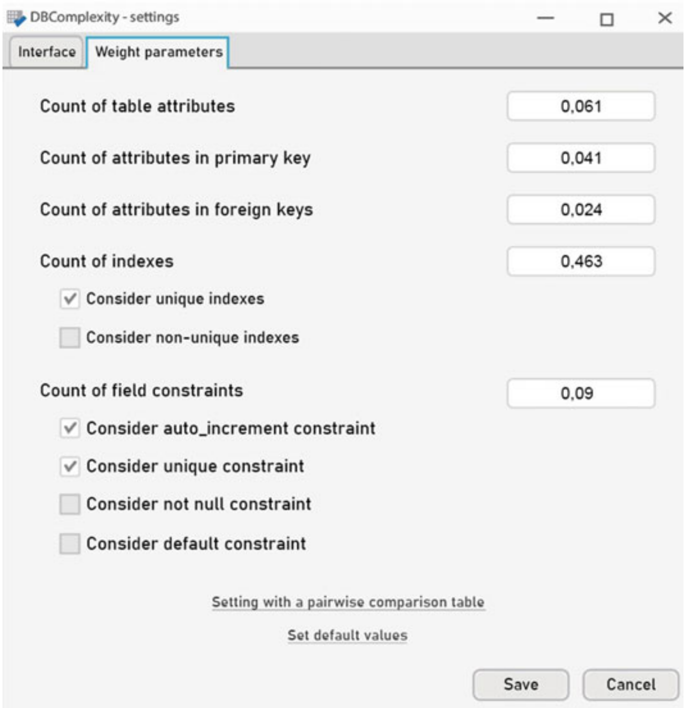

Fig. 2. Weight coefficient setting window

In addition to the implementation of the adjustment of weight coefficients presented above, it is possible to call the extended adjustment function by the method of analysis of hierarchies by T. Saati. In order to do this, the user needs to fill in the matrix of paired comparisons. An example of filling the matrix is shown in Fig. 3.

An example of calculating the database complexity is shown in Fig. 4.

Each calculation of the database complexity is automatically saved in the calculation history. In the history management window, one can delete individual, unnecessary records, or clear the entire history. It is also possible to leave a comment to remember which actions led to an increase or complexity of the database.

If the database storing the history of calculations is deleted, the program will create it again on its own.

The calculation history storage window is shown in Fig. 5.

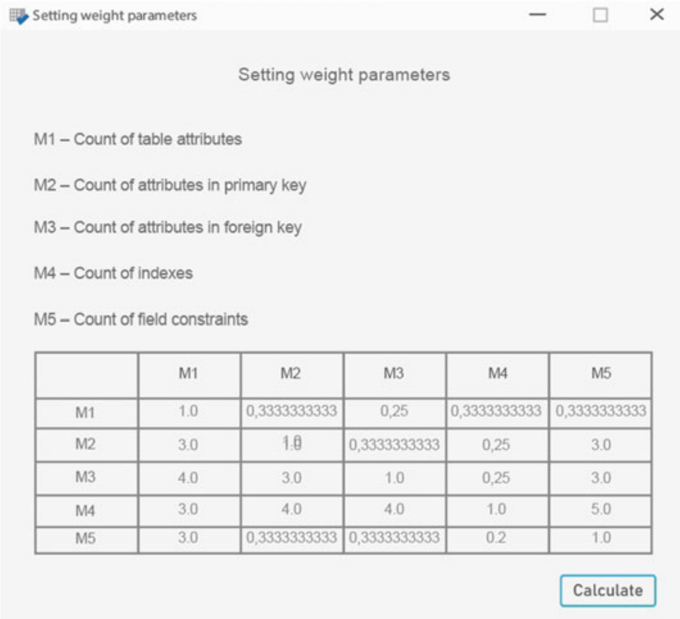

Fig. 3. The window for setting the weight coefficients by the method of T. Saati

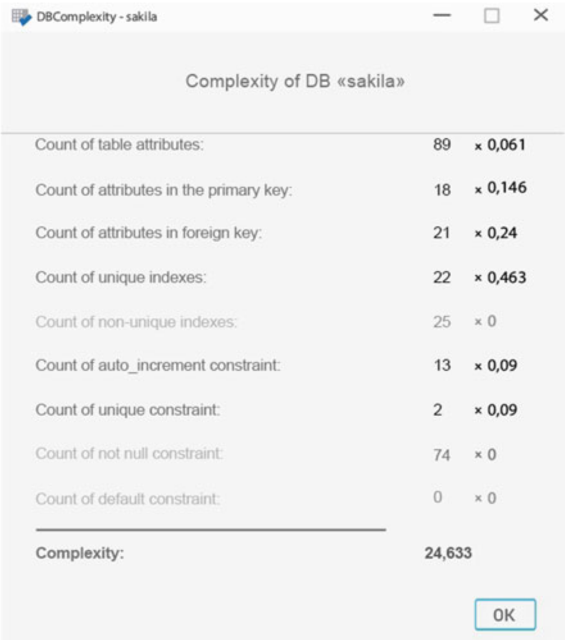

Fig. 4. Calculation of the “Sakila” database complexity

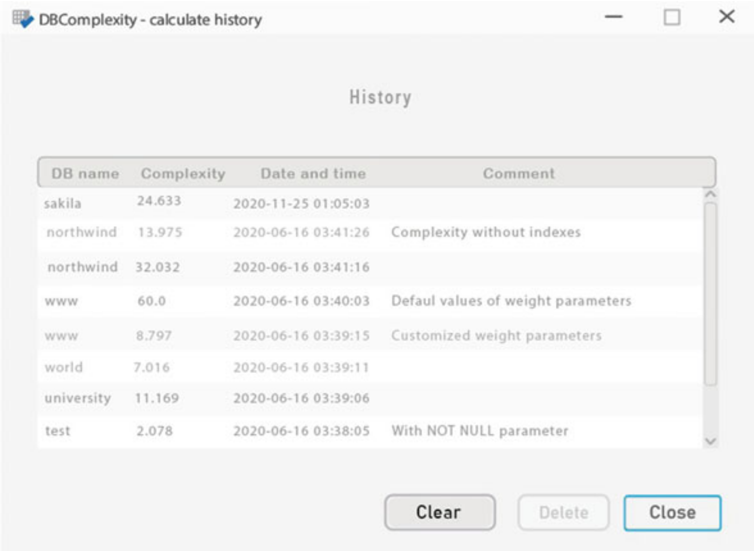

Fig. 5. Calculation history management window

4 Field of Application

The developed software tool makes it a ready-made tool that allows one to quickly assess the complexity of the MySQL database on the basis of quantitative metrics. Among the distinctive features of the developed complex are automatic connection to MySQL, analysis of additional metric characteristics (in the form of restrictions imposed on the fields: auto_increment, unique, default, not_null) that are absent in similar solutions, calculation of the resulting estimate using matrices of paired comparisons.

Among the promising areas of research, it is worth mentioning that the developed program will help in teaching students mastering database design. Students will be able to visually see how the creation of additional links or indices complicates the database design, thereby forming professional competencies. It will become easier for teachers to assess the complexity of the work done by the students, on the basis of which the idea of the successful assimilation of the material is formed.

5 Conclusions

The developed application will help students learn how to create better databases; employers determine the labor expended by programmers to create a database.

Integration with other DBMS is considered as prospects for the development of the project; creation of a database manager, which would enable to load a dump through the program and delete unnecessary databases; as well as the introduction of calculation statistics, on the basis of which to create a statistical setting of the coefficients.

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Operational Control of Wheat Leaf Rust in a Hyper-continental Climate

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Abstract. Observations of the infection of spring wheat with the leaf rust pathogen in the hyper-continental climate of the Ural region of the Russian Federation showed that the moderate and epiphytotic development of the phytopathogen took place in 58% of the years. It was during these years that the use of fungicidal plant protection products was mandatory to preserve wheat productivity and grain quality. The biological effectiveness of more than 90% against the local racial composition of leaf rust was provided by chemical preparations, especially the variants with combinations of active ingredients "propiconazole + tebuconazole" and "thiophanate-methyl + epoxiconazole" were distinguished. A microbiological preparation based on the bacterium *Bacillus subtilis* during the years of epiphytes provided a decrease in the development of this infection by only 35–47%. The yield of spring wheat for the period of research on the control variant of the experiment varied from 9–12 dt/ha in severely arid years to 39 dt/ha, on average during the research period it was 21.3 dt/ha. The use of chemical fungicidal plant protection during the years of epiphytes retained 32–45% of the yield or 7.0–9.4 dt/ha. In years with moderate leaf infections, the increase in productivity averaged 2.8 dt/ha. In arid years, in the second half of the growing season, the manifestation of leaf rust was single and had no economic significance.

Keywords: Brown leaf rust · Spring wheat · Fungicides · Microbiological preparations · Phytopathogens · Productivity · Biological effectiveness

1 Introduction

When mastering advanced technologies for the cultivation of grain crops, the issues of plant protection from leaf-stem infections are especially relevant. The shortage of harvest from which in the years of epiphytes can reach 40–60% [1, 2].

In the Ural region of the Russian Federation, the most harmful are brown rust (Puccinia triticina Eriks.), powdery mildew (Erysiphe graminis DC.), stem rust (Puccinia graminis), septoria (Parastagonospora nodorum), tan spot (Pyrenophora tritici-repentis) [3].

Rust fungi are highly specialized parasites. Many species have a large number of physiological races, for example, the causative agent of wheat leaf rust is known to

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have more than 200 of them. Each territory can form its own racial composition of the pathogen, up to adaptability to a particular cultivar variety [4].

Wheat rust pathogens belong to the genus Puccinia; a distinctive feature is 2-celled, dark brown (mostly black) teliospores, sitting on short legs. Urediniospores are ellipsoidal, irregular, yellow, orange or brown in color. Species of this genus develop both in a full cycle (in the uredinio and teliostages they parasitize on wild and cultivated grasses, spermogonial and aecidial—on dicotyledonous plants), and they can develop in an incomplete cycle. The Uredinaies order unites over 4000 species [4, 5].

The gap between the onset of the first symptoms and the onset of sporulation is usually very short. So, for powdery mildews, a day passes from the yellowing of the tissue to the formation of conidia. For rust, this interval is 1–2 days. The resulting spores cause new infections, giving rise to a new generation of the pathogen. The development time of one generation of rust and powdery mildew pathogens averages 7–10 days [2].

Brown rust—a dangerous disease of spring and winter grain crops, is diagnosed by the appearance of brown subepidermal pustules (uredinium or urediniopustules) on the leaves and sheaths. Subsequently, they turn black and acquire a glossy shade due to the formation of telium on them. The leaves of the affected plants reduce assimilation and die off, and the absolute weight of the grain decreases. During the growing season, it develops in several generations. It is leaf rust that has the maximum rate of increasing the infectious potential [4–6].

According to the Russian Agricultural Center, the damage to crops in the Russian Federation by leaf infections over the past five years of spring cereal crops amounted to 949 thousand hectares. In the Ural Federal District, leaf damage was recorded on an average of 103 thousand hectares of spring crops. Protective treatments were applied on 90–100% of the area. In 2015–2017, the main harmful object on wheat was leaf rust, which caused significant losses in yield and grain quality [3].

The system of effective control of the phytopathogen under discussion can be based on the use of immune varieties, which is a very environmentally friendly way of plant protection [4–6]. However, for varieties that are valuable for any traits, but do not have genetic protection against a phytopathogen, control measures consist in the timely use of fungicidal preparations [7–9].

Currently, the arsenal of chemical protection agents has a fairly wide range of fungicides for wheat [10, 11]. For their successful application, constant monitoring of the dynamics of the disease and the rate of its development is necessary, the timeliness of application and high-quality technological application of the pesticide are important. The use of drugs should be targeted [12–14].

The aim of the research was to determine the levels of damage to spring wheat by the leaf rust pathogen in different years in the hyper-continental climate of the Ural Federal District of the Russian Federation, as well as to establish the effectiveness of fungicidal protection of crops during the mass development of wheat leaf rust.

2 Research Conditions and Methods

The research was carried out within the framework of the State task of the Ministry of Science and Higher Education on the topic: "To improve the system of adaptive landscape farming for the Ural region and to create a new generation of agricultural technologies based on minimizing soil cultivation, diversifying crop rotations, rational use of pesticides and biological products, preserving and increasing soil fertility and to develop an information and analytical complex of computer programs that provides innovative management of the farming system" on the experimental field of the Kurgan Scientific Research Institute of Agriculture—branch of Federal State Budgetary Scientific Institution «Ural Federal Agrarian Scientific Research Centre, Ural Branch of the Russian Academy of Sciences». The crop rotation is three-field grain-fallow, the experiments were conducted on fallow wheat in crops of the widespread variety of spring bread wheat Omskaya 36 without genetic protection against leaf rust. The soil of the experimental site is low-humus heavy loamy leached chernozem. Agricultural technology of wheat cultivation is zonal. Fertilizers were not applied. The area of the plot in the experiments was 20 m^2, the placement of the variants was systematic fourfold repetition. The experimental schemes include chemical systemic fungicides, biological products, active ingredients, formulations and terms of application are given in the "List of pesticides…" [10]. Crop treatment was carried out by knapsack sprayers with a "Solo 456" boom in the phase of the flag leaf emergence (p. 37 according to Zadoks). The technique of phytopathological research is generally accepted in the Russian Federation [15]. Taking into account the prevalence of leaf-stem diseases, the prevalence and development of infections were determined. The development of powdery mildew (the intensity of plant infestation) was determined according to the Geshele scale, brown rust - Peterson, etc. The calculation was carried out according to the formula: $R = \Sigma (a \times b) \div N$, where R is the development of the disease, %;

$\Sigma (a \times b)$—the sum of the products of the number of diseased plants (a) by the corresponding% of infestation (b); N is the total number of plants in the samples. The analysis of the infestation of plants was carried out 10 and 20 days after treatment; the article presents the results of the first determination. Grain harvest accounting was carried out by direct combining with Sampo-130 combine harvester. Harvest data processing was carried out by the method of analysis of variance [16].

The weather conditions during the study period varied significantly and significantly influenced the development of leaf-stem infections and crop yield. In 2010 and 2012, there was an acute drought throughout the growing season (HTI in May–August was 0.3). In 2009, 2014, 2019 and 2020, the conditions were characterized as arid and the HTI did not exceed 0.8. Satisfactory weather conditions during the growing season of wheat were in 2011, 2013, 2015, 2016, 2017, and 2018. It was during these years that the intensive spread of aerogenic infections in crops was noted.

The field experiment scheme included the following options for fungicidal protection: propiconazole (Title 390 0.3 l/ha), cyproconazole + propiconazole (Alto super 0.5 l/ha), thiophanate methyl + epoxiconazole (Rex duo 0.5 l/ha), pyraclostrobin + epoxiconazole (Abacus ultra 1.5 l/ha), spiroxamine + tebuconazole + triadimenol (Falcon 0.6 l/ha), Bacillus subtilis (Fitosporin-M 1.5 l/ha) and control without fungicidal protection.

3 Research Results

In our studies, the biological, economic efficiency of the chemical and biological method for controlling leaf rust on a susceptible variety of spring wheat in years with different intensity of damage was determined.

Long-term observations of the infection of spring wheat with the leaf rust pathogen in the Ural Federal District showed that the moderate and epiphytotic development of the phytopathogen took place in 58% of the years. It was during these years that the use of fungicidal plant protection products became mandatory to preserve wheat productivity and grain quality.

The damage of spring wheat leaves by phytopathogens in the experiments during the observation period varied from weak (single and depressive) in 2010, 2012, 2018, 2019, 2020 to epiphytotic—in 2013, 2014, 2016, 2017 (Table 1). Most often leaf rust appeared in early July, feeding mainly on flag leaves. The most intense infection of wheat was noted in 2016 (the development of leaf rust in the heading phase on flag leaves was 32%, the lower layers of leaves were affected by powdery mildew). Besides, in 2015, 2016 and 2017, the development of stem rust on the straw took place. The development of the pathogen in the phase of wheat maturation (p. 76–79 according to Zadoks) was more than 40% with 100% prevalence.

Table 1. Levels of development of leaf infections on spring wheat in different hydrothermal conditions of the growing season, 2009–2020

Year	Hydrothermal coefficient	Level of development of leaf infections
2009	0,7	Epiphytotia
2010	0,3	Single leaf lesion
2011	1,2	Moderate development
2012	0,3	Single leaf lesion
2013	1,1	Epiphytotia
2014	0,7	Epiphytotia
2015	1,1	Moderate development
2016	1,0	Epiphytotia
2017	1,2	Epiphytotia
2018	1,2	Depressive development
2019	0,8	Depressive development
2020	0,6	Depressive development

In our studies, the biological, economic and economic efficiency of the chemical and biological method for controlling leaf rust on a susceptible variety of spring wheat in years with different intensity of damage was determined.

The first signs of brown rust in the experiment were noted at the beginning of July, when rainy warm weather set in, spring wheat was in the phase of the flag leaf emergence (phase 37 according to Zadoks). The further spread of the infection in the crop was highly dependent on weather conditions, a particularly high rate of the process was observed in 2016, 2017.

As a rule, leaf infections on wheat are not limited to one species, and powdery mildew of cereals (*Blumeria graminis*) was a constant companion of brown rust. This fungus appears in wheat crops almost every year, with the exception of severely arid (2010, 2012).

The harmfulness of leaf infections in the experiment was 15–44% in years with moderate and mass infection of wheat crops. In the years with the depressive development of aerogenic infections, manifestations of brown rust were either not observed or did not exceed 1%. The species composition of phytopathogens in such years was represented by pyrenophorosis, powdery mildew and septoria.

In the field experiments, fungicidal preparations were used by the leading pesticide manufacturers on the Russian market (Syngenta, Bayer, Basf, August), as well as a biological fungicide from BashInkom. Treatments of plants with preparations were carried out in the phase of the flag leaf emergence (phase 37 according to Zadoks), calendar July 1–9.

The effectiveness of fungicidal control when using different drugs was different. On the 10th day after the treatment of crops, the biological effectiveness of more than 90% against leaf rust was provided by chemical preparations, especially the variants with combinations of active ingredients "propiconazole + tebuconazole" and "thiophanate-methyl + epoxiconazole" (100% effectiveness) (Table 2). A biological preparation based on the bacterium *Bacillus subtilis* during the years of epiphytes provided a decrease in the development of this infection by only 47%.

Taking into account the development of leaf rust 20 days after the application of fungicidal treatment of crops, it showed that the protective effect of the preparations decreased relative to the first registration and amounted to 60–72%, the fungicide based on pyraclostrobin and epoxiconazole had the best duration of effective control (72%). Rust control with biofungcide was low, as in the first count (35%) (Table 2). The prevalence of the disease was noted at the level of 93–100% in all variants of the experiment.

Comparing the obtained data on the effectiveness of chemical and microbiological protection of wheat from leaf infections, it should be noted that in the years of epiphytotic development of brown rust, only chemical protection is advisable, and with moderate and depressive development, biological preparations based on hay Bacillus can be recommended (Fig. 1).

The yield of spring wheat for the period of research on the control variant of the experiment varied from 9–12 dt/ha in severely arid years to 39 dt/ha, on average during the research period it was 21.3 dt/ha. The use of chemical fungicidal plant protection during the years of epiphytes retained 32–45% of the yield or 7.0–9.4 dt/ha.

By the effectiveness of action against the local racial composition of *Puccinia triticina Eriks.*, drugs based on combinations of such active substances as "propiconazole + tebuconazole" and "thiophanate-methyl + epoxiconazole" were indicated. In years with moderate leaf infections, the increase in productivity averaged 2.8 dt/ha. In the years with active arid phenomena in the second half of the growing season, the manifestation of leaf rust was single and had no economic significance.

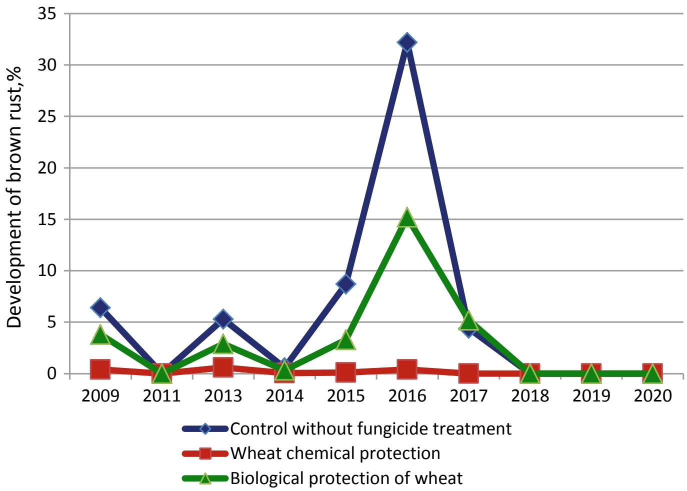

Fig. 1. Dynamics of the development of brown rust on spring wheat during the earing-flowering period (form 55–65) when using various methods of protection, 2009–2020

The data obtained indicate that in the years of mass development of leaf rust in wheat crops, the correlation dependence between crop yield and the degree of leaf damage was characterized by the Chaddock scale as strong and very strong (r = 0.76…0.91). In the case of depressive development of infections, it was insignificant (r = 0.33…0.45).

4 Conclusions

Observations of the infection of spring wheat with the leaf rust pathogen in the hyper-continental climate of the Ural region of the Russian Federation showed that the moderate and epiphytotic development of the phytopathogen took place in 58% of the years. Biological effectiveness of more than 90% against leaf rust was provided by preparations based on such active substances as propiconazole + tebuconazole and thiophanate-methyl + epoxiconazole. A biological preparation based on the bacterium Bacillus subtilis during the years of epiphytes provided a decrease in the development of this infection by only 47% (Table 2).

The use of chemical fungicidal protection of wheat during the years of epiphytes of leaf infections retained 32–45% of the yield or 7.0–9.4 dt/ha. In years with moderate leaf infections, the increase in productivity averaged 2.8 dt/ha. In arid years, in the second half of the growing season, the manifestation of leaf rust was single and had no economic significance.

Table 2. The effectiveness of fungicidal preparations against leaf rust during the years of its mass development on spring wheat, 2013–2017

Variant	10 days after treatment (p. 49–50)[a]		20 days after treatment (p.65–70)[a]	
	Disease progression (%)	Biological effectiveness (%)	Disease progression (%)	Biological effectiveness (%)
Control	10.2	–	22.5	–
Propiconazole	0.6	94	12.0	47
Cyproconazole + propiconazole	0.6	94	9.1	60
Propiconazole + tebuconazole	0.0	100	9.0	60
Thiophanate methyl + epoxiconazole	0.0	100	8.8	61
Pyraclostrobin + epoxiconazole	0.2	98	6.4	72
Spiroxamine + tebuconazole + triadimenol	0.2	98	7.9	65
Bacillus subtilis	5.4	47	14.7	35

[a]Calendar dates of counts—the second decade of July and the beginning of August

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Reclamation of Mechanically Disturbed Soils Using Forest Plantations

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Abstract. The method of reclamation of mechanically disturbed soils with the help of forest plantations is based on the fact that in the initial (before disturbance) state of forest soils, the predominant part of the elements of mineral nutrition of plants—nitrogen, phosphorus, potassium is concentrated in the forest litter and humus horizon. Their removal sharply reduces soil fertility, negatively affects reforestation, productivity and quality of forest ecosystems. The main objects of reclamation of mechanically disturbed soils with the help of forest plantations are the territories of forest and forest-steppe zones disturbed by open-pit mining of mineral deposits; forest lands from under the routes of dragging rig derricks; exploration well drilling sites; quarrying; forest lands disturbed outside industrial facilities; temporary roads. In order to restore the fertility of disturbed forest soils, it is proposed in the paper to ensure the "return" of nutrients to the upper soil horizons by oligotrophic tree species. It has been proven that forest reclamation without the use of intensive agricultural technologies is inexpensive, but it takes decades to form full-fledged coniferous (primarily pine) plantations. Therefore, it should provide for the restoration of not only soil fertility, but also the original phytocoenosis capable of reproducing all types of forest resources.

Keywords: Reclamation · Disturbed lands · Forest zone · Forest-steppe · Forest soils · Reforestation · Humus

1 Introduction

The characteristic features of forest soils are: patchiness due to uneven arrangement of trees, the presence of forest litter, humus horizon, leaching zone, illuvial horizon. Due to the unequal structure of root systems and the biochemical quality of dead litter, forest-forming species have a different effect on the structure of the soil, its chemistry, aeration, microflora [1–4].

Forest soils are predominantly wetted by leaching. All water-soluble nutrients (nitrogen, phosphorus, potassium, trace elements) released from the organic matter of dead litter continuously move along with the sediment down the soil profile. If they were not intercepted by plant roots, they would be washed out along with the flow of groundwater

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into rivers or inland water bodies. But as long as there is a forest, this does not happen [5, 6].

Forest vegetation, extracting nitrogen, phosphorus, potassium, trace elements from the root horizons of the soil and parent rock, accumulates them and partially discharges them with annual litter. A certain part of organic matter of litter is converted to humus [7–9]. If the upper humus layer is disturbed or completely destroyed, soil fertility is sharply reduced, and the underlying parent rocks, which have an extremely low content of all nutrients, are exposed. As a result, the rate of natural regeneration of forest vegetation slows down, which negatively affects reforestation, productivity and quality of forest ecosystems [10–12].

The aim of the work is to study the processes of self-restoration and substantiate technologies for the reclamation of forest lands.

2 Materials and Methods

The authors studied more than 300 km of linear and 210 on-site oil and gas production facilities in the Khanty-Mansi Autonomous Okrug (KhMAO) and Yamalo-Nenets Autonomous Okrug (YaNAO). 24 temporary test plots were laid, and 817 model trees were taken to analyze the growth of young stands on technologically disturbed lands. 24 soil profiles were laid, of which 46 soil samples were taken. The total content and mobile forms of nitrogen, phosphorus and potassium were determined in them according to generally accepted methods.

On the test plots, 2 levels of soil cover disturbances were compared: strong—removal and displacement of a soil layer of 10–20 cm thick in more than 70% of the disturbed area; moderate—damage up to 30% of the soil cover, which was used as a control for simulating soil disturbance in clear-cut areas.

Elements for the reclamation of mechanically disturbed soils with the help of forest plantations were laid in the Khanty-Mansiysk forestry of the KhMAO—UGRA in 1995. The total content and mobile forms of NPK in the soil were determined in 1995, 2005 and 2015.

3 Results and Discussion

There are tens and hundreds of tons of the total stocks of organic and mineral substances in forest soils per hectare. However, only tenths of phosphorus, potassium and hundredths of nitrogen are in the mobile form assimilable for plants [5]. In the taiga soils of Western Siberia [13], the reserves of mobile forms of phosphorus and potassium are 2–2.5 times less than in the soils of the European part of Russia (Table 1).

The annual consumption of NPK by forest plantations is 13–199 for nitrogen, for P_2O_5—1–24, for K_2O—5–125 kg/ha in mobile form [14].

Nitrogen reserves in taiga soils are commensurate with the volume of its annual consumption by forest plantations. Considering that it is concentrated mainly in the upper soil horizons, any disturbance of the soil cover leads to a deficiency of nitrogen in the nutrition of woody plants and the need to “return” it to the soil during reclamation.

Table 1. Stocks of mineral nutrients in the meter layer of forest soils in Western Siberia

Phytocoenosis	NPK content kg/ha				
	Soil	Nitrogen[a]		Mobile, kg/ha	
		Total	Mobile	P_2O_5	K_2O
Northern taiga					
Lichen pine forest	Podzolic sandy	5030	70	206	165
Green moss-lingonberry pine forest	Podzolic sandy	2270	32	185	159
Green moss-berry pine forest	Podzolic sandy	5300	–	375	434
Green moss and berry larch	Podzolic sandy	3440	–	200	739
Blueberry-lingonberry-moss larch	Podzolic sandy	8720	–	206	395
Middle taiga					
Lingonberry pine forest	Podzolic sandy	2450	34	190	320
Lingonberry-berry pine forest	Podzolic sandy	4830	68	302	320
Blueberry-lingonberry-moss pine forest	Podzolic sandy	3000	42	251	305
Green moss pine forest	Podzolic sandy	7630	107	364	894

Note[a] To calculate mobile nitrogen for total stocks, a coefficient of 0.014 was applied, the value of which was determined for sandy soils

The reserves of mobile phosphorus and potassium are distributed in the soil profile relatively evenly and exceed their annual consumption by young stands and middle-aged stands by 20–60 times. Therefore, during the reclamation of disturbed lands, the need for the introduction of phosphorus and potassium is several times less than that of nitrogen fertilizers. Nitrogen reserves limiting the fertility of forest soils vary within 0.55–4.2 t/ha in the A0 + A1 horizons in various types of forest, in the 20-cm layer—1.4–5.6 t/ha (Table 2).

After removing the forest litter and humus horizon during construction work, the soils lose 28–88% nitrogen and 14–60% phosphorus and potassium.

Cutting a layer of soil of 0.2 m thick leads to the loss of 73–100% of nitrogen contained in the 0.3-m soil layer that is assimilated by the roots.

Cutting off 70% of the upper most fertile soil horizons negatively affected soil fertility and natural reforestation. The total amount of self-seeding has sharply decreased, the species composition has worsened, the height and productivity of young stands have decreased.

The most catastrophic situation has developed on dry sandy soils of pine forests oflichen, shrub-lichen and lichen-lingonberry groups of forest types. Removal of A0 and A1 horizons in them is accompanied by a large loss of organic matter [16], and, accordingly, total soil nitrogen. The podzolic horizon is exposed, and with a deeper disturbance—ortstein and ortsand interlayers of sands. They are not favorable for deciduous and most dark-coniferous species; only Scots pine, which is not very demanding for fertility, is naturally renewed. However, reforestation is extremely slow. A sufficient

Table 2. Nitrogen content in the upper horizons of forest soils in Western Siberia [15]

Forest type	Soil difference	Thickness of A0 + A1 horizons, cm	Soil layer of 20 cm thick			
			t/ha	% to stocks in 30 cm layer	t/ha	% to stocks in 30 cm layer
Northern taiga						
Lichen pine forest	Sandy	3	0.98	44	1.93	87
Green moss-lingonberry pine forest	Sandy	5	1.36	64	1.96	92
Green moss-berry pine forest	Loamy	4	3.50	88	3.80	98
Green moss and berry larch	Loamy	2	2.04	62	3.30	100
Blueberry-lingonberry-moss larch	Loamy	10	4.22	61	5.57	80
Middle taiga						
Lingonberry pine forest	Sandy	5	0.55	28	1.45	74
Green moss-lingonberry pine forest	Sandy	6	0.78	41	1.38	73
Blueberry-lingonberry-moss pine forest	Sandy	15	1.55	71	1.76	81
Green moss pine forest	Loamy	7	0.98	30	2.68	82

amount of undergrowth (7–9 thousand pcs/ha) accumulates over 12–16 years (Table 3). Such slowness is unacceptable either from an economic or an ecological standpoint, since mobile forms of nitrogen, phosphorus and potassium are intensively washed out from soils devoid of woody vegetation. On weakly disturbed areas, 1.5–1.9 times more undergrowth appeared over the same period.

On fresh (moderately moist) sandy soils in pine forests of lingonberry-green moss, green moss-berry and blueberry-lingonberry-moss groups of forest types, natural reforestation is more successful, mainly due to the admixture of birch. However, here, the productivity of young stands on strongly disturbed soils is 2 times lower than on slightly disturbed areas. The soil reclamation properties of the young generation of birch are not realized, therefore, the need to plant coniferous crops remains.

The negative consequence of the strong disturbance of loamy soils is expressed primarily in the fact that young stands with a predominance of birch are formed in the place of forest stands with an absolute predominance of conifers (pine, larch, spruce, cedar). On light fresh loams, the proportion of birch and aspen in the composition increases to 6–8 units (Table 3). The replacement of conifers by low-value, unmarketable birch and aspen stands is causing enormous damage to forestry.

Table 3. Influence of soil disturbance on taxation indicators of 10–20-year-old young stands of northern and middle taiga forests of Western Siberia

Forest type, species composition of parent stands	Removal of AoA1 (%)	Average taxation indicators of young stands				
		Species composition	Age, years*	Height (m)	Number of trees (thousand pcs/ha)	Stock (m^3/ha)
Northern taiga Sandy soils						
Lichen-lingonberry pine forest, 5P5L	More than 70	9S1B	16	2.2	9.3	2.1
	Less than 30	9S1B	17	2.8	13.6	8.7
Green moss-lingonberry pine forest 8P1L1B	More than 70	9S1B	16	2.6	6.8	4.8
	Less than 30	9S1B	16	2.6	10.6	7.9
Loamy soils						
Green moss—berry pine forest, 5P3L2B	More than 70	6B4P few L,As	19	4.4	24.8	38.7
	Less than 30	6B4P few L,As	20	3.6	27.6	31.6
Blueberry-lingonberry-moss pine forest, 5P3B2L	More than 70	7B2P1As few L	19	7.4	17.8	31.3
	Less than 30	8B2P few L,As	17	4.5	27.3	34.2
Middle taiga Sandy soils						
Shrub-lichen pine forest, 10P few B	More than 70	8P2As few B	12	1.9	7.3	7.6
	Less than 30	8P1B1As	13	2.8	13.6	25.5
Green moss-berry pine forest, 9P1C few B,S	More than 70	9P1B few As	14	2.5	18.5	25.1
	Less than 30	10P few B,As	15	3.4	23.5	47.7

(*continued*)

Table 3. (*continued*)

Forest type, species composition of parent stands	Removal of AoA1 (%)	Average taxation indicators of young stands				
		Species composition	Age, years*	Height (m)	Number of trees (thousand pcs/ha)	Stock (m^3/ha)
Blueberry-lingonberry-moss pine forest, 8P1C1B few S	More than 70	9P1W few B	13	2.4	18.7	21.0
	Less than 30	7P3B few As	13	2.9	34.3	50.2
Loamy soils						
Green moss—berry pine forest, 10P few S,B,As	More than 70	5P5As	12	2.5/3.3	10.3	9.7
	Less than 30	9As1P	14	2.6/4.4	21.8	35.1
Green moss—berry pine forest, 5P1S1C3As	More than 70	6P4As	11	2.5/2.6	15.1	9.9
	Less than 30	5P5B	11	2.5/3.6	13.2	10.3
Green moss—berry cedar forest, 5C3P1S1As	More than 70	10P	12	2.1/-	4.5	3.2
	Less than 30	9B1P	13	2.9/3.4	25.3	46.9

Forests are natural self-regulating biogeocoenosis. Therefore, their reclamation should provide for the restoration of not only soil fertility, but also the original biocosnoses capable of reproducing all types of forest resources, having environmental protection functions and being formed on the principles of self-regulation.

The introduction of organic and mineral fertilizers before original conifers take a dominant position will give advantages to the seizure of the territory by birch and aspen, since they not only have far-reaching volatile seeds, overtake pine, spruce, and cedar in growth, but are also more responsive to fertilizers.

Given the low natural fertility of disturbed taiga soils when carrying out the biological stage of reclamation, one should focus not on intensive agrotechnical technologies, but on agrotechnologies that help to reduce erosion processes for natural restoration of soils under forest vegetation.

Reclamation of mechanically disturbed soils with the help of forest plantations should be based on the following principles:

- immediate restoration of the forest environment on disturbed lands immediately after the end of the technical stage of reclamation;

- maximum preservation during reforestation of the remnants of sub-forest vegetation, primarily berry dwarf shrubs;
- application of mineral fertilizers in fractional doses during the period of closure of young stands, in the middle age, and at the age of ripe stands;
- protection of restored forest stands from fires that prevent the accumulation of dead litter and the formation of a humus-accumulative horizon.

Immediate restoration of forest vegetation is necessary in order to prevent the leaching of mobile forms of nitrogen, phosphorus, and potassium from the soil profile and create an upward flow of ash elements. Only woody plants are able to assimilate a significant thickness of the soil profile and parent rock, extract and transport ash substances to the surface.

The application of mineral fertilizers immediately after the technical stage of reclamation, before closure of the young stands, will contribute to the formation of a superficial root system of trees, since the roots grow vigorously in the soil horizons richest in mineral nutrients. As a result, the formation of tap and anchor roots that can extract NPK and water from deeper horizons is inhibited. After the depletion of NPK reserves in the surface soil layers, there will be a depression in the growth of forest plantations, and sometimes their degradation. Therefore, it is necessary to wait for the young stand to form a deep root system, and only then apply fertilizer. When these conditions are met, a continuous process of growth of the aboveground phytomass of the stand will be ensured. As a result of the annual fall of leaves, needles and bark, forest litter will begin to accumulate in 10–15 years. After another 10–15 years, the lower layers of the forest litter, in the process of partial decomposition, will acquire the structure of coarse humus and regularly replenish the soil with ash elements.

For the complete restoration of the humus-accumulative horizon and saturation of the surface soil horizons with NPK to the extent that is observed in natural soils, several generations of forest are required. But it can be conditionally considered that in areas where original conifers immediately gained a dominant position, the main stages of forest reclamation will end by the age of ripe stands, i.e. within 80–100 years. By this time, a natural balance has been established between the upward and downward flows of ash substances.

4 Conclusions

1. In forest soils, the main part of the elements of mineral nutrition of plants—nitrogen, phosphorus, potassium—is concentrated in the forest litter and the humus horizon. Removal of A0−A1 sharply reduces soil fertility, negatively affects reforestation, productivity and quality of new forest ecosystems.
2. On moderately moist soils in pine forests of lingonberry-green moss, green moss-berry and blueberry-lingonberry-moss groups of forest types, reforestation is more successful due to the admixture of birch. However, here, the productivity of young stands on strongly disturbed soils is 2 times lower than on slightly disturbed areas.
3. To restore the fertility of heavily disturbed (more than 70%) forest soils, it is proposed to provide a "return" of mineral nutrition elements to the upper (A0−A1) horizons

of the soil by oligotrophic tree species with a deep root system, which consume nitrogen, phosphorus, and potassium from the accumulative horizon of soils and the parent rock.

4. Reclamation of mechanically disturbed soils using forest plantations without the use of intensive agricultural technologies is low-cost, but it takes decades to form full-fledged coniferous (primarily pine) plantations. It should provide for the restoration of not only soil fertility, but also original phytocenoses capable of reproducing all types of forest resources.
5. Reclamation of mechanically disturbed soils with the help of forest plantations should be used only with a strong degree of soil destruction, when the removal of the A0 + A1 horizons or backfilling them with low-fertile soil exceeds 70% of the site area.

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Practical Application of Precision Farming in Russia

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Abstract. The main driver for the precision farming market worldwide is cost optimization and increased yields. It is these two factors that basically induce farmers to introduce precision farming into their farms and rebuild their work for new technologies. The article examines the practical aspects of application of precision farming in Russia, the existing problems and possible solutions. The most important and urgent problem of domestic farmers in the introduction of precision farming technologies into the economy is the financial aspect of the issue. Most Russian farmers are ready to introduce the latest technologies in their fields, but lack of funds and fear of taking on financial risks are an obstacle to innovation. On the other hand, an acceptable price, along with a high level of support from the supplier and clear and accessible operating rules, can play a decisive role in a farmer's decision to purchase a particular solution for use on his farm.

Keywords: Precision farming · Russia · Technology · Digital technology · Production · Agricultural sector · Crop

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1 Introduction

Precision farming is an innovative farming method that uses the latest technology to improve crop quality. Precision farming technologies involve the use of precise remote sensing data such as imagery or video from drones or satellites. Precision farming is an integrated high-tech agricultural management system that includes global positioning technology (GPS), geographic information systems (GIS), yield assessment technologies (Yield Monitor Technologies), Variable Rate Technology, and remote sensing of the earth (ERS) and aimed at obtaining the maximum volume of high-quality and cheapest agricultural products, taking into account environmental safety standards.

Depending on the temporal relationship between the collection of information and the use of appropriate agrotechnical measures, there are:

- two-stage approaches (off-line) or approaches based on mapping;
- one-step approaches (on-line) or approaches with decision-making in real time ("real-time") or sensory approaches;
- various combinations of one- and two-step approaches or a touch-based approach with map overlay support.

The use of precision farming requires taking into account additional costs, among which the following categories can be distinguished:

- costs of data collection (maps, global positioning systems (GSP), sensors);
- costs of data management (hardware and software);
- the cost of special equipment for the precise implementation of agricultural practices and navigation (GSP-controlled machines and equipment for differentiated tillage, sowing, fertilization, plant protection products, etc.).

The Global Navigation Satellite System (GNSS) is designed to determine the spatial coordinates that make up the velocity vectors, adjustments to the clock readings and the rate of change of the consumer's clock readings at any point on the Earth's surface, the world's oceans, air and near-earth space [1–3].

2 Materials and Methods

On the basis of the content analysis the authors study the role of the precision farming.

The emergence of global satellite navigation fell on the mid-90s XX century.

On the territory of Russia, the main types of satellite free differential corrections are the following systems: EGNOS (only the European territory of Russia, not including the Southern Federal District and the Volga region), providing an accuracy of the range of 40–50 cm; StarFire 1 (John Deere) works only with original equipment and provides 35 cm accuracy.

Among the paid correction systems, Omnistar satellite differential services should be noted, which provide for several types of corrections:

Omnistar VBS with an accuracy of 15–20 cm, Omnistar HP/XP—8–10 cm, and StarFire 2—10–18 cm.

Paid ground corrections include RTCM and RTK systems, which can achieve an accuracy of 50 and 2–5 cm, respectively. RTK requires two dedicated GPS receivers and two radio modems. One receiver, being the base station, transmits the correction as a message to the rover. Both receivers receive additional data from GPS satellites over the L2 channel, which improves accuracy. Such corrections are transmitted over a radio channel within a radius of 11 km from the base station and are limited by the transmitter power and the terrain [4–7].

Corrections that are generated by special software built into the GPS receiver are called internal corrections. They contribute to the accuracy of the movement of signals along parallel rows from 20 to 30 cm. These corrections are characterized by the so-called “drift” of position (decrease in accuracy over time), which is eliminated by periodic correction of the baseline.

Satellite navigation systems are developing in the direction of increasing accuracy, improving the service provided to users, increasing the service life and reliability of onboard equipment of satellites, achieving maximum compatibility with other radio engineering systems and forming differential subsystems.

Geographic Information System (GIS) provides collection, storage, processing, access, display and dissemination of spatially coordinated data. GIS are designed to solve scientific and applied problems of inventory, analysis, assessment, forecasting and management of the environment and the territorial organization of society. They enable the creation of databases with spatial information.

Geoinformation technologies are a set of techniques, methods and methods of using software and hardware for processing and transmitting information, which make it possible to implement the functionality of geoinformation systems. They include: methods of remote sensing of the earth (ERS), database management systems (DBMS), global positioning systems (GPS), methods of analysis, Internet technologies, mapping systems, digital image processing methods.

Mandatory modules of a geographic information system (GIS) are: graphic and thematic databases; transformation of coordinate systems and transformation of cartographic projections; control, analysis and modeling system, data output and presentation system; user interaction.

Among foreign GIS—Maplnfo, ArcGIS, AtlasGIS, WinGIS, MGE, MapPoint and domestic—GeoDraw, Sinteks ABRIS, GIS “Economy”, “Panorama AGRO”, “Map 2011”, mobile GIS of electronic accounting of agricultural lands “GEOUchetchik”, informational and analytical system “GEO-Agro”, GIAS “Management of an agricultural enterprise”, etc.

The introduction of digital economy technologies, according to the Analytical Center of the Ministry of Agriculture of Russia, provides positive economic effects and allows you to reduce costs by at least 23% when implementing an integrated approach.

With an unbalanced approach to the use of seed potential, plant protection products, the capacity of the machine and tractor fleet, new technologies, up to 40% of the harvest is lost. Due to the introduction of digital technologies, the total increase in agricultural production may amount to 361.4 billion rubles.

The actual volume of crop production in 2017 amounted to RUB 3033.2 billion. The volume of crop production using digital technologies is 3227.1 billion rubles.

The expected increase in crop production due to the introduction of digital technologies is 193.9 billion rubles. In the Russian Federation, there are about 112.9 thousand IT specialists in the agricultural sector, or 2.4% of the total population employed in agriculture.

To achieve the indicator as in the leading countries (USA, Germany, Great Britain), Russia needs another 90 thousand IT specialists in agriculture. In Russia, there is approximately one IT specialist for every 1000 people employed in agriculture.

The average cost of production of cereals for a cult will amount to an average of 6579.5 rubles/ton, and after the introduction of the digital economy—5066.2 rubles/ton. (saving about 30%).

Based on the rating of countries by the level of innovation Global Innovation Index-2017—Russia is in 45th place out of 127 (–2 positions in 2017 in relation to 2016). Moreover, the share of innovative products in the total volume of goods shipped and work performed in the agro-industrial complex (according to the National Research University Higher School of Economics): Spain—12.7%; Denmark—11.6%; Netherlands—9.2%; Russia—1.4%.

According to the Analytical Center of the Ministry of Agriculture of Russia, digital platforms increased by 11% in 2017. In Russia, in recent years, in the field of precision farming, the systems of parallel driving, informatization and monitoring, yield mapping and differentiated fertilization have been most actively used. Many agricultural holdings and farms are switching to the creation of electronic maps of fields.

When introducing a system of precision farming technologies, it is necessary to take into account the estimated costs for each of them and the numerous factors and circumstances that ultimately provide an effect.

Some cost categories are implemented once every 5–10 years, others—annually. The attractiveness of precision farming technologies, like other technological innovations, in practice is determined by economic efficiency.

The following Tables 1, 2 and 3 present the ratings of regions of Russia in precision farming шт 2018. The ratings were compiled on the basis of the data obtained from 52 regions and the reliability of the research results, primarily with the reliability of the presentation of information by the regional departments of the Ministry of Agriculture of Russia.

Table 1. Use of elements of precision farming by the number of farms.

Region	Number of farms using precision farming elements
Krasnodar territory	189
Voronezh region	182
Nizhny Novgorod region	144

Source Using elements of precision agriculture in Russia, https://agriecomission.com/base/ispolzovanie-elementov-tochnogo-selskogo-hozyaistva-v-rossii

The number of farms in the region using elements of precision farming are presented in the Table 1.

Table 2. Use of elements of precision farming by area.

Region	Total area on which elements of precision farming are used, hectares
Voronezh region	1,129,164
Krasnodar territory	962,981
Omsk region	921,293

Source Using elements of precision agriculture in Russia, https://agriecomission.com/base/ispolzovanie-elementov-tochnogo-selskogo-hozyaistva-v-rossii

Table 3. Programs for the development, support and implementation of elements of precision agriculture.

Region	Number of programs
Sverdlovsk region	49
Vologda region	30
Kaliningrad region	11

Source Using elements of precision agriculture in Russia, https://agriecomission.com/base/ispolzovanie-elementov-tochnogo-selskogo-hozyaistva-v-rossii

As a result of the analysis of farms in the Krasnodar Territory, using elements of precision farming, it was determined that about 156 farms use parallel driving, 94—satellite monitoring of vehicles, 83—determination of field boundaries. As a result of the analysis of farms in the Krasnodar Territory, using elements of precision animal husbandry, it was determined that about 33 farms use an electronic database of the production process, 29—identification and monitoring of individual individuals using modern technologies, 21—monitoring the health status of the herd.

Most of the modern approaches to the economic analysis of precision farming technology are reduced to the assessment of the applied equipment and related technologies in the cultivation of a particular crop. At the same time, it is obvious that the overall agroeconomic effect from the integration of precision farming technologies on the scale of the economy, taking into account the synergistic effects, will be higher compared to the use of individual technological complexes.

Unlike other modern innovation processes, such as genetic engineering, the attitude of the population and consumers towards precision farming is usually positive or neutral. The knowledge-intensiveness of agricultural production and the attractiveness of agricultural professions are increasing, especially among the younger generation of farmers and specialists. However, precision farming technologies are being introduced into agricultural practice relatively slowly.

3 Results

On the basis of the above mentioned analysis, the following conclusions can be made. The state and problems of the digital economy in the agro-industrial complex (according to the Analytical Center of the Ministry of Agriculture of Russia):

- low penetration of digital technologies in rural areas and agricultural production (less than 10% of digitalization), weak coverage by data transmission networks;
- lack and incompleteness of information about existing and developed digital technologies;
- insufficient regulatory and legal consolidation of the legal framework that ensures coordination and interdepartmental interaction in collecting information and introducing digital technologies for the needs of agriculture, providing the population with food and increasing agricultural exports;
- the lack of programs that facilitate the introduction (subsidizing production costs) for the digitalization of the agro-industrial complex for small and medium-sized agricultural producers, including private household plots;
- the lack of legal grounds for interaction and collection of information on the introduction of agricultural activities by households (private households) and the associated limited opportunity to support their activities;
- low marginality (developing segment) of the industry—unattractiveness for the technological and infrastructure investor.

Proposals of the Ministry of Agriculture of Russia for the development (amendment) of legislative and regulatory legal acts in the field of the digital economy of the agro-industrial complex:

- within the framework of the implementation of the Federal Law "On the Development of Agriculture", provide funding for measures to retrain personnel in connection with the release of labor resources and training for the collection and management of data and devices "Internet of Things";
- to increase funding for the construction of infrastructure—antenna mast structures and other information and communication facilities to ensure coverage of rural areas with data transmission networks;
- consider the possibility of preferential provision (subsidizing costs) of land for the placement of infocommunication facilities;
- provide for the possibility of financing developments that develop wireless technologies for building access networks for the "Internet of things";
- provide for the possibility of financing developments in cryptographic algorithms and protocols (schemes) that ensure the security of the formation, storage and transmission of data in the field of the "Internet of Things";
- to provide funding for the promotion of new domestic digital solutions and the protection of intellectual rights, including in accordance with international standards;
- provide for the possibility of state support measures for the implementation (overhaul and modernization) of new technological, digital solutions in the technological chains of food production and sale;

- financing of measures for the creation of agricultural technology parks to support the localization of assembly and production of the necessary foreign ICT equipment;
- to provide for the adoption and financing of measures within the framework of the order of the Government of the Russian Federation "On the approval of the system of state information support in the field of agriculture of the Russian Federation" for a period of at least 5 years.

Many holdings and peasant farms are moving to the creation of electronic maps for more efficient field monitoring. The use of informatization and monitoring systems, and yield mapping should also be expected.

Differentiated technologies will be used more actively. Some farms are starting to use unmanned aerial vehicles. In general, according to forecasts, the number of smart (smart) devices in agriculture in 2–3 years may increase by 1.5–2 times.

4 Discussions

One of the founders of the precision farming methodology, Dr. P. Robert, in 1994 defined it as an agricultural management system based on information and technologies for identification, analysis and management, taking into account differentiated spatial and temporal soil variations in a single field, to optimize costs, increase sustainability of agrocenoses and ecological stability of production. The main goal of precision farming in crop production is to maximize yield, financial benefits and minimize capital investment, environmental impact. The scientific concept of precision farming is based on the concept of the existence of heterogeneities within the same field. To assess and detect these irregularities, the latest technologies are used, such as global positioning systems (GPS, GLONASS), special sensors, aerial photographs and satellite images, as well as special programs developed for agricultural management. The data obtained is used for planting planning, calculating the application rates of fertilizers and plant protection products, more accurate prediction of yield and financial planning.

5 Conclusion

To conclude, the main driver for the precision farming market worldwide is cost optimization and increased yields. It is these two factors that basically induce farmers to introduce precision farming into their farms and rebuild their work for new technologies.

Some of the most used solutions around the world include yield mapping, thrusters and parallel driving, satellite monitoring of crop health, differential seeding, and fertilization and crop protection. Among the countries in which precision farming technologies are at the peak of their development, the USA, Argentina, Brazil and some European countries should be highlighted. Russia, according to the Ministry of Agriculture, ranks only 15th in the world in terms of the digitalization of agriculture.

A large-scale study of what factors are hindering the introduction of such technologies, which the Kleffmann Group company conducted throughout Russia (1756 people in total), studying the awareness and application of integrated solutions for precision farming, showed the following. As a result of the study, it turned out that only 43% of the respondents have experience in using such solutions. The rest stated that they had never used such systems in their economy.

The most important and urgent problem of domestic farmers in the introduction of precision farming technologies into the economy is the financial aspect of the issue. Most Russian farmers are ready to introduce the latest technologies in their fields, but lack of funds and fear of taking on financial risks are an obstacle to innovation. On the other hand, an acceptable price, along with a high level of support from the supplier and clear and accessible operating rules, can play a decisive role in a farmer's decision to purchase a particular solution for use on his farm.

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Basics of Developing a Web-Based Software Complex for Calculating the Chemical Process Characteristics

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Abstract. The article presents the main stages of developing a web-based software complex for calculating the technological parameters of chemical and technological processes taking into account a work with Wolfram Mathematica. The main stages of work, tables, modules, stages of integration of a mathematical model implemented in Wolfram Mathematica with a web-based software complex are presented. The way users and user groups function is taken from a Unix system. Thus, the system administrator is able at any time to easily hide/open a section from a user or an entire group of users. To optimize the time spent on the calculation of characteristics, all user requests (which is recorded without belonging to any user) and their results are entered into the database. If the user entered the query parameters that were already entered earlier and the result was calculated for them, then the results are immediately taken from the database without resorting to the mathematical model itself, and this is the most time-consuming step. The main task of the developed system is to calculate the required calculated parameters based on input data. The program gives a forecast about the characteristics of the resulting product and output technological parameters based on mathematical models of chemical and technological processes.

Keywords: Mathematical model · Web-based software complex · Wolfram Mathematica system

1 Introduction

Industrial development involves finding the parameters of conducting the industrial process which is as close as possible to optimal, and optimization of the process due to the use of different mathematical models of production processes [1–3]. The mathematical model of the technological process, consisting of mass transfer, hydrodynamic and energy modules, can be taken as a basis that is presented in Table 1.

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Table 1. The basis of the mathematical model.

The name of an equation	Equation
Non-stationary convective diffusion equation	$\frac{\partial c_i}{\partial \tau} + \overrightarrow{w} \cdot grad\ c_i = (D_i + D_{iT})\nabla^2 c_i, \quad i = \overline{1, n}$ $\frac{\partial c_i}{\partial \tau}$—the partial derivative of the concentration of the *i*-th component by time (in case of stationary process $\frac{\partial c_i}{\partial \tau} = 0$) where D_i is the molecular diffusion coefficient of the i-th component, c_i is the concentration of the *i*-th component, $\nabla c_i = \frac{\partial c_i}{\partial x}\bar{i} + \frac{\partial c_i}{\partial y}\bar{j} + \frac{\partial c_i}{\partial z}\bar{k}$, D_{iT} is the turbulent diffusion coefficient of the *i*-th component $\nabla^2 c_i = \frac{\partial^2 c_i}{\partial x^2} + \frac{\partial^2 c_i}{\partial y^2} + \frac{\partial^2 c_i}{\partial z^2}$
Convective heat transfer equation (Fourier-Kirchhoff equation)	$\frac{\partial}{\partial t} + \overline{w} \cdot grad\ t = a\nabla^2 t$ $\frac{\partial t}{\partial \tau}$ is the partial derivative of the temperature of the component by time (in the case of a stationary process $\frac{\partial t}{\partial \tau} = 0$), $\nabla t = \frac{\partial c_i}{\partial x}\bar{i} + \frac{\partial c_i}{\partial y}\bar{j} + \frac{\partial c_i}{\partial z}\bar{k}, \nabla^2 t = \frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2}, a = \frac{\lambda + \lambda_T}{C_p \rho}$ is the coefficient of temperature conductivity, λ is the thermal conductivity coefficient, λ_T is the turbulent coefficient of thermal conductivity C_p is the fluid heat capacity, ρ is fluid density
Differential equations of the motion of viscous fluid substance are the Navier–Stokes equations. Special cases	The momentum transfer equations during the flow of incompressible Newtonian fluid are $\frac{d\overrightarrow{w}}{d\tau} = \frac{\mu}{\rho}\nabla^2\overrightarrow{w} - \frac{1}{\rho}\nabla p + \overrightarrow{a}$, where $\nabla p = \frac{\partial p}{\partial x}\bar{i} + \frac{\partial p}{\partial y}\bar{j} + \frac{\partial p}{\partial z}\bar{k}$, (in particular case $\overrightarrow{a} = \vec{g}$) $\nabla^2\overrightarrow{w} = \frac{\partial^2\overrightarrow{w}}{\partial x^2} + \frac{\partial^2\overrightarrow{w}}{\partial y^2} + \frac{\partial^2\overrightarrow{w}}{\partial z^2} = \overrightarrow{i}\left(\frac{\partial^2\overrightarrow{w}_x}{\partial x^2} + \frac{\partial^2\overrightarrow{w}_x}{\partial y^2} + \frac{\partial^2\overrightarrow{w}_x}{\partial z^2}\right)$ $+j\left(\frac{\partial^2\overrightarrow{w}_y}{\partial x^2} + \frac{\partial^2\overrightarrow{w}_y}{\partial y^2} + \frac{\partial^2\overrightarrow{w}_y}{\partial z^2}\right) + \overrightarrow{k}\left(\frac{\partial^2\overrightarrow{w}_z}{\partial x^2} + \frac{\partial^2\overrightarrow{w}_z}{\partial y^2} + \frac{\partial^2\overrightarrow{w}_z}{\partial z^2}\right)$

The Navier–Stokes equations together with the flow inseparability equation, supplemented by initial and boundary conditions, describe the fields of velocities and pressures during the flow of incompressible viscous fluids.

In the case of an ideal fluid (for which viscous friction can be neglected), the Navier—Stokes equations transform into Euler equations:

$$\frac{d\vec{w}}{d\tau} = -\frac{1}{\rho}\nabla p + \vec{a} \tag{1}$$

$$-\frac{1}{\rho}\nabla p + \vec{a} = 0 \text{ is the Euler equilibrium equation (w = 0)} \quad (2)$$

The analysis of viscous fluid motion using the Navier–Stokes equations is carried out for the flow core and for the boundary layer.

2 Materials and Methods

The main task of the system being developed is to calculate the required calculated parameters based on the input data. Thus, the program will give a forecast about the characteristics of the resulting product [4–10].

The system is a web application that allows to carry out the following actions:

- To calculate the characteristics according to the mathematical model
- To keep a log of user requests
- To provide administration capabilities.

3 Results

The main stages of the software complex work [11–16]:

1. After authorization, the main page of the program opens to the user.
2. This page is intended to enter data by a factory worker with the name of each parameter and units of measurement.
3. After clicking on the "Calculate" button, the system checks the correctness of the data input on the client side and, if successful, transfers the data to the server.
4. The calculation process is quite long (on average 30 s) and is conducted in the background. Whereby, the system interface gives the user to understand, that it is important to wait, through special drawings and changing the status of the system.
5. After a successful calculation, the output characteristics of the synthesis are displayed in the results window in formatted form.
6. If required to vary one or more output characteristics, the user has changed the input data and started the recalculation. It is important to note that if the user enters a set of input parameters typed early by him or another user, the calculation will occur without time delay, as in this case query results are already stored in the system.
7. A special query log is provided for each user of the system. In this section, the user will be presented with his latest requests detailing the date, time and results. The results are initially displayed in a closed form and represented by a pseudo-link [17–20].

After the user is authorized as an administrator, a page of two frames is opened. There is the menu in the left column and there is the current section of the cms system in the right column. Here it is possible to add/edit/delete system documents, give some users moderator/administrative rights.

The system can be used simultaneously by several users. Also, each user can run some requests for calculation at once.

To reduce the wait time for results it is permissible to run each query as a separate kernel process when integrated with Wolfram Mathematica. After the process has completed, it saves the result to a special file and sends a signal to the network script, notifying of completion of work.

During development, it was necessary to ensure the secrecy of the source code of the system which was a commercial secret. The structure of the database of this project is defined on the basis of tasks. The description of all used tables and their fields is presented in Table 2.

Table 2. Used tables and their functions.

Table	Function
“Users”	Keeps information about all users of the program
“Requests”	Keeps information about all calculation requests
“Query results”	Keeps the results of calculation requests
“Query log”	Keeps information of all user requests
“Static pages”	Keeps information about all static pages of the site
“Meta Documents”	Service table, administration subsystem documents
“Meta Tables”	Service table, used administration subsystem tables
“Meta Elements”	Service table, functional elements of the administration subsystem
“Meta Properties”	Service table, properties of functional elements of the administration subsystem
“Meta Group”	Service table, administrative subsystem user groups
“Meta Users”	Service table, administration subsystem users
“Meta Group privileges”	Service table, privileges of administrative subsystem user groups
“Meta Group privileges”	Service table, privileges of administrative subsystem user groups
“Meta Pages”	Service table, used pages of administration subsystem

When designing the system, the following modules should be highlighted. The modules are presented in Table 3.

The network client–server scheme of user interaction is preferred as a method of implementation of the software product. This choice solves the tasks in the easiest way:

- All source code of the program is on “his” computer. The *result* of the work is sent to the user and therefore he does not have direct access to the code [21].
- To work, the user only needs a browser as a client application.

Table 3. Modules.

Module	Function
"Calculation of queries"	It is responsible for data input and calculation of synthesis characteristics
"Query log"	It is responsible for collecting information about the requests of the current user and displaying them in the form sorted by execution time
"Administrator"	It is responsible for capabilities of administration resource and power

- To make updates and find errors.

To do this, a software package was installed and configured. The package consists of:

- Web servers
- DBMS
- Wolfram Mathematica system

Integration with Wolfram Mathematica occurs in the following way:

- After the user has entered the input in the correct form, it is sent to the server. The server script exposes them to a secondary validation. If successful, the data becomes a part of the shell command that is passed to the math file. A file where the result of the Mathematica process will be written is assigned using the *tee* command. The php function *popen* is used, which opens the thread to the process specified in the shell command and returns a pointer to the stream receiver file.
- On the Wolfram Mathematica side, the mathematical model was presented in the format *.nb (Mathematica Notebook file). So that the model becomes available to the system core and input parameters can be passed into it. These parameters must be rewritten in a special package that uses the Mathematica core language. Thus, it became possible to call it from the script and it is run as a separate process.
- After Mathematica has worked out and written to the file the result of the calculation of the mathematical model, the *popen* function receives the end signal and continues to the execution of the script. There are parsing and formatting of the result and its output to the user.

4 Discussion

In order to optimize the time spent on calculation of characteristics, all user queries and their results are entered into the database. Requests are recorded without belonging to any user. Thus, if the user entered the query parameters that were already entered before and the result was calculated for them, then the results will be immediately taken from the database without resorting to the mathematical model, and this is the most time-consuming stage.

At the same time, each request will be written to the user's query log, where he can view the dynamics of the results.

In terms of own developing product for web resource development, the system allows not only to add/edit/delete records in database tables, but also to organize from one or more tables semantically whole documents. Each field will become a function element of the document with its own type and properties.

Using this principle, a special section was built for the product administrator with documents:

- Users
- User requests
- Query results
- Query log
- Static pages.

Also, there is a special SQL section that allows to import sql dumps or write sql queries manually with the opportunity to debug in the system.

The "Users" and "Access Rights" sections should be implemented, each of which splits into two subsections that are "Users" and "Groups". Sections are responsible for ensuring that administrator can divide low-ranking admin-users and moderators into groups and assign rights (view-edit-delete areas) to them as specific users and groups. The way of users and user groups function is taken from the Unix system. Thus, the system administrator can hide/open a section from the user or a whole group of users at any time.

As a result of the performed works, a software product is obtained, allowing to calculate the required parameters of conducting an industrial chemical product.

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Mathematical Modeling of Cyber-Socially-Physical Systems in Transport

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Abstract. The implementation of plans to create "smart cities" as one of the most important areas of the digital economy requires the priority development of transport infrastructure, ensuring the movement of people and goods within the city and adjacent territories. Safe operation and maximum throughput of the resulting cyber-physical system are possible provided that a diagnostic technology is created for transport infrastructure facilities, including video-based road conditions. The authors' vision of the problems of mathematical modeling of cyber-physical systems in transport is presented as a three-level hierarchical structure, including environmental sensors at the lower level, data processing centers (DPC) at the middle level and a single data storage center for developing management decisions at the upper level. Prospects for data center modeling based on a multi-agent approach and a technical vision algorithm that is proposed to be implemented as a program on a mobile device to identify objects of transport infrastructure and their defects using stereometry are explored. The presented algorithm can be used in the planning of road repairs, in the analysis of road accidents, in the processing of applications of road users, etc.

Keywords: Roads as a cyber-physical system · Multi-agent method · Photogrammetry

1 Introduction

Automation of the diagnostics of state transport infrastructure facilities and the related need to develop modules for mathematical modeling, design and production of devices and diagnostic tools as part of the control system of the transport cyber-physical system, which provides physical accessibility of infrastructure and cities, causing an urgent problem within the concept of "smart cities" as one of the most important directions of digital economy [1]. At first, the quality of the road surface along with the category of the road, its visibility, the width of the roadway, and the location of the suitable road signs has a significant influence on road safety and traffic flow capacity. Together, they define the concept of "road conditions", on which the trajectory and the car's speed depend. According to experts the influence of road conditions on the occurrence of road

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traffic accidents, is from 60 to 80% of cases [2, 3]. Moreover, accidents are one of the most common causes of death in the world. Though in 2020, taking into account that most countries experienced some periods of lockdown due to Covid-19, which reduced people's mobility and thus, crash risk, the total number of road deaths decreased (-4.9%) [4], the task of null road fatalities is still far from the full solution. Secondly, according to the results of road accidents' analysis, there is need to identify those who is responsible for the violation of traffic rules (traffic regulations) and the cost estimate of damaged auto motor-vehicle's repair (AMV) [5]. Thirdly, economic and social losses due to a decrease in the traffic flow's speed and the according road's capacity, caused by the existence of cracks and potholes in the road surface tend to increase with untimely detection and repair [6].

Quite often controversial situations arise, the investigation and examination of which is carried out on available materials, including photographs and video filming. According to the European Protocol, participants in a road incident can use mobile devices to record and register all circumstances (Fig. 1). In Fig. 1a, the driver of the motorcycle recorded a general traffic situation. In Fig. 1b, to understand the scale and size of potholes, the driver used a glove as a marker for scale [7].

a) b)

Fig. 1. Pictures of potholes in the road surface

In this situation, the motorcycle owner will have to prove that the road surface does require operating conditions acceptable for road safety.

A definite breakthrough in solving the problem of objective diagnostics of road conditions was mobile systems based on laser scanning [8] (Fig. 2). However, the high cost of this technology and the lack of information about the texture of road objects complicate the situation.

The use of modern inexpensive photogrammetric methods [9–15] for determining damage and unevenness of the road surface and structural elements of the road gives a new impulse to the development of digital technologies for designing road repairs, increasing mobility and reducing the cost of work.

Based on the foregoing, the development of autonomous mobile devices capable of "on the spot" to perform the tasks of collecting and analyzing road data, including photographs and video, in a form suitable for investigation and examination of disputed situations, is an urgent task.

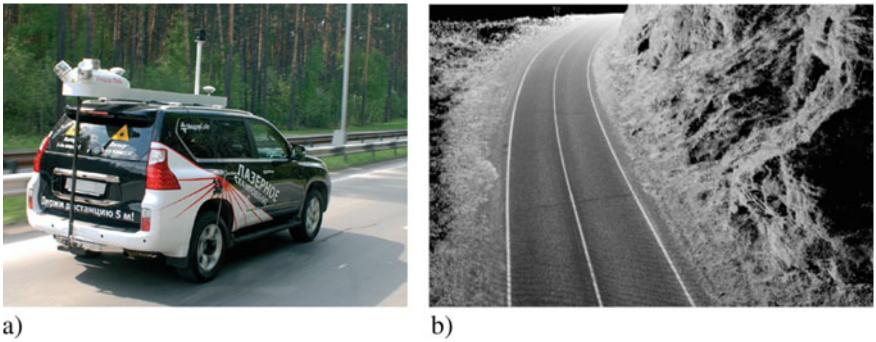

Fig. 2. **a** Image of a mobile laser scanning laboratory of IndorSoft LLC, Tomsk; **b** the resulting cloud of laser scanning points includes reflections from people, equipment, vegetation, etc. located on the object

2 Cyber-Physical Management System of Urban Transport Movement

2.1 Cyber-Socially-Physical Systems in Transport

The considered above autonomous mobile road data collection and analysis de-vices, which operate as part of a single measuring and processing complex, are an affordable example of a cyber-physical system in transport (Fig. 3a, b). This also adds a system of stationary city security cameras for road safety and, possibly, a system of unmanned vehicles, which, having a complex software system of artificial intelligence on board, are able to analyze independently the surrounding situation, make decisions and learn from previous experience.

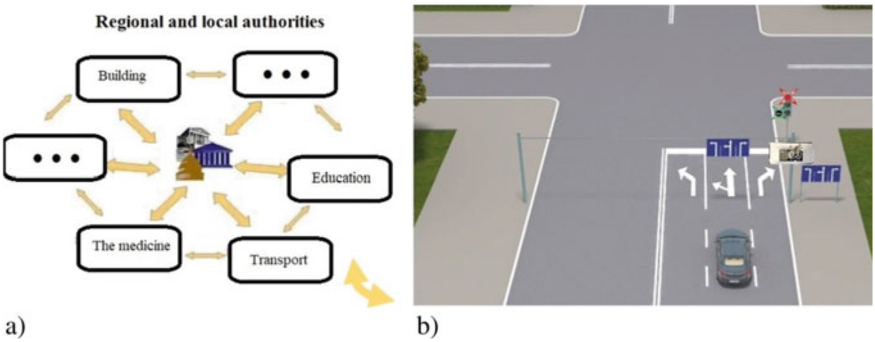

Fig. 3. **a** The regional "electronic" government, **b** the cyber-physical system of urban traffic control

As a result, the totality of such devices forms a heterogeneous distributed system of artificial intelligence, which should be enriched by some hierarchical structure, which would provide the distribution of tasks between devices, their interaction with the environment and the exchange of information in accordance with fundamental goals and settings (Fig. 4). This implies the existence of protocols [16] for their joint work at the lower level of interaction, as well as protocols for sharing in data processing centers (DPC) at the mid-level and further for transfer to a single data center and development of management decisions at the upper level in order to form a global cyber-sociophysical urban traffic management system as part of the concept of creating "smart cities". The appearance of the word "socio" as applied to the road here is by no means accidental, since the road is not a factory or field with the prospect of a deserted production technology, but an indispensable element of the "smart city", providing accident-free operation and maximum throughput of the transport system, with the presence in it of active road users, creating the effect of unpredictability of conscious or unconscious behavior of people, drivers, pedestrians and etc. [17].

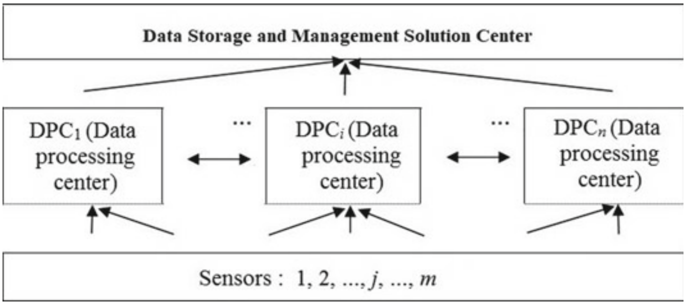

Fig. 4. Block diagram of a cyber-physical urban traffic control system

2.2 Multi-agent Systems as a Tool for Modeling the Interaction of Environmental Sensors in Transport

Foundations of multi-agent approach were presented in a series of works [18–21], where also the possibility of applying stochastic models for the design and research of multi-agent systems of economic actors were discussed. For systems with swarm intelligence as a model Markov random field was proposed. The agents are located at the top of the final graph and are modeled by random variables. In [22–25] was shown the possibility of using multi-agent technology for solving problems of planning in industry and in [26–28] proposed situational approach to the management of resources and developed a multi-agent platform for development of intelligent systems that preserves the scene in the context of the situation, to improve the quality and efficiency of planning in the process of events' changes, including the development of methods of receiving and processing actual data from production resources in real time [29]. The study of connected subsets (clusters) of agents deserves special attention. The formation of clusters corresponds to the allocation of road objects, the creation of a production or transport associations. Under the assumption that agents are located at the vertices of a regular lattice, an estimate of the probability of cluster's existence, penetrating the entire system, can serve the analytical results, obtained for these lattices in the percolation theory. The critical probabilities of nodes and links serve as lower estimation for the agent's coefficients availability, which defines the probability of existence of global cluster and coherent subsets of agents [30].

3 Linear Approach Localization and Identification of Projections of Interpolation Points on Images Determined from Reference Frames of a Video Sequence and Forming a Stereo Pair

The bibliography [10–14] analyzes the key component of the proposed cyber-physical system for diagnosing transport infrastructure objects, the role of which is the technical vision system [9], based on the method of photogrammetric processing of stereoscopic images of a three-dimensional 3D object obtained from different angles.

Highlighting the boundaries of flat images is one of the important auxiliary tasks in recognizing defects in transport infrastructure objects, in particular, damage to the road surface. They contain comprehensive information about their form for subsequent analysis [31–34]. As a preliminary conclusion, we note that the images of objects of transport infrastructure are characterized by the presence of angles formed by the intersections of generators (curves or straight lines). Therefore, for the analysis of such images, it is advisable to use the so-called «angular» filters, in particular, the use of the Harris detector is popular [32, 34].

3.1 Experiment Results

To illustrate the photogrammetric method, let's consider a real stereo pair corresponding to two photographs of the packaging box, including the four corners of a label with a bar code (Fig. 5). The experiment was to test the ability to automatically search for graphic markers and anchor points in photographs (Fig. 6). Remind that precisely these points must be found on each image in order to successfully solve the problem of photogrammetry. In particular, in Fig. 7, 84 show the use of the Harris detector [32, 34] for detecting conjugate points on the left and right frames of a stereo pair [35–41].

4 Conclusion

The implementation of the resulting algorithms and the automation of the searching process for graphic markers and reference points on the photos are supposed to be implemented on a smartphone running the Android OS. In conclusion, we must say that the mobile collection of data about defects of transport infrastructure, particularly road surface can be much more effective with the use described in this report metods. It is also worth considering that because of the peculiarities of image defects of a roadbed (the lack of clear boundaries, the presence of extraneous objects, the insignificance of some of the defects) should be pre-see the possibility of «manual» marking of characteristic point on images.

The practical application of photogrammetric diagnostics methods of the transport infrastructure is quite wide, including, fixing and determining the real size of the damage motor vehicle (MV) on the measured coordinates of surface's points of the body parts (Fig. 7) [7].

Fig. 5. A stereo pair of two photos of the packaging box

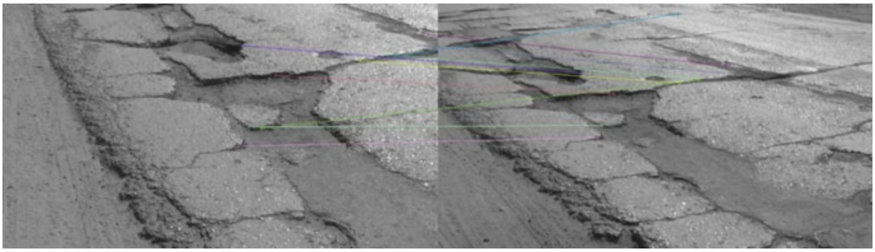

Fig. 6. A stereo pair of two photographs of a real road surface depicting damage to the road surface

Fig. 7. Photos of a car damaged by falling snow mass

Examination of the nature and list of injuries motor vehicle (MV) provides fixation of the damage to determine whether their formation and involvement in the studied event. The results of visual inspection of the damaged vehicle and photographing are issued by the relevant act. Photographs and an inspection of the damaged motor vehicle (MV) shall be attached to the expert opinion or valuation report of the repair motor vehicle (MV). Of course, the photogrammetric method is a strong argument to determine the decision of disputable situations, and to determine actual dam-age of motor vehicle (MV) elements on photos and video is the actual task [7].

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Influence of Agroecological Factors on the Qualitative State of Soils of Krasnodar Krai

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Abstract. The paper discusses agroecological factors affecting the quality of the soil. The data on changes in climatic indicators in the period from 1980 to 2015 are presented. The results of studies on changes in the structure of the soil cover in typical areas of the Northern and Central climatic zones of the Krasnodar Krai are presented. The influence of agricultural land use on soil properties is revealed. The change in the density of chernozems is given depending on the degree of soil washout. The patterns of changes in the hydrophysical properties of ordinary chernozems of different degrees of washout were revealed. The change in the structural state of soils is given. It is concluded that changes in the structure of the soil cover and morphometric characteristics of the soils of the polygons (Timashevskiy district, Novokubanskiy polygon, and the municipal district of Krasnodar) under the influence of natural and climatic factors indicate the manifestation of degradation processes in soils. In particular, in the Timashevsky district, the processes of waterlogging and flooding are most developed, as evidenced by the dynamics of their areas. In the Novokubansky district, erosion processes (water, wind) are developed, as evidenced by the data obtained in the course of studies on reducing the humus layer, depending on the degree of manifestation of degradation processes. In the municipal district of Krasnodar, compaction and merging are developed.

Keywords: Agroecological assessment of soils · Erosion · Waterlogging · Flooding · Compaction · Merging

1 Introduction

Recently, soil fertility, depending on its functions, acts not only as an agronomic category, but also as a philosophical, social, economic and ecological category. Management of soil fertility is carried out through the impact of elements of farming systems and agricultural technologies on the soil [1–5]. Assessment of soils is currently carried out according to the degree of degradation, pollution, forecasting the processes of erosion, salinization, desertification, waterlogging, violation of ecological and economic balance, etc. The restoration of soil fertility and the preservation of highly productive lands are the main component of regional adaptive landscape systems of agriculture [6].

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Agroecological factors are one of the factors affecting the quality of soils [7–11]. These include: climate, relief, soil and others. In the context of obsolescence of data on soil surveys carried out in the 60—80s of the last century, the need for obtaining relevant information is increasing. The last areas of continuous soil survey in Krasnodar Territory were Abinsky (2000), Seversky, Yeisky, Krymsky districts (1999), Krasnodar (1999) and Novorossiysk (1994) [12].

2 Materials and Methods

The analysis of factors affecting the assessment of soil quality and soil cover structure was carried out in the most typical areas of the Azov-Kuban lowland—Yeisky, Beloglininsky, Kanevsky, Novokubansky, Timashevsky districts, Krasnodar. A detailed study of the changes in the structure of the soil cover, its composition and properties was carried out in the Novokubansky, Timashevsky districts at the polygons of the state soil monitoring network and on the lands of the Krasnodarskoye educational farm in Krasnodar.

In addition, materials of three rounds of soil surveys of Yeisky, Timashevsky and Novokubansky districts, lands of Krasnodar, a report on "Dynamics of the areas of lands exposed to adverse effects ..., in the Timashevsky district, 1998–2000", materials of the III and IV rounds of the cadastral assessment of agricultural land, images of the QuickBird satellite (2004–2007) and KALandsat-7, Google (Google images, aerial photographs taken by the North Caucasian branch of the RRDC "AIUS-AGRORESURSY" in 1988–1991 in the Timashevsky district); materials of agrochemical surveys in 1985–2015 (ASC "Krasnodarsky", agro-climatic bulletins of the Krasnodar Krai (1980–2015), own materials obtained in the course of soil surveys (2017–2018).

In the process of performing the work, the following methods were used: comparative geographical, comparative historical, profile, remote sensing, and GIS technologies.

3 Results

The climatic indicators that are most widely used in the agricultural practice were taken—the amount of precipitation and the sum of active temperatures. We have analyzed the dynamics of agro-climatic factors for the period 1980–2015, according to the following indicators: the amount of precipitation for the year and for the cold period, as well as for the periods April–June, July–September; the sum of active temperatures ($>10°$) for the entire period and for the period April–June, which revealed a different trend. According to the sum of active temperatures $>10°$ in typical areas of the Northern and Central natural and climatic zones, there is a tendency to increase this indicator for the entire period and for the period April–June with rather high values of reliability (approximation—R^2). The most reliable increase in the sum of active temperatures was noted in the Yeisky district (for the year $R^2 = 0.7549$, April–June $R^2 = 0.8397$) and Krasnodar $R^2 = 0.6949$ and 0.5355, respectively (Fig. 1). Despite the studies of a number of authors on the increase in the amount of precipitation in almost all regions of Russia, we found that for the observed period, the amount of precipitation for the year, for the cold period and for the period April–June did not show a reliable trend of increase or decrease. Probably, we can talk about extremalization of the climate.

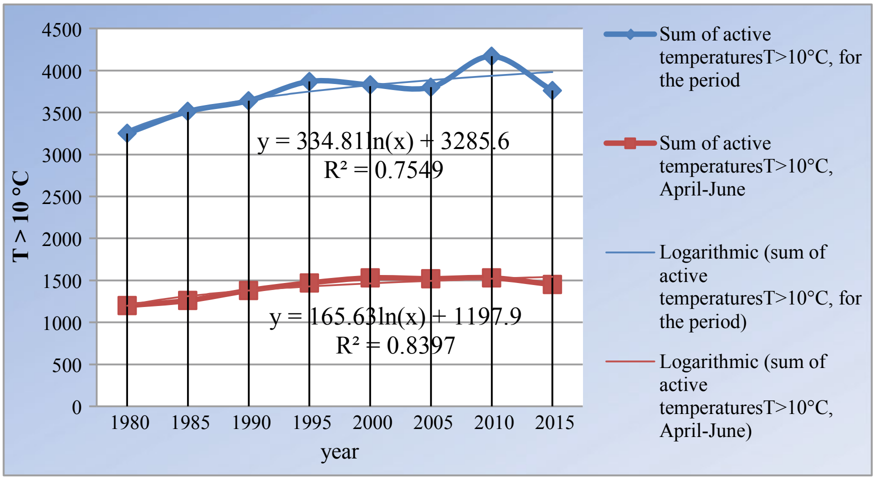

Fig. 1. The trend of an increase in the sum of active temperatures (T > 10 °C) on the territory of the Azov-Kuban lowland (Yeysk weather station)

Changes in the structure of the soil cover and morphometric characteristics of soils. Generalization of information from different sources (topographic maps, aerial and satellite images, and materials of soil surveys) made it possible to compile an objective picture of the development of the processes of waterlogging and flooding of lands in the Timashevsky district (Fig. 2). The data on the change in the structure of the soil cover were obtained on the basis of generalizing the materials of the soil survey of the Timashevsky district, carried out by the KubanNIIgiprozem Institute for three periods (rounds): I-1972, II-1987, III-2000. During the first survey, 86% of the arable land was occupied by zonal typical and ordinary chernozems, the share of leached and leached compacted chernozems confined to the bottom of the ravines was 7.2% in total, and meadow and meadow chernozem compacted and merged soils of closed depressions were about 6%.

After 15 years (in 1987), the leached chernozems disappeared. The area of zonal chernozems decreased by 1.3%, due to which the share of hydromorphic soils increased to 15.2%, and meadow-chernozem compacted soils appeared. Further, this process developed on an increasing basis. After another 13 years, the share of zonal soils decreased to 81.3%, and almost 19% were their semi-hydromorphic analogs (meadow and meadow chernozem soils), and the final point of modern evolution was meadow-chernozem compacted soils.

Attention is drawn to the growth of areas of flooded and waterlogged lands, on average 528 hectares per year.

Differences in the morphometric characteristics of the soils of the Timashevsky district are associated with different degrees of moisture.

The difference between meadow chernozem soils, according to “KR,…1977”, was established by our research and consists (by 15 cm) of the thickness of the “A + AB” layer—127–132 cm, and a higher occurrence of hydromorphic features.

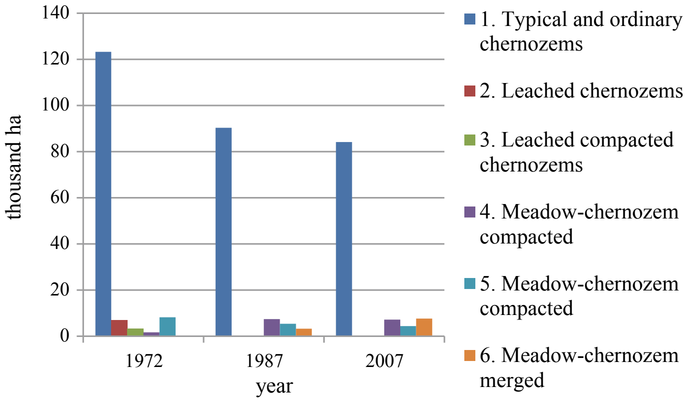

Fig. 2. Changes in the structure of the soil cover of the steppe agrarian landscapes of the Timashevsky district (data from the KubanNIIgiprozem)

When studying the structure of the soil cover of the Krasnodarskoye educational farm, the catena approach was also used, i.e. the establishment of soil sections along the line connecting different, but geomorphologically and geochemically conjugated, relief elements.

To characterize the morphological structure of the profile of leached chernozems, meadow and meadow chernozem compacted soils, a description of the sections laid in the Krasnodarskoye educational farm at the top of the watershed (arable land) is given. In meadow and meadow chernozem compacted soils, periodic waterlogging contributed to the appearance of hydromorphic features in the form of ocher spots, strong compaction and deterioration of the structural state of horizon B.

The Novokubansky polygon is located in the zone of intense manifestation of the processes of wind erosion of soil (deflation), which led to a decrease in the thickness of the humus layer. Weakly deflated chernozems are allocated on an area of 100,359 hectares, medium deflated—11,719 hectares. To study the dynamics of the structure of the soil cover and determine the actual thickness of the humus horizon in ordinary chernozems in the Novokubansky district of the Krasnodar Krai, we carried out a set of field studies.

As a result of the research, the following conclusions were made: the thickness of the humus layer of non-eroded chernozems averages 118 cm; for ordinary weakly washed out chernozems, the lower boundary is set to a depth of 83 cm, which corresponds to a 30% decrease in the A + AB horizon; for the medium washed out—59 cm (31—50% reduction in the reference horizon A + AB); for strongly washed out—less than 56 cm (50% and more reduction of the reference horizon A + AB).

The influence of agricultural use on the agrophysical properties of soils. Analysis of changes in the structural state of soils in lowland depression agrarian landscapes made it possible to reveal a difficult-to-explain tendency towards a decrease in the content of agronomically valuable aggregates over a 45-year observation period by 10% in the lower part of the profile of ordinary chernozems. Research has established a significant difference in the content of agronomically valuable aggregates in the profile of chernozems and their semi-hydromorphic analogues:

- 60.4–79.8% for ordinary chernozems
- 50.4–52.1% for compacted meadow chernozems
- 36.0–32.0% for merged meadow chernozem soils.

Krasnodar city. Analysis of the micro-aggregate composition of the upper part of the humus layer of leached chernozems indicates a relatively high water resistance of the microstructure—the dispersion factor is 10.3–18.5%. It should be noted that its greatest value falls on the plow sole. Due to the intense influence of the anthropogenic factor (the influence of the working parts of the processing tools), the structural state of the soil profile changes significantly: artificially created layers are formed—loose arable and compacted—"plow sole" [13].

Due to this differentiation of the packing of soil aggregates, the soil density along the profile is very different: 0.98–1.14 g/cm^3 in the arable layer, 1.37–1.46 g/cm^3 in the plow sole, 1.35–1.49 g/cm^{3}in the lower horizons.

Novokubansky district. The structural factor shows the water resistance of the structure, which decreases due to water erosion, and the structural factor also decreases. Its dynamics is manifested in a decrease from 88.0 to 81.6% during the transition from non-eroded soils to strongly washed out soils. A similar pattern was revealed in terms of the degree of aggregation. However, in the dynamics of this indicator, the differences are more significant: for ordinary chernozems not subject to water erosion—91.2%, for weakly washed out—83.8%, for medium washed out—83.0%, for strongly washed out—77.6%.

Studies of the density of soils of varying degrees of washout at the Novokubansky polygon (Fig. 3) led to the conclusion that there is a relationship between them, and the nature of this relationship is different, which is probably associated with the degree of anthropogenic impact, or lack thereof.

Our research has established a fairly high total porosity at natural moisture, which reaches 53.0–54.9% in the arable layer of non-eroded and slightly eroded varieties [14, 15]. With depth, it decreases up to 48.2% in highly eroded chernozems (Fig. 4).

The regularities of changes in the total porosity of soils for the arable and underlying soil layers of different degrees of washout are the same, and the approximation value is almost the same ($R^2 = 0.8638$–0.8832).

4 Discussion

During the study period, the change in the main climatic indicators has not been established with sufficient reliability, but there is a high degree of approximation of the trend of an increase in the sum of active temperatures—$R^2 = 0.5151$–0.7549 in the Northern zone and somewhat lower (0.5355–0.6007) in the Central zone. The trend of changes in the amount of precipitation (both annual and for the cold period of the year) is even less reliable ($R^2 = 0.05$–0.49). The reliability of the change in the amount of precipitation

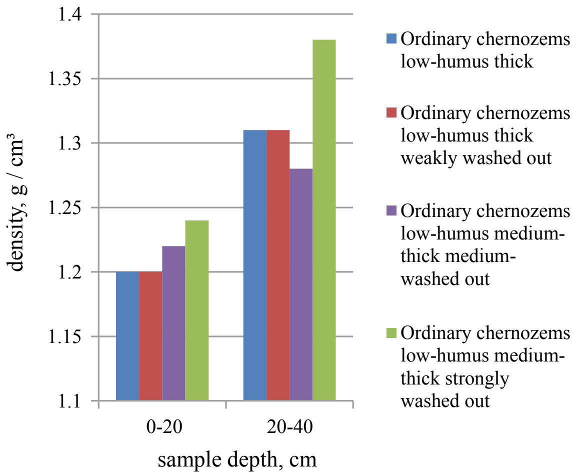

Fig. 3. Changes in the density of chernozems depending on the degree of manifestation of water erosion (washout)

for the year or for the cold period is low ($R^2 = 0.05–0.35$), as a result of which the factor "change in the amount of precipitation", in our opinion, is not decisive.

The dynamics of the structure of the soil cover is revealed, which manifests itself in the annual increase in areas:

- hydrometamorphosed (waterlogged and flooded) soils: Timashevsky district—528 hectares;
- eroded soils: in the Novokubansky district, the area of weakly and moderately deflated soils almost did not change, the area of eroded soils increased by 470 hectares per year (with varying intensity in terms of the degree of erosion).

The change in the morphometric characteristics of the structure of the soil profile consists in:

- the appearance (previously not identified) or an increase in the level of occurrence of hydromorphic signs—an increase of 30–40 cm in the Timashevsky district;
- a decrease in the thickness of humus horizons due to the manifestation of erosion to 83 cm in weakly washed out soils, to 59 cm in moderately washed out soils, and 53 cm in highly washed out soils in the Novokubansky district.

The dynamics of the agrophysical properties of soils consists in an increase in the density of semi-hydromorphic analogs of chernozems (meadow and meadow chernozem compacted and merged soils) of the Timashevsky district and the municipal district of Krasnodar by 7–10% and 18–36%, respectively, a decrease in the number of agronomically valuable aggregates from 60. 4–79.8% in ordinary chernozem to 50.4–52.1% in compacted meadow chernozem, and only 36.0–32.0% in merged meadow chernozem soils.

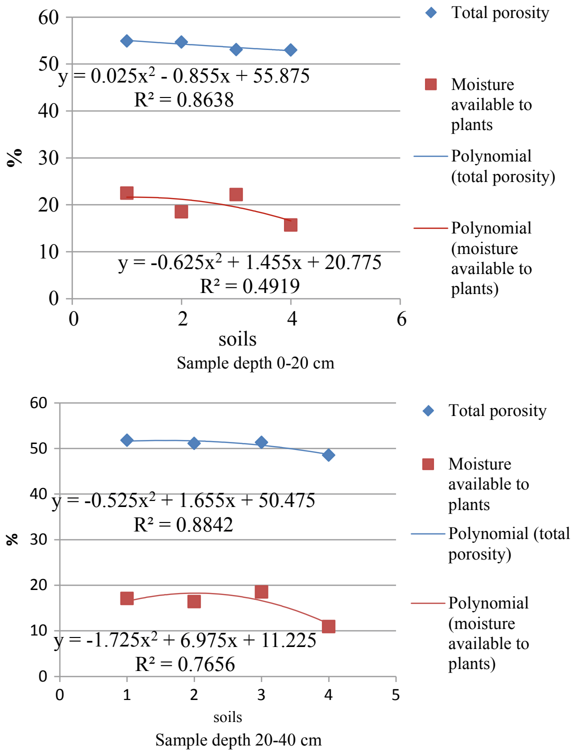

Fig. 4. Hydrophysical properties of ordinary chernozems of varying degrees of washout: 1—Ordinary chernozems low-humus thick; 2—Ordinary chernozems low-humus thick weakly washed out; 3—Ordinary chernozems low-humus medium-thick medium-washed out; 4—Ordinary chernozems low-humus medium-thick strongly washed out

The structural state of soils, described using the indicator "dispersion factor", indicates an increase in the degree of dispersion in soils of lowland depression agrarian landscapes (Timashevsky district and Krasnodar city):

- 10.2–11.2 for chernozems,
- 20.8 for meadow and meadow chernozem compacted soils,
- 24.5–29.6 for meadow and meadow chernozem merged soils.

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An Assessment of the Local Positioning System Effectiveness

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Abstract. An important task in the design of a system for determining the location of mobile objects is to assess the effectiveness of its functioning, since the use of these systems inside premises for managing production processes, ensuring security or logistics, in modern conditions, is one of the digital economy's paramount goals. This scientific work is dedicated to the characteristics of a ZigBee technology sensor network, which is the basis for a local positioning system. The ultimate goal of the study is to build an effective hardware and software complex for indoor geolocation. As a research tool, the authors have chosen an analytical modeling method using the mathematical apparatus of closed queuing networks, which is the most suitable for obtaining the quality of service indicators of telecommunication networks. The time-probability characteristics, which are the quality of service indicators in a geolocation system based on the IEEE 802.15.4 (ZigBee) standard equipment, were obtained in the course of modeling. The aforementioned results make it possible to manage the traffic of the existing or planned sensor network effectively.

Keywords: Geopositioning · Location · Queueing network · Zigbee · RSSI · Model

1 Introduction

The most popular means for determining the location of a mobile object are satellite-based global positioning systems such as GPS (Global Positioning System) or GLONASS (Global Navigation Satellite System) [1, 2]. They provide high measurement accuracy from three to five meters, but are practically inapplicable indoors due to significant strength losses during the satellite signal's passage into buildings and the multipath impact. In addition, the high power consumption of satellite communication systems and their high cost have to be taken into account.

For local positioning purposes, it is customary to use the systems applied in cellular networks, or based on measuring the Wi-Fi access point's signal, or utilizing the active RFID tags to detect an object and track its movements [3, 4].

Another type of geolocation system, combining high accuracy in determining the object's location with low energy consumption and low implementation cost, is considered in this paper. It is the ZigBee sensor network using IEEE 802.15.4 standard

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equipment for positioning. To calculate the sought object's coordinates, it is necessary to measure the RSSI (Received Strength Signal Indicator) parameter from several sensors or the ToF (Time of Flight) parameter [5, 6].

A problem to assess the functioning effectiveness arises when building such a system, since the location data update must be carried out quite promptly and without the accuracy loss. The authors applied the analytical modeling method based on closed homogeneous queuing networks for the assessment.

2 Building a Model of Positioning System Basing on a ZigBee Sensor Network

ZigBee specification is based on the IEEE 802.15.4 standard, which defines the physical layer and media access control (MAC) sublayer of the channel layer, and implements the network and application layers protocols. The short range, low transmission rate, small size and low power consumption of devices, as well as their low price have led to the use of ZigBee technology in the form of wireless sensor networks. The ZigBee main application area is related to the automation of housing, industrial premises, monitoring the movements and locations of property, tracking medical indicators and much more.

Typical characteristics of the IEEE 802.15.4 standard are [7]:

- frequency range: 2.4 GHz;
- throughput: 250 kbps;
- device's maximum output power: 0 dBm (1 mW);
- number of connected devices: up to 65,000.

ZigBee devices are connected to each other over a short distance, forming a piconet with mesh topology. There are three types of devices in the network:

- the piconet coordinator—a master device that manages connections and is able to communicate with other piconets;
- the router that is capable of receiving and transmitting data between the devices that are remote from each other and is responsible for data transmission paths;
- the terminal equipment—a sensor or a switch that can only communicate with a router (or coordinator) and cannot transmit data from other devices. Most of the time the sensor is in a "sleeping" state, which allows it to save battery power.

An example of an indoor positioning system is shown in Fig. 1. The network contains a number of nodes, some of which have known coordinates and called anchor, and the rest are called blind and determine their own positions based on the coordinates received from the anchor nodes and RSSI [8]. Typically, the anchor nodes with downward pointing antennas are located near the ceiling. They are outlined with dark circles in Fig. 1.

Network nodes with known or calculated coordinates receive the radio signal of the mobile object and transmit the information to the piconet coordinator, from which this information is sent to the server, where the calculation of the object's position is happening. There must be at least three anchor nodes in the network to obtain the coordinates of a mobile object. Increasing the number of anchor nodes improves the measurement accuracy, but complicates the wireless routing process and degrades quality of service parameters.

A model of a local positioning system in the form of a Markov homogeneous closed queueing network is shown in Fig. 2.

The nodes of this queueing network are the time delays in devices and interfaces of the system shown in Fig. 1. The model is built taking into account the technical characteristics of ZigBee standard and allows for scalability.

Transitions of jobs from node to node are specified by the routing matrix:

$$\Theta = \left\| \theta_{ij} \right\|, \quad i, j = \overline{1, N},$$

where θ_{ij} is the probability of job transfer from ith queueing system to jth [9, 10].

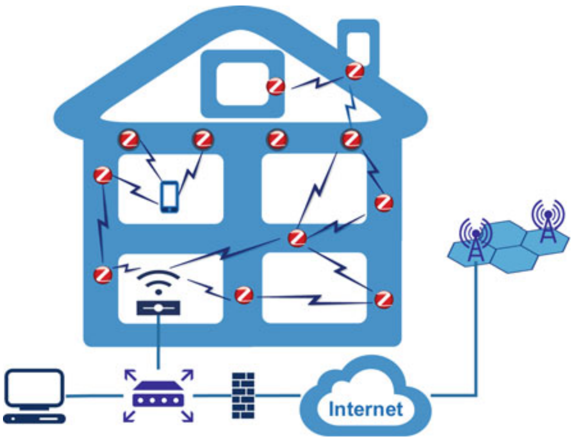

Fig. 1. Local positioning system based on ZigBee

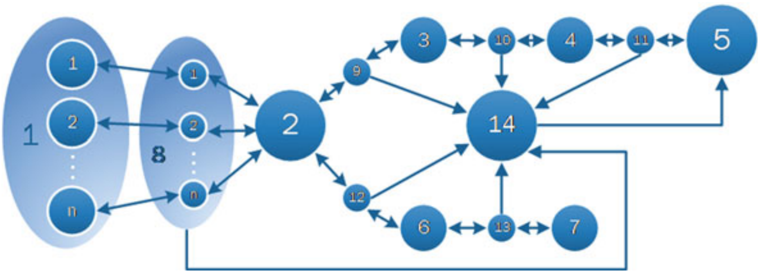

Fig. 2. Closed homogeneous queuing network that is a positioning system model

In Fig. 2 nodes 1–3 have serving devices with infinite server (IS) queueing discipline, nodes 4–8 are queuing systems with processor sharing (PS) servicing order, and the rest are single-channel or multi-channel queueing systems with first-come, first-served (FCFS) servicing order.

3 Mean Value Analysis

The following methods can be used to analyze queueing network [9, 10]:

- global balance equations;
- local balance equations;
- Gordon–Newell theorem;
- Buzen's algorithm;
- mean value analysis.

The mean values analysis (MVA) method, which does not require significant computational resources and allows calculating time-probability characteristics in a recurrent way, was chosen by the authors. Through applying the MVA it is possible to determine such parameters as the average number of jobs in the queueing network nodes, which are queuing systems, the average job service waiting time, the average time spent by a job in the node, etc.

The method is based on the queuing theory's two fundamental relations: Little's law, which expresses the average number of jobs in the system through the intensity of the incoming job flow and the average job stay time in the system, and the arrival theorem [11].

The arrival theorem allows us to recurrently calculate the average job stay time at the ith node as the sum of the average service time of previously received $\overline{K_i}(k-1)$ jobs with the average service time of the current job, taking into account the servicing order used in the given queuing system and the fact that the average number of jobs in each queueing system, provided that there are 0 jobs in the queueing network—$\overline{K_i}(0) = 0, \quad i = \overline{1,\ N}$. This is possible, because this theorem states that if we consider the ith node of a Markov closed queueing network, in which there are k jobs, at the moment when a new job arrives at it, the stationary probability of this node's state coincides with the stationary probability of its state provided that there are $k-1$ jobs in the network. The total number of jobs in a closed queueing network is constant and equal to K.

Thus, the characteristics calculation begins with the calculation of the average reaction time $\overline{T}_i(k)$:

$$\overline{T}_i(k) = \frac{1}{\mu_i} \cdot \overline{K}_i(k-1) + \frac{1}{\mu_i} = \frac{1}{\mu_i}\left[\overline{K}_i(k-1) + 1\right].$$

Next, it's possible to determine the average time spent by the job in the queueing network:

$$\overline{T}(k) = \sum_{i=1}^{N} e_i \overline{T}_i(k),$$

where $e_i = \frac{\lambda_i}{\Lambda}$ is the relative arrival rate (the average number of job arrivals to the node (i), λ_i is the intensity of the job flow entering the ith node; Λ is the queueing network throughput.

Using Little's law, we determine the throughput of queueing network:

$$\lambda(k) = \frac{k}{\overline{T}(k)}.$$

Then the intensities of the job flows entering the *ith* nodes:

$$\lambda_i(k) = e_i \cdot \lambda(k).$$

Average number of jobs in the *ith* queueing system according to Little's law:

$$\overline{K}_i(k) = \lambda_i(k) \cdot \overline{T}_i(k).$$

The calculation is repeated for $k = 1 \ldots K$ values—the number of jobs in a closed queueing network.

According to the well-known formulas of the queueing theory [12], the remaining characteristics of the queueing network are calculated: utilizations, downtime rates, average job service waiting time, average queue length, etc.

Figures 3, 4, 5, and 6 show the analytical modeling results, which are the graphs of the relationships between of the quality of service indicators and the network load for the different numbers of active devices (5, 10 and 20).

4 Results

Figure 3 illustrates the changes in data transmission delay. An increase in the number of traffic generating devices leads to a deterioration of the indicator, the value of which, however, does not exceed the value established by the IEEE 802.15.4 standard.

Figure 4 shows the relationship between the loss probability and the network load, which undergoes minor changes with both an increase in the number of jobs in the network and an increase in the number of active devices, without violating the requirements of the standard.

As can be seen in Fig. 5, system performance increases with the raise in the input load and decreases with the addition of new anchor nodes. This is explained by the fact that a larger number of active devices generate a larger volume of network traffic, which leads to an increase in delay and buffer memory losses of the transit devices due to mutual interference in the radio channel. However, even the lowest performance value guarantees a minimum transfer rate of 64 kbps, which is considered acceptable for this technology.

The utilization shown in Fig. 6 behaves predictably with an increase in the input load and the anchor nodes number, while its value in the worst case does not exceed 1, i.e., the stationarity of the system is not violated.

Thus, the calculations results show that the time-probability characteristics of the local positioning system are determined by the network load and anchor nodes number and coincide with the constraints defined by the IEEE 802.15.4 standard.

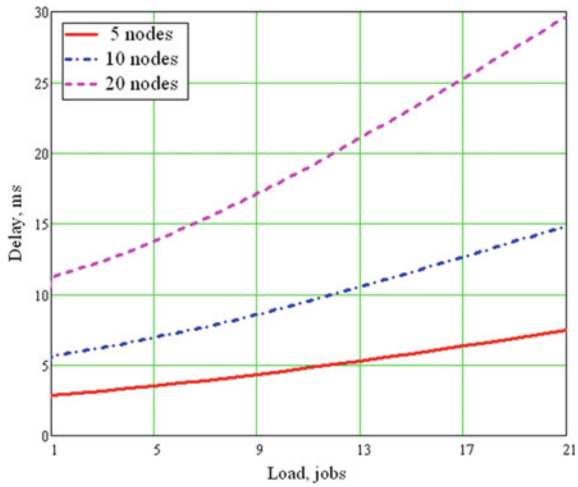

Fig. 3. Relationship between the delay and the network load

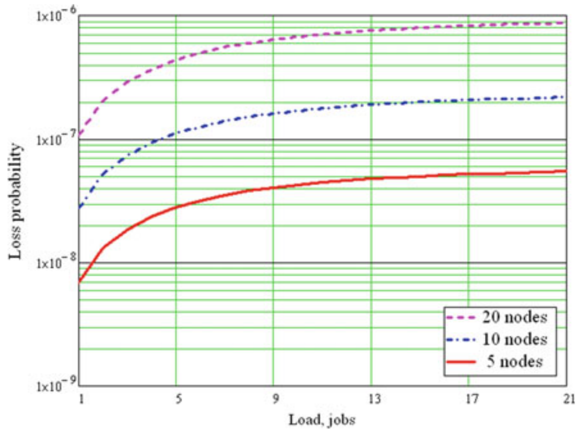

Fig. 4. Relationship between the loss probability and the network load

5 Conclusions

The conceptual, algorithmic and software models of the positioning system in the ZigBee network were built by the authors.

The mathematical apparatus of Markov homogeneous closed queueing networks was used as a modeling tool.

The mean value analysis, adapted to the real conditions of ZigBee network functioning, was used to calculate the time-probability characteristics.

The time-probability parameters of the IEEE 802.15.4 standard sensor network obtained as a modeling result are delay (ms), throughput (ms-1), network utilization

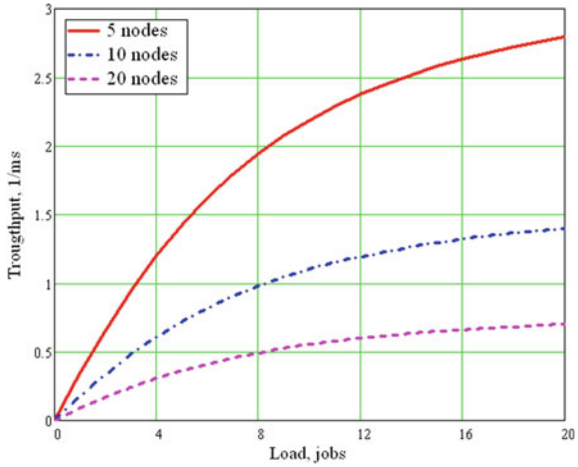

Fig. 5. Relationship between the throughput and the network load

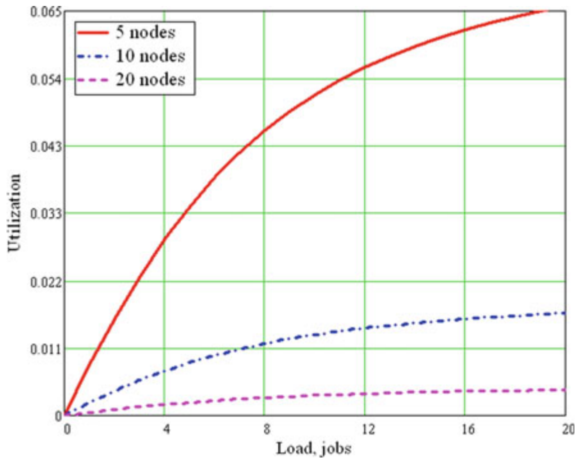

Fig. 6. Relationship between the utilization and the network load

and loss probability, all of which are required to evaluate the quality of service for the transmitted data.

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Transport and Logistics in Agriculture

Digital Technologies in the Development of Reverse Logistics and Circular Economy

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Abstract. The object of special attention is the possibility of using digital technologies to transform linear supply chains, which were previously aimed at improving the human material base through the extraction of natural resources, mass production and consumption, and cost optimization at the sacrifice of the environment. For the simultaneous achievement of economic, social and environmental goals, linear models of production and consumption are replaced by closed supply chains, reverse logistic and a circular economy, the effective formation and development of which from theoretical concepts into practice is possible with the use of digital technologies. The methods for assessing the level of maturity of various objects, investigated in the article, contributed to the development of special tools for assessing the readiness for the development of a digital economy with a closed cycle at the macro, meso and micro levels as the first and necessary stage for developing a step-by-step strategy for transforming the economic model lines into a circular form using supporting digital technologies, reverse logistics and closed supply chains.

Keywords: Digital technologies · Closed supply chains · Reverse logistics · Maturity assessment · Circular economy

1 Introduction

The exponential growth of digital technologies has transformed progressive development into a new industrial revolution, in which the borders between the physical, digital and biological spheres are blurred, which allows to create a new level of value for both business and society. It should be noted, however, that the fourth industrial revolution, the digital economy and advanced technologies are applied in linear models of production and consumption, which are a threat to sustainable development. The linear economic model is based on the following principles: resource extraction, production of goods, their use and ultimately economically viable disposal after initial use [1]. Thus, the linear model maximizes economic efficiency without taking into account the consequences for the environment and human health, which leads to a large amount of waste, greenhouse gas emissions, depreciation of the cost of secondary raw materials and energy resources and depletion of primary ones.

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Concurrent to the digital economy and as a counter to the linear model of production and consumption, reverse logistics and closed supply chains have been actively formed over the past decade and are the basis for the concept of a circular economy which is aimed. Kirchherr J., Reike D., Hekkert M. define circular economy as an economic system that replaces the concept of "end of life" with reuse, restoration, recycling during the production process, distribution and consumption, with the goal of sustainable development and simultaneous achieving positive effects for the environment, economic prosperity and social justice for the benefit of present and future generations through new business models and responsible consumers [2].

Interest from scientists, business representatives, governments of various states and non-governmental organizations is constantly increasing due to the significant benefits reaped during the circular economy development. According to research, the development of a circular economy will reduce greenhouse gas emissions by 70%, increase jobs by 4%, and reduce waste generation by 87% [3]. Digital technologies are highly important in the development of closed supply chains, and today of the particular relevance is the formation of a fundamentally new model of a digital circular economy, defined by authors as an economy in which closed value chains are optimally modeled and implemented for the purposes of restoration, reuse, optimization and resource saving using digital technologies and innovative business models for the simultaneous achievement of zero waste production and consumption, sustainable economic growth, socio-economic and environmental efficiency.

Not all countries and regions have sufficient capacity to move to digital closed-loop production models. Today, the global circularity is estimated at 8.6% [4], and this indicates that most countries and regions are only at the beginning of the transformation of the linear model of the economy into a circular form. One of the first steps in building a strategy for the development of a digital circular economy is to assess readiness at the macro, meso and micro levels for digital transformation, the use of reverse logistics, and the transformation of production and consumption models into a closed form. An analysis of the current literature on existing methods for assessing the level of maturity has shown that there is no single mechanism for determining the readiness to transform the linear model of production and consumption into a digital circular economy. In this regard, the research is aimed, first, at substantiating the importance of digital technologies in the development of closed supply chains and reverse logistics; second, to develop tools for assessing readiness for the transition to a digital circular economy at the macro, meso, and micro levels, taking into account existing research and techniques in this area.

The article consists of five sections: after the introduction, Sect. 2 discusses the research methodology. Section 3 presents the results of the analysis of the role of digital technologies in the formation of closed supply chains, as well as the index of readiness for the development of a digital circular economy and its approbation (case of Michelin). Section 4 provides a discussion of the results and concluding observations.

2 Material and Methods

The solution of the tasks set in the study is based on the application of a number of theoretical and methodological approaches: the modern version of the concept of sustainable socio-economic development, the theory of external (environmental and social) effects, the concept of natural and industrial cycles, methods of institutional and economic and legal analysis. To assess the level of readiness for the formation of a digital circular economy at the macro, meso and micro levels, the index method was used, including the development of own assessment tools by the authors. The developed index is tested on the practical experience with the application of the case study methodology and statistical methods of data analysis. The development of the index provides for the formation of its universal structure and algorithms for adaptation to the specifics of a certain entity (country, region, industry or enterprise), depending on the level of digitalization, scale, socio-economic development, environmental problems, etc. Development of the index includes several stages:

Step 1. Analysis of the existing indices for assessing the level of readiness, the possibilities of using existing tools to solve the problem of determining the level of readiness for the formation of closed supply chains and a digital circular economy at the macro, meso and micro levels.

Step 2. Creation of an algorithm for designing and updating a model for assessing readiness for the transformation of a linear economy into a digital circular economy, taking into account the specifics of the development of countries and regions, companies and industries. To increase the justification of the structure and content of the readiness assessment model, it is necessary to rely not only on the existing scientific base, but also take into account the best practical experience. In this regard, the study carried out the following types of analysis:

- analysis of the practices of companies, countries and regions implementing projects on digital transformation and the formation of closed supply chains and reverse logistics with an emphasis on the principles of a circular economy. To collect information about the experience of companies and countries, classical methods were used: case study and data analysis statistical methods.
- analysis of existing modern methodologies for managing institutional changes for the implementation of the principles of a circular economy, practices for managing closed supply chains and reverse logistics using digital technologies in order to substantiate the criteria and characteristics of readiness.

Step 3. Development of readiness assessment index for the formation of a digital circular economy at the macro, meso and micro levels, including criteria, indicators, metrics. The developed assessment index differs from the known ones by the justification of the structure and the specifics of the assessment at different levels. The index includes the framework and algorithms for its adaptation to the specifics of a particular country, region, company. The framework is a systematized description of the criteria, detailed to the level of characteristics and indicators, grouped by the assessed areas.

3 Results

3.1 The Role of Digital Technologies in the Development of Closed Supply Chains and Reverse Logistics

Prospects for the development of closed supply chains and reverse logistics are appropriate from a macroeconomic point of view, since they lead to the spread of the principles of circular economy and help to achieve waste-free production and consumption, reduce CO_2 emissions into the atmosphere, and save primary raw materials and energy resources [5]. However, at the micro level of separate companies or regions, the introduction of closed loop supply chains and reverse logistics may be limited due to the need for significant investments with a long payback period. Thus, digital transformation is a driver for the formation of circular business models and closed supply chains at the micro level, and the transformation of a linear economy into a closed form to achieve the sustainable development goals is difficult to imagine without digital technologies that support the implementation of the following principles of reverse logistics and the circular economy in practice:

1. Eco-design for waste-free production and consumption, resource intensity reduction and improvement of the raw materials and energy resources efficiency throughout the value chain. Companies need transparent and secure data for eco-design with a focus on a closed loop, which can be provided by Blockchain [6], creating databases of products, materials, suppliers and technologies. Digital technologies such as big data analytics and high-performance computing, supplier search automation, and digital twins provide a wide range of opportunities for eco-design development.
2. Optimization of the production process. Efficient use of resources and waste-free production can be achieved with the help of industrial Internet of things, 3D printing and robotics technologies. The infrastructure of the industrial Internet of things is a network of sensors that collect data from various devices, which analytics help to anticipate equipment failure and replace worn parts in advance, perform maintenance and repair; it is also possible to track deviations of the production process from the prescribed standards, which allows to quickly track the problem in order to avoid rejects and waste, etc. Robotics, replacing manual labor, optimizes the production process in terms of accuracy and minimization of the operation costs. 3D printing not only allows to personalize products and reduce consumption, but also to recycle 3D waste into usable 3D materials.
3. Waste-free, environmentally friendly consumption and use of products. The manufactured products must meet the potential for its use within innovative consumption models, such as sharing or product-as-a-service. Sensors allow to track the product, collect and analyze data about its use in order to increase sustainability. Thus, data collection and analysis allow to provide up-to-date advanced post-warranty service, provide timely delivery of certified spare parts and components to increase the duration of product use, and establish an effective system for returning products from the user to the owner for environmentally efficient disposal or reuse. Digital platforms are necessary for sharing and optimal consumption of products, because they help to establish communication between users and the manufacturer, provide

information about the correct sustainable consumption for a long service life of the product, optimize the repair process through the use of related products and predictive maintenance, proactive automatic notifications about diagnostic maintenance.

4. Sustainable and highly productive agricultural systems. The development and implementation of almost the entire range of digital technologies into the agricultural sector is a driver for optimizing costs, increasing productivity and improving environmental efficiency in livestock and agriculture. Technologies such as precision guidance systems during planting and fertilization are used to save seeds, fertilizers and fuel for machinery, reduce working hours, etc.; machine learning and big data analytics analyze information about specific seeds and crop units, detect pests and diseases based on satellite images or using unmanned aerial vehicles, also forecast supply and demand for agricultural products, make forecasts of droughts or floods based on precipitation data transmitted by Internet of things sensors.
5. Environmentally efficient disposal. To spread reverse logistics and preserve products at the end of their use within the closed chain through efficient disposal or reuse, it is necessary to use digital technologies such as the Internet of things, feedback platforms, and big data analytics to monitor the location, quality, and ownership of products, identify responsible parties for disposal, and collect, store, and process information about the quality and quantity of products, their composition, and disposal capabilities.

Thus, digital technologies can assist with the efficient formation of closed supply chains and ensure the holistic development of the principles of a circular economy, allowing companies to optimize production processes, efficiently reuse materials, reducing waste and demand for primary resources.

3.2 Assessment of the Level of Readiness for the Development of a Circular Digital Economy and Reverse Logistics

The importance of assessing the readiness for the development of reverse logistics and a circular digital economy is caused by determining the level of maturity of a particular area for the development of a phased strategy and sequential tactical actions to transform linear production and consumption models into a closed form using digital technologies in connection with the various capabilities and needs of individual enterprises and industries, cities, countries and regions. At the first stage, a readiness assessment is required to determine the main actions and build a transformation plan; at later stages, this assessment helps to track the main results and identify deviations from the initial strategy. The first models for assessing the level of maturity or readiness date back to the eighties of the XIX century, so Crosby in 1979 determined five stages of quality management maturity control [7]. The term "maturity" itself refers to a state of completeness or readiness [8], which models are a tool used to define and describe a roadmap from immature processes to qualitatively improved and efficient ones [9].

Due to the awareness of the need to manage digital transformation while achieving sustainable development goals, readiness assessment is playing an increasingly important role in the spread of digital technologies, reverse logistics and closed supply chains. In recent years, studies in the field of assessing readiness for digital transformation have been published. Most studies are empirical and assess the level of readiness for digital transformation of a particular country, industry or company, so Noonpakdee et al. assessed the readiness for digitalization of Thailand [10], and Bandara et al. assessed the banking sector [11]. Published literature reviews on the readiness of companies, regions, and countries for digital transformation, prepared in particular by Reis et al., emphasize the significant potential for further development of mathematical modeling [12]. As noted in this study, to date, there is no universal model for assessing readiness for digital transformation that can be applied to a company, industry, city or region. In addition, there is no model for evaluating the circular economy at the macro level and application of its principles at the meso and micro levels.

Assessment of the level of readiness for digital transformation, in conjunction with the principles of reverse logistics and a circular economy, should be systemic and carried out at the level of products and technologies used, enterprises and consumers, industries, cities, countries and regions, and include a variety of economic, technological, environmental and social indicators (Table 1).

In general, the index for assessing the level of readiness for the formation of a digital circular economy is as follows:

$$IRDCE = \frac{\sum_{i=0}^{n} (C_n \times D_{c_n})}{n} \times 100\% \tag{1}$$

where

- *IRDCE* an index for assessing the level of readiness for the formation of a digital circular economy;
- n the number of criteria (C_n) of the area being assessed;
- C_n the evaluation criteria presented from the evaluated area;
- D_{Cn} percentage or criterion level (C_n) depending on the target state.

The *IRDCE* index will vary from 0 to 100%, and the closer the target state of the evaluated object, the higher the index value.

3.3 Assessing Michelin's Readiness for a Closed Loop Digital Production and Consumption

The main product manufactured by Michelin is tires, which are in many countries an object of the mandatory disposal of manufactured products at the end of their life cycle after loss of consumer properties. Therefore, the company develops reverse logistics and is setting up infrastructure for the collection of used tires, uses eco-design for future recovery and recycling purposes and innovative digital business models. Thus, Michelin supports 4 out of 6 initiatives to assess the level of readiness for the development of reverse logistics and a circular digital economy.

Michelin uses digital product eco-design to develop and manufacture innovative products of the future. For example, in 2017, the company introduced the Visionary Concept tire for the entire life of the vehicle with built-in sensors that monitor the state of the tread, which can be restored when worn using 3D printing [13]. At the same time,

Table 1. A system for assessing the level of readiness for the development of a circular digital economy [compiled by the author]

Level	Estimated area	Criteria for evaluation
Nano	Product	• Material costs per service unit (M); • Index of all direct and indirect costs of energy flows needed to produce a product or service (TC); • Increased product life and durability (UL); • Recyclable materials and eco-design with a focus on the closed life cycle (SM)
Micro	Company	• Extended producer responsibility (EMR); • Product eco-design (ED); • Waste-free production (WP); • Resource-saving technologies (RST); • Innovative and environmentally friendly business models (CMB)
Meso	Industry	• Industry reuse and industrial symbiosis indicators (R); • Industry unions for environmentally responsible business (ERB)
	Consumers	• Use of new consumption models with an emphasis on waste-free consumption (ICM); • Participation in separate waste collection (SWC); • Consumption of environmentally friendly and safe products (EFP)
Macro	State, region, city	• Quality of the institutional environment and legal framework for environmental policy (ILF); • Digitalization level and digital infrastructure (DT); • Financing (F); Environmental issues (EP); • Sustainable food systems (SFS)
	Society	• Education (E); • Health (H); • Digital and environmental literacy (DEL); • Creating jobs in new closed-loop industries (W)

the polymer from which the tire will be made is completely biodegradable and the tire at the end of its service life can be recycled without residue.

The company is already applying innovative and environmentally friendly business models. Michelin develops a product-as-a-service business model based on distance driven. In mining vehicles, IoT technology allows technicians to replace tires based on the cumulative wear and tear caused by heavy loads. In Japan, the Michelin IoT Tire Pressure Monitoring System (TPMS) was launched to provide increased safety and efficiency and cost savings for industries such as fleet management and building.

Michelin is developing resource-saving technologies for the recycling of waste tires, and at the end of 2017 purchased Lehigh Technologies company, which recycles end-of-life tires into a special material called micronized rubber powder (MRP). In addition to reducing waste, the resulting MRP material is subsequently used to make new tires and helps save raw materials and energy [14]. In addition to recycling, Michelin is engaged in tire remanufacturing, i.e. restoration of a used product to the state of a new product. By removing the worn tread and replacing it with a new one, while maintaining the same structure, retreading optimizes resource use and brings social, economic and environmental benefits. Compared to the production of a new tire, the retreading can reduce extraction of minerals (ore, oil) by 70%, CO_2 emissions by 24%; water consumption by 19% [15].

At the same time, Michelin's circularity cannot be estimated at 67%,

$$(IRDCE = \frac{EMR \times ED \times D_{ED} + WP \times D_{WP} + RST \times D_{RST} + RES \times D_{RES} + CMB \times D_{CMB}}{6}$$
$$\times 100\% = \frac{1 \times D_{EMR} + 1 \times D_{ED} + 0 \times D_{WP} + 1 \times D_{RST} + 0 \times D_{RES} + 1 \times D_{CMB}}{6}$$
$$100\%)$$

since not all products released by the company are involved in recycling and recovery processes, and digital technologies and innovative business models are used only for limited areas of the company. At the same time, for an accurate assessment there is no open necessary data (D_{C_n}) on the level of application of certain initiatives across the entire company. At the same time, it can be concluded that Michelin is on the way to build a digital closed-loop business model.

4 Discussion

The developed index will help assess the level of development of the digital circular economy at different levels, which will make it possible to develop a strategy taking into account the interaction of the state, business, and the scientific community for the transition from a linear to a circular economy using reverse logistics and digital technologies to achieve sustainable development goals in the field of economic, environmental and social efficiency. Due to the fact that not all indicators at each level are presented in statistical databases, especially at the nano and micro levels, the assessment should include survey method to collect and interpret information, which will form the basis for future research. With the transition to the macro level, data for assessing the maturity of the digital circular economy are publicly available on the information portals of public authorities. The strategy for the development of a digital circular economy begins with the nanoscale—products that should be made using eco-design with an emphasis on a closed life cycle, while incentive measures should come from the macro—level-the state through the formation of regulatory regulation in the field of development of the principles of reverse logistics and the circular economy.

5 Conclusions

The development of closed supply chains on a widespread basis and the transition to a circular digital economy are broader processes than transformation at the enterprise level, because they are related to the reform of global value chains, institutional environment, infrastructure, ways of commercialization, methods of distribution and consumption, which have an impact on society as a whole. Without a targeted government policy and the development of a long-term strategy for the formation of a digital circular economy, its development will be sporadic and horizontal in some industries, limited by urban infrastructure and small consumption groups, which will disrupt the achievement of the sustainable development goals of economic prosperity and social justice for all countries and peoples. Therefore, the development of the principles of a circular economy with the introduction of digital technologies must be vertical: at the micro-level of enterprises by adopting the practice of product eco-design with an emphasis on a closed life cycle, waste-free environmentally efficient production for the formation of innovative consumption patterns; at the meso-level of industrial parks and sectors of the national economy through the development of requirements for the use of the best available technologies, increased efficiency in the use of resources, increased producer responsibility and greening global industrial supply chains by the introduction of a closed cycle; at the macrolevel of cities, countries and regions through the formation of an institutional environment, infrastructure, conscious consumption, education and a system of retraining of personnel, the inclusion of companies into international alliances of environmentally responsible business. All this will help to gradually achieve the goals of sustainable development, improving the quality of the environment, economic stability and well-being of the population of countries of different levels of development.

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Business Intelligence Systems Application in Transport and Logistics Companies

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Abstract. In a digital economy where rapid changes in the internal and external business environment occur, mistakes in making strategic decisions can have dire consequences for a company. Today, many large companies use full-fledged BI systems to support (strategic) management decisions, which combine many sources of information. These digital systems provide analyses of huge amounts of information, focusing on important indicators, allowing the prediction and simulation of various scenarios, providing aid in decision-making. This article describes digital business intelligence systems and specifically what role they play in transport logistics. The authors highlight the key advantages of using business analysis systems in enterprises. The research results highlight the main challenges that BI systems can solve in digital transport and logistics companies. Moreover, a map of the main directions of BI functions in logistics is provided. A list of key performance indicators in tabular form is provided, which can be analyzed and reflected upon in an analytical reporting system. The main methods deployed are benchmarking and clustering.

Keywords: Business intelligence · Transport and logistics companies · Digital economy

1 Introduction

In the current development stage of transport and logistics companies, one of the main priorities of managers is to introduce tools for managing the growth of cargo turnover, to increase the efficiency of employees, and the efficiency of the company in general [1, 2]. Another priority of a company, is to search for new opportunities to reduce production-, and distribution costs, in order to increase company profits and improve quality, by providing a range of services to the consumer [3]. In order to improve market relations, the principle of "calculation - benefit - consumer" can be used, which leads to an increase in the importance of logistics. In this regard, an urgent task is to develop a convenient decision support tool at all levels of management. BI solutions help to identify negative trends related to operating costs and business performance, quickly identifying

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sources of problems, and take corrective actions. Finally, a good solution allows you to conduct a detailed predictive (what-if) analysis and evaluate the impact of various strategies and tactics of organizing logistics processes, regarding quality of services, operational, and other related costs. Logistics businesses demand BI tools focused on analyzing everything related to supply chains. This requirement is associated with the increasing implementation of TMS-, WMS- and SCE-solutions, in order to increase the efficiency of transport, warehouse capacity and operational management of supplies, making logistics companies receive huge amounts of data at their disposal [4].

The key benefits of implementing business intelligence systems in enterprises are [5, 6]:

- Increased accuracy of indicators of the company's performance in reporting systems;
- data analysis in real time and forecasting;
- support for the development of business processes and structural changes in the enterprise;
- the ability to simulate various business situations in a single information environment;
- conducting operational analysis of non-standard user requests;
- reducing the routine workload on staff and increasing the amount of time for deeper analytical work;
- stable work with a large amount of data entering the system.

2 Materials and Methods

To solve the set tasks, the authors reviewed the most popular solutions in the field of business intelligence. Moreover, the existing practices of introducing business intelligence systems in companies in the transport and logistics sector were analyzed. The main methods are benchmarking and clustering. The key materials are Internet sources, scientific journals and previous experience of authors in solving the problems of logistics companies.

3 Results

During the study of the main business intelligence systems, the focus was on the use of leading BI solutions (e.g., QlikView, Tableau, Microsoft Power BI) to create an automated reporting system that allows to evaluate the work of the supply chain management service [7]. The main objectives of the report are:

- providing up-to-date information on the financial results of the supply chain management service to manage the company and improve the efficiency of business processes;
- providing a convenient application from the point of view of customer use;
- reducing the time for creating reports;
- the ability for the user to quickly get the necessary data in the section of interest without additional requests to other services.

Table 1. The main challenges that BI systems can solve in transport and logistics companies

Group	Challenges
Logistic	Traffic variance analysis
	Analysis of deviations from the standard cost
	Transport movement analysis
	Analysis of the cost of repair and maintenance of vehicles
Finances	Analysis of the cost structure, adjustment of regulatory indicators
	Analysis of financial statements
	Analysis of budget execution
	Control of receivables
	Consolidated financial statements
Sales and marketing	Analysis of profitability by customers, services, territories, directions, flights, etc
	Market analysis, pricing of services
	Customer loyalty analysis
	Evaluation of the effectiveness of marketing campaigns and promotion channels
Other	Executive dashboards
	Portfolio analysis
	Analysis of IT infrastructure effectiveness
	Analysis of suppliers and contractors, rating of contractors

Table 1 presents the main challenges that BI systems can solve in transport and logistics companies [8].

In approaching these challenges, some developments are noteworthy. Decades ago, when IT was in its childhood, it was difficult to obtain data at all. For instance, in Sales&Marketing, it was quite a struggle to retrieve the elements of the marketing mix (the 4Ps: product, price, place, promotion). When BI systems started to develop, marketeers felt tempted to introduce new parameters to the original mix. Baumgartner (1991) suggested the concept of 15 Ps, while Goldsmith (1999) suggested that there should be 8 Ps (product, price, place, promotion, participants, physical evidence, process, and personalization). Nowadays, when data retrieval is easy, practitioners feel themselves drowning in data, they do not want loads of them. Instead, they only want data that are useful. For instance, for marketing analysis (see Table 1), they only want the pricing of services versus the demand generated by these prices.

The key functions of BI in logistics can be roughly divided into six main areas (see Fig. 1). In logistics, one of the most popular types of BI reports is carrier and supplier scorecards. They may reflect the rating of timely delivery of goods, the percentage of orders accepted, fulfillment of quotas and other parameters. The cards can reflect both the absolute values of metrics and KPIs, and the average figures necessary to assess the overall performance. The purposes of such reports are [9]:

- using them in negotiations with suppliers;
- making informed decisions about the strategy of further work with companies.

Real-time update dashboards are the most frequent analytics reports in companies. The reports are the source of daily summaries of the company's operations. Executives need a snapshot of the company's performance in terms of supply chain or trucking activity. Data must be updated in near real-time so that managers can quickly identify problems and resolve them. The point is not to wait for the delivery of reports, but to see the real picture of what is happening and react immediately [10].

Fig. 1. Main directions of BI functions in logistics

The advantage of dashboards is an intuitive visual presentation of data and the ability to immediately detect certain trends and bottlenecks in business processes. For example, monitors with shipping and supply chain data are commonly used. The shipment dashboard shows the number of shipments planned for shipment, issued lots and the number of trucks. The supply chain dashboard works differently. This is an exceptions panel, the task of which is to notify you about outages. Let us say that some cargo needs to be picked up tomorrow, but the documents have not yet been issued for it. In this case, a notification will be displayed on the monitor [11, 12].

BI solutions allow to conduct a comparative analysis of the key competitive parameters of different companies, which allows to assess the effectiveness of your own business. For example, you can take the rates for transportation. They are subject to change, so at some point it may seem like a good move for management to lower prices. However, a comparative analysis of the market by means of BI may show that in the end, revenue decreases, which means that it is necessary to look for other ways to increase profitability [13, 14].

Another option is predictive analysis, which is based on identifying patterns in the data for previous periods. By analyzing historical data, the BI system can provide an assessment of future risks and opportunities in the field of supply chains and transportation. With specific numbers in hand, management can make informed decisions and flexibly regulate operations in the supply chain.

The listed areas do not constitute an exhaustive picture of the use of BI in logistics. Each business has its own specifics, special needs, and unique approaches. It also describes the basic, integral functionality that is important for everyday work.

Table 2 presents a list of the main indicators (basic and calculated), which are key for assessing the activities of a logistics company (these indicators were highlighted after interviewing the main stakeholders of the logistics company) [15, 16].

Table 2. List of main indicators

Cost	Assessment of quality and level of service
Profit	% of fulfillment of the standard cost of the delivery service to the client
Number of deviations from the schedule of shipments by trucks	Transportation loss rate
Number of complaints with the defect "Assembly defect"	Service level for managing regional offices
% of deliveries canceled on the day	Service level for the delivery of goods
Number of cancellations per delivery day	Delivery plan
Transportation costs for delivering products to the client	Number of projects in progress
Share of projects on schedule	Supply chain development service level
Number of disrupted export shipments	The number of SKU materials in excess of the actual price from the planned
Freight turnover	Turnover of raw materials and supplies
Share of fixed costs to revenue	Share of variable costs for logistics to revenue

In practice, using these BI tools allows companies to transform raw data into effective solutions and actions that help optimize supply chains, reduce operating costs, improve customer service, and even build relationships with partners.

The specific methods can vary from the simple to complex. At the top level, this is the categorization of costs within the supply chain and the detailing of the cost tree for further revision. A deeper analysis involves searching for and identifying pain points in all chains and trying to solve problems in each individual case. Moreover, the availability of processed data for all departments is important, one way or another related to logistics [17].

When companies already have certain classic analytics systems that allow you to compose conventional reports, such information is typically isolated. In other words, departments do not see what is happening with their neighbors. In such situations, management receives reports with completely different numbers. Failure to build a single picture of the business can lead to unpredictable income, falling margins, the formation of excess inventory of goods and a lack of understanding of the real effectiveness of promotions.

On a practical level, a single BI platform ensures the unification of all data within the company, their visibility, high-quality processing, and manageability. Whole divisions can create their own dashboards, customizing them to suit their needs. As a result, employees within departments have all the information they need, and at the corporate level, data uniformity and consistency are ensured. This factor alone can significantly increase the efficiency of the company.

For example, in-store promotions are traditionally calculated by the marketing department. However, irregular growth in sales affects transportation costs, shipping and delivery schedules, warehouse coordination and other things that are within the jurisdiction of the logistics department. And here, between an isolated system and one coordinated at the level of planning and analytics, the difference will be very, very significant [18].

The BI solution makes it easy to assess the distribution impact of promotions. Unable to obtain consolidated figures for the growth of sales during the campaign, the company will overpay for express delivery to guarantee the exact timing of the delivery of goods. Modern BI tools not only provide accurate forecasting of sales volumes, but also help to create an optimal delivery schedule. Accordingly, the company can refuse express delivery services and pre-ship the goods on the days before the holidays and before the weekend. Thus, predictive analytics makes it possible to move from the use of expensive services in a difficult mode to more systematic work with carriers—at reduced rates [19].

BI tools strongly influence production planning and fulfillment planning. High-quality analytics allows managers to see the volume of goods in stores. Dashboards show balances and alerts you when thresholds are reached in real time. This makes it possible to replenish stocks in time and prevent their exhaustion. As a result, potential lost sales drop. On the other hand, strict control of changes in demand allows you to reduce the staff in production, optimize work schedules and reduce the cost of paying for overtime [20].

Load planning and workforce planning is one of the strengths of BI. Advanced analytics highlight clear patterns and trends in the distribution of workload to staff. With all the necessary data on hand, the management of the relevant departments can bring the number of staff to the desired indicators or reduce the volume of contracts when it comes to outsourcing individual processes.

A modern BI platform provides enterprise-wide data integration, improves manageability, opens access to self-analytics not only for technical specialists, but also for business users. It was this platform that enabled the American soft drink maker Sunny Delight Beverages Co. optimize processes according to the scheme described above and reduce the costs of transportation of products by 7%, increase sales by 2% and reduce outsourcing costs by about $ 200,000 per year.

4 Discussion

As part of further research, it is planned to formulate requirements (functional and technical) for working out the issue of prototyping the application, considering its key advantages and technical characteristics of the base platform.

Conclusions

BI solutions offer several additional benefits to companies—certain functions that greatly simplify the work with BI tools, making them available to a wide range of business users:

- BI Automation Using Artificial Intelligence Algorithms—Automation using artificial intelligence algorithms has taken data manipulation to a new level. Now the system itself analyzes the data, identifies dependencies, and presents the results in a visual format—in the form of dashboards.
- Increasing the productivity of BI solutions using machine learning mechanisms. These systems can now process huge amounts of data at high speed, which will allow every business decision to receive more weighty reinforcement and adoption faster than before. Large manufacturers with a wide distribution range can now quickly make accurate forecasts of product demand by analyzing data over several years. Reliable estimates help prevent disruptions in deliveries and replenish inventory on time, since the user knows in advance how much and where to deliver.

The introduction of new technologies into BI platforms dramatically increases their efficiency and accessibility for regular employees of the company. The results of implementing a BI solution in transport and logistics companies are:

- Increase in profit by increasing customer loyalty and increasing sales.
- Timely identification of problem areas, control of deviations—tracking controlling processes that are reflected in BI in the form of services.
- Minimization of costs by increasing the efficiency of transportation, more efficient management of the fleet of vehicles and a warehouse complex, assessing the effectiveness and adequacy of costing.
- Increase the value of the company.

The research highlighted the key advantages of using business analysis systems in enterprises. A map of the main functions of the analytical reporting systems of transport companies has been formed. The research findings highlight the main challenges that business intelligence systems can solve in transportation and logistics companies. In addition, a map of the main areas of BI functions in logistics is presented. A list of KPIs is provided in the form of a table, which must be analyzed and reflected in the analytical reporting system.

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Directions of Development of Port-Industrial Complexes in Russia in the Digital Era

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Abstract. The development of the port and industrial complexes (PIC) has become large-scale. The changes cover a significant number of major ports around the world. Ports are points of territorial growth and channels of integration into the world economy. The development of the port and industrial complexes as a complex territorial and industrial entity has its own peculiarities in Russia and abroad. The complexity of port and industrial complexes (as an object of management) is caused by a combination of many factors: industry, corporate, logistics, infrastructure, institutional, biological, geographical, etc. This leads to the need for an interdisciplinary study. Therefore, a multidimensional approach and an adequate methodological framework are required. Research on the development of the first port and industrial complexes in Russia shows that the institutional environment is not ready for such territorial and industrial projects. This work is devoted to the definition and systematization of the development directions of Russian port-industrial complexes. The research is based on the system economic theory in the digital age. In this paper, the main directions of development of PIC were considered from the point of view of organizational, managerial, and information technology aspects. The research focuses on the concept of "smart digital ports", based on the digital circuit Board and IoT. When implementing information technology projects based on PIC, it is proposed to use the project management methodology. Managing port digitalization projects will allow port and industrial complexes to adapt to the digital age and significantly increase the efficiency of business processes.

Keywords: Port and industrial complexes · Intelligent digital port · System economic theory · Information and technology projects · Automation of container terminals

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1 Introduction

In the context of globalization of the world economy, port-industrial zones are points of growth of territories and channels of integration into the world economy. Moreover, recently one of the main trends is the digitalization of the activities of port and industrial complexes.

Until the 1960s seaports of the first generation were mainly places of collection and transshipment of goods between land and sea transport and functioned rather isolated. In the 1960s and 70s ports of the second generation were formed, in which there was a strengthening of integration processes and coordination of production planning with the distribution area. In the 1980s the ports began to establish partnerships with companies operating in the port and create industrial enterprises not related to the main activities of the port. The emergence of third generation ports, and since the 1990s and the fourth generation was driven by the development of large-scale container and intermodal transport coupled with the growing needs of international trade. There are characteristics that make it possible to talk about the fundamental possibility of the formation of port-industrial complexes (PIC).

With the advent of ports of the fourth generation, the problems and tasks of the economic and managerial order have become more complicated and urgent. Therefore, the purpose of this study was to identify the directions of development of domestic PIC in the digital era and the factors that determine them.

Verhoeven, Managing Director of Policy and Strategy of the International Association of Ports and Harbors (IAPH), identifies three dimensions of fourth-generation ports: operational, spatial and social [1]. As noted above, it is on the basis of the fourth-generation ports that industrial port complexes are formed.

From the point of view of information technology changes, the following features should be noted: the main logistics hubs, represented by seaports and "dry ports", are changing their business rules and models, moving from "industrial or logistics centers" to the developed concept of "smart digital ports", based on a digital platform and IoT, which creates opportunities for the collection and exchange of data in real time [2].

2 Material and Methods

The ports of the third and fourth generations, which became the basis for the development of the PIC, emerged during the development of the institutional paradigm- 1980–2000, when institutions were the main factors in the behavior of agents.

At the present stage, the complexity of this territorial-sectoral formation requires the use of an adequate methodological base. The concept of a four-dimensional coordinate system for the analysis of economic systems in a broad sense provides for the interaction of key subsystems of the national economy [3, 4]: economic science (environmental system); policy (process system); management (design system) and practice (object system: country, region) [5].

Port researchers in the UK are raising the issue of the sustainability of port systems as subsystems of port cities with many stakeholders: government departments, port operators, ship operators, importers, agents, and logistics firms. The complexity of the ports complicates the interaction of stakeholders and actualizes the problem of barriers in communications, especially during periods of crises and natural disasters [6].

The growth in the number and size of Dutch ports has prompted a comparative analysis of municipal port management strategies in four different countries along the Rhine-Alpine Corridor. Increasing port capacity requires alignment with city government policies to avoid mutually exclusive land-use decisions. [7].

Of particular interest is a survey work that highlights management issues, in which the authors formulate 6 areas of strategies for further improving ports: maritime strategy and integrated coastal zone management; sustainable port infrastructure; port network initiatives; regionalization of ports; urban and landscape connections; social integration of ports [8].

When implementing information technology projects based on PIC, it is proposed to use the project management methodology. It will allow port and industrial complexes to adapt to the digital age and significantly increase the efficiency of their business processes. In the opinion of the authors, here it is possible to use the international standard Prince 2, which allows you to manage a project, adapting to changes in the external environment and within this PIC [9].

The problem of introducing digital technologies in port-industrial complexes is presented in works [10, 11]. The publications are devoted to the issues of automation of port terminals in Russia [12, 13]. Features of the stages of evolution of the port system from the industrial to the intelligent digital field are described in the article [14]. The issues of transformation of the market of transport and logistics services in the context of digitalization of the economy were studied in [15]. Features of project management of automation of seaports and cargo terminals are disclosed in publications [16].

2.1 Organizational and Managerial Directions of Development

The study made it possible to identify the following organizational and managerial aspects and trends:

- the tendency to consolidate the interests of the PIC stakeholders and close cooperation with city administrations;
- the decentralization of port management by transferring authority to development companies with state participation;
- the complexity of the used management models and, as a consequence, the problem of barriers in communications.

The example of the development of the first PIC in Russia demonstrates the unpreparedness of the institutional environment for such territorial and sectoral projects [15]. So, for example, the participation of government agencies in the development of a strategically important facility—the port of Ust-Luga, took place “according to the situation”, without developing a strategic plan. Therefore, organizational problems arose and became more complicated: coordination, coordination, management of economic projects.

The regulation of activities in the seaports of Russia is carried out by the state organizations “Administration of seaports” and “Rosmorport”. The Federal Law “On

Seaports" states that the purpose of their activities is to increase the competitiveness of seaports. However, this regulation does not apply to the financial and economic activities carried out by private companies on the territory of seaports, as well as the issues of attracting investments and developing the PIC. That is, there is a contradiction between the goals and objectives of the development of Russian ports and the powers of the institutions of port activity.

Russian seaports and land plots can be both state and private property, which opens the opportunity to develop port infrastructure not only at the expense of federal funds.

The economic policy of the state is aimed at developing its own production (including import substitution) and infrastructure, including the port, which is reflected in the Strategy for the development of the seaport infrastructure of Russia until 2030. Economic policy at the regional level is also of great importance [14].

In modern conditions, the hopes of enterprises are associated with relationships with administrative structures. However, 85% of enterprises do not receive such support from either federal, regional or municipal structures.

2.2 Information Technology Directions of Development

One of the most promising areas of development of PIC in the field of information technology is the concept of "smart digital ports". It involves the use of smart sensors (IoT devices) that allow to receive and store a huge amount of data managed by a cloud or other digital database. The data comes from various areas of ports such as: quays, cargo yards, gates, as well as various information systems such as: the port community system, terminal operating system and digital stakeholder platform. [16]. This concept also implies the exclusion of humans from operations of navigation, docking, loading and unloading [16].

The highest level of automation today is typical for large container terminals. This is due to the fact that container logistics are more progressive compared to the logistics of other types of cargo. Currently, several companies are involved in the development and supply of automation systems for Russian port terminals. The largest market players are SOLVO, Rolis, Dialogue IT, IT Marine, SeaData, Transposoft and Ant Technologies. As for western port terminal management systems, at the moment in Russia there are two main barriers to their use—the cost and the lack of consideration of all the features of work in Russian conditions.

The study examined several directions of automation of port equipment in the field of sensor technology. The first direction of automation of port equipment is berths. Here, the most significant factors of work are the uninterrupted dispatch of ships, as well as the prevention of damage from possible collisions. The second direction is container mines. Different vehicles are used for handling containers depending on the volumes to be handled. If the volume is small, a forklift with a driver is enough. If the handling volumes are significant, portal cranes with crane operators are required, as well as automatic robotic stacker cranes. The third direction is intermodal terminals. Container handling is carried out at intermodal terminals and transshipment sites. Further transportation of containers takes place along one of several routes. For example, on roads and railways, as well as on rivers. The sensors support highly automated container handling processes. The fourth area is land transportation. Gantry loaders, gantry vehicles, terminal tractors and heavy vehicles transport containers from warehouse to ships and vice versa. These processes are in most cases automated and require special safety functions and support using special sensors.

However, the development of the PIC requires the development of not only its production component but also the improvement of the traditional port subsystem, which, in turn, will contribute to the development of production processes within the PIC.

3 Results

In this study, on the basis of systemic economic theory (SET), problems are systematized and directions for the development of port-industrial complexes in Russia are proposed.

The following problems were identified in the port areas:

- the lack of a general strategy for the development of PIC and the business strategies of the elements (enterprises that are part of the PIC) agreed with it;
- companies are not interested in cooperation with the authorities and pursue only their own commercial goals;
- conflict of interests of potential participants in the development of the PIC;
- there is no unified information base that allows potential investors to have access to up-to-date and reliable in-formation for making decisions on financing such projects.

In large European PIC (Rotterdam, Antwerp, Hamburg), management companies are developing a port development strategy, coordinating it with the relevant committees of the city senate and federal structures.

The subject of the activity of the Federal State Budgetary Institution (FSBI) of the Seaports Administration (SA) is the organizational, logistical and financial support for the performance by the captains of seaports of the functions provided for by the Federal Law “On Seaports in the Russian Federation” and other Federal Laws, regulatory legal acts of the Government of the Russian Federation.

From the point of view of this methodology, the key in the development of PIC as a socio-economic subsystem is the interaction of four subsystems of the national economy (in a broad sense): economic science (environmental subsystem), economic policy (process subsystem), economic management (project subsystem), business practice (object subsystem).

The proposed systematization allows us to distinguish four subsystems, these conclusions have scientific novelty. The developed methodology allows the analysis of the following interrelated subsystems:

1. Environmental subsystem (economic component). Based on the analysis of the work on the formation and development of port-industrial territories, the necessity of conducting research from the point of view of strategic management, including investment and institutional aspects of activity, is justified.
2. The object subsystem. The analysis of the functioning of port-industrial complexes has shown that there are contradictions between the economic and managerial goal (to increase the competitiveness of the port) and the functions assigned by the state to the

management organizations in the port. The creation of a general information space, the development of information and technological support will allow identifying problems and contributing to their solution.

3. Process subsystem (economic policy). The development of the port subsystem and industry is an important area. It is also important to use a systematic approach in the formation of economic policy and in relation to the PIC at the regional level.
4. Project subsystem (economic management). The paper identifies problems in the project subsystem, as well as the causes of their occurrence. With the existence of a large number of stevedoring companies, there is no single purposeful management of the port-industrial complex subsystem and its information and technological support (see Fig. 1).

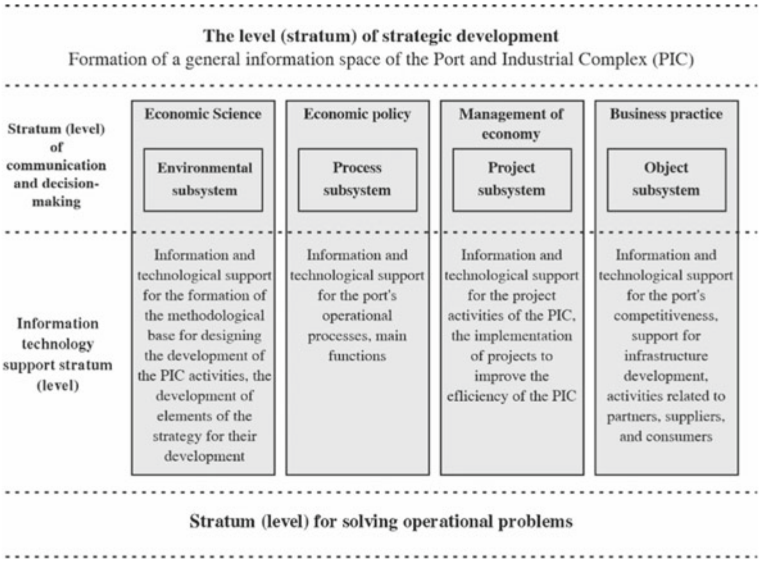

Fig. 1. Formation of the unified information space of the PIC

Thus, the systematic development of port-industrial complexes, the development of a general information space, the formation of integrated information and technological support will significantly increase the efficiency of port-industrial complexes. Figure 1 shows a diagram of the formation of a general information space of port-industrial complexes.

Among the information systems for managing seaport terminals, depending on the purpose, the following classes were distinguished:

1. Automated operational control systems designed to manage personnel and equipment.
2. Document management systems are used for registration and accounting of documents and cover the entire document circulation of the container terminal.

3. Specialized automation systems supporting technological processes.

One of the risks of ineffective implementation is the presentation of potential customers about information systems as a typical product with a fixed business model. However, when introducing systems of this degree of complexity, it is necessary to use a project approach, which includes the stages of describing the terminal's business processes, adapting the system, implementing data exchange, connecting data collection devices, training personnel, etc.

As a result of the use of the project approach and the transition to digital interaction, it becomes possible to in-crease the port capacity, significantly reducing the load on terminals and production facilities. There is a decrease in threat risks (for example, loss of containers), and the exchange of information with partners is improving. With the transition to a "smart port", the possibilities of using different classes of ships increase, and the efficiency of intermodality increases. Projects for the development of IT support for port activities and the transition to digital business will significantly increase efficiency by reducing costs.

Information technology support for port activities will not only improve the efficiency of one particular PIC, but also enable port networks to develop. This will attract a significantly larger number of partner companies, and will give impetus to projects for the further development of all ports and nodes connected to a single network. Information technology support for such activities will allow for a smooth transition to the concept of an "intelligent digital port".

"Smart port" allows not only to automate all aspects of the PIC's activities, but also to integrate processes, increase the level of security, and significantly change the approach to management, technology, and it support. An important direction is the development of digital counterparts of ships and ports. This allows you to analyze real processes and their relationships on these models.

4 Discussion

The complexity of the research object, such as a territorial-industrial formation, requires a corresponding research methodology. Previous studies did not allow a comprehensive and comprehensive approach to the systematization of factors for the development of PIC, which made it impossible to formulate the concept of their formation and strategic development.

In particular, the authors previously considered the methodological aspects of the balanced scorecard model (BSC) in relation to the analysis of the investment potential of the PIC [21]. The formation and development of PIC requires a multi-aspect approach: analysis of areas of activity (industry aspect), research of institutional conditions for the development of PIC at the macro-, meso-, micro-level, management aspect. The use of the BSC model in the study of the investment potential of the PIC has proved problematic: a broad statistical base is needed, which is not sufficiently represented in official statistics.

The study of the European PIC based on the SET has demonstrated its broad application for systematization of problems and determination of development potential.

5 Conclusions

In this paper, we analyze the most characteristic features of the creation and operation of Russian PIC. The analysis is carried out from the point of view of system economic theory. Possible directions of the development of ports in the era of digitalization are proposed. One of the most significant problems is the lack of readiness of the institutional environment for such territorial and sectoral projects. In the future, it is assumed that it is possible to design the concept of a balanced state of the Russian PIC.

Special attention is paid to the concept of "smart digital ports". This concept is based on a digital platform and IoT. Research has shown that separate information technologies and automated systems predominate in Russian sea-ports In this regard, one of the most promising areas of development is the creation of "smart ports". This is possible through the use of digital technologies: the Internet of things, artificial intelligence, 3D printing of spare parts, virtual and augmented reality, digital twins, technologies for maintaining distributed registers of accounting and certification of rights, etc. These technologies will create a completely new logistics.

When implementing information technology projects based on PIC, it is proposed to apply the methodology of project management. At the same time, it should be borne in mind that the choice and implementation of digital solutions in the activities of seaports is a transformational and complex process.

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Value Propositions of Restaurant Delivery Systems: A Text Mining-Based Review

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Abstract. Due to the e-commerce rapid development during the COVID pandemic, the demand for logistics and its importance is increasing. A satisfied customer can drive e-commerce business forward. As logistical needs become more complex and logistics market becomes more competitive, service companies must strive to continually improve their value proposition to maintain their competitive edge. This study investigates the impact of two types of presentation formats (qualitative: text reviews and quantitative: star ratings) of online restaurant customer reviews on the value proposition. The study examines online restaurant reviews based on the review's usefulness and the service experience enjoyment. Text mining was applied to online reviews to identify the driving forces behind explicit recommendations. Using semantic analysis, text mining technique, online customer reviews were analyzed from 16 largest restaurant chains, in St. Petersburg, Russia, which include 242 restaurants. Data from 201 reviews were collected from TripAdvisor, using web data collection technology. The relationships in the model were tested using multivariate analysis of variance. The results show that the delivery menu, ordering possibility through aggregators and delivery time were significant factors in the directionality of the reviews tonality. These three factors all relate to the service format logistics and restaurant business value proposition. This provides restaurateurs with clues on how to increase their efficiency and reduce dissatisfaction with restaurant delivery services. In contrast to similar studies on the relationship between value proposition factors and online reviews, this article explores the perceptions of the online reviews usefulness and focuses on the customer experience sentiment.

Keywords: Text mining · Online delivery · Value chain · Sentiment analysis · Value proposition · Restaurant business model

1 Introduction

During the COVID pandemic, business transformation and the ability to sell online are driving global shopping and service delivery in contactless shopping. In other words, customers can now directly purchase products and services through websites and online marketplaces that were previously inaccessible or expensive as the number of companies selling products online has grown significantly. This phenomenon, known as e-commerce, has recently gained traction due to advances in risk and cost reduction, such

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as those related to payment security and contactless payment methods, logistics and language barriers. Any service has been forced to develop in the field of e-commerce and have an established logistical mechanism today, because users are interested in simplifying the purchase of goods and services online.

Companies trade online through specialized e-commerce trading platforms, and goods and services are delivered to customers through logistical services. Without being able to be acquainted with a product or service in the current conditions related to the virus before ordering delivery, the only safe way most potential customers decide to make a purchase is online reviews of consumers who have already had the opportunity to purchase service and shared their experiences.

Studies showed that potential customers increasingly rely on online reviews, rather than commercial advertisements or expert opinions, to analyze experiences that are more relevant to their own interests, and so they know what to expect when they make a purchase decision [1]. Despite the fact that there are a number of studies have examined the direct recommendations role regarding the intention to make a purchase [2, 3], researching direct recommendations possibility can be important for understanding the shaping of the value proposition of companies.

This study investigates the dependence of service format factors (qualitative: text reviews and quantitative: star ratings) on the direction of the sentiment of online reviews of restaurant customers, and as a result, on the value proposition. The central objective is to study online restaurant reviews based on the usefulness of the review and the enjoyment of the experience of the service provided, to identify the key factors that shape the value proposition of the restaurant business.

With the rapid development of e-commerce, quality of service and timely online delivery became a priority in both marketing and logistics research [4–6], where both areas looked at service attributes, that is, the factors that customers expect from service providers [7]. This statement is true for this study as well, as it takes into account how to increase efficiency and reduce visitor dissatisfaction by improving the service format.

The way the elements of the service format included in the provision of services of restaurant companies work directly affects customer satisfaction and loyalty, and these attributes are essential factors that must be considered when forming a value proposition. For example, research in the field of logistics and restaurant business modeling has focused on examining the impact of service factors on the feelings and behavior of customers after making and receiving the delivery of a purchase, and justifying expectations and loyalty after providing a service [8]. However, the relationship between satisfaction (or dissatisfaction) with customer experiences and service elements is not fully understood. It is believed that service companies should analyze the feelings of customers to determine their preferences when shaping the value proposition of a service format [9, 10]. Exploring the relationship between customer feelings and service elements in online restaurant reviews based on the review usefulness and enjoyment of the service experience can be a good guideline for service providers seeking to offer high-quality services, and increase service intent of potential customers at the pre-purchase stage.

A positive sentiment focus on the tone of the review often helps customers avoid choosing restaurant services that may not meet their expectations. Peer reviewers can indicate exactly those factors that best reflect their experience [11]. Customers can freely choose the positive or negative sentiment direction of the tone of the text when discussing the factors of the service that influenced their overall impression.

Few reviews directly indicate the incentive to buy a specific restaurant service, and those that comment on a target purchase are studied in research as the driving force behind star rating in online reviews and target purchase intentions [12]. However, there is no clear agreement as to whether a directive recommendation is an explicit or implicit expression of a recommendation, there is agreement that it is a direct incentive act that strongly influences decision-making by potential clients.

This study supports the identification of the value proposition factors in online restaurant customer surveys that influence recommendations and indicate that the service is appropriate for other potential customers. The focus of the tone of the reviews and the emotional attitude are important markers of customer satisfaction.

Previous research has also shown that customer feelings and emotional experiences play an important role in customer satisfaction, and that competent and well-established service logistics can also influence ratings, reviewers, and the former are more related to the format of the company's service, and the latter to the functional factor of the quality of the dishes themselves. The author defines the service format as the level of service provision based on the perception of the client, which includes solving the problems of the buyer, meeting the desires of a certain lifestyle, analyzing and controlling measures to create value for products, forming a competitive strategy expressed in the initiation of emotions when selling goods and services for long-term customer support, and stimulating repeat purchases through a positive brand image.

Understanding the motivations and determinants behind online review recommendations can help managers improve the competitiveness of their food service offerings to better meet consumer expectations and better shape their value proposition. However, due to the unstructured nature of online reviews, building a model that uses text to identify prior explicit recommendations without using formal methods to structure such information is challenging. Text mining has been successfully used in research to solve these kinds of problems, and this method has been used in the current study.

Nowadays, digitalization has a significant impact on the logistics processes of service delivery and can create intrinsic value for the restaurant industry and society as a whole. Building a logistics network using digital technologies will provide a new level of resiliency and efficiency in the provision of services, which will allow restaurant companies to gain a competitive advantage in an effort to provide their customers with the most efficient and transparent service delivery.

2 Material and Methods

Online reviews analytics influences the entire process of planning, manufacturing, and delivering restaurant products, including improving logistics processes, streamlining workflows, and reducing lead times. Digitalization affects logistics in terms of economic and social aspects of sustainability through the optimal formation of a value proposition that relies on customer requests in online reviews. In other words, digitalization in logistics allows restaurants to create an affordable service delivery system that works efficiently, offers solutions that meet the current demand in the market. It also takes into account the basic needs of potential customers.

Online reviews were analyzed using a text mining method based on natural language processing. This approach allows words processing in a text review, in such a way as to determine the sentiment direction of the text (positive or negative) and to group the factors that reviewers pay most attention to. Unlike traditional methods of conducting qualitative research, text mining allows automatic breakdown of text into keyword groups, taking into account contextual and semantic component of the data.

The first phase of domain formulation: The demand for logistics and its importance in service delivery continues to grow with the rise in popularity of e-commerce in the restaurant business, much of which is based on the online reviews of previous customer experiences. In this study, the analysis of service format factors is based on the Kansei engineering method (Human Factors Emotional Engineering). Kansei engineering transforms the human experience that customers describe in online reviews into value proposition factors in a service format to create an optimal value chain and quality restaurant business modeling. In other words, this method is a great tool for improving existing products and concepts in the restaurant delivery business. In particular, catering services and their e-commerce delivery logistics were identified as the design area in this study. Service users include both customers and e-commerce restaurants. Customers order food transportation via e-commerce and use online platforms to exchange experiences gained from receiving orders in offline space. Sellers entrust orders to logistics providers (aggregator companies) for packaging and handling goods, or directly serve the client through their own logistical structures.

Based on this, the overall service described in online reviews of restaurant business customers can be divided into five sub-processes factors:

1. Time (preparation time and delivery time);
2. Quality of the heat treatment of dishes for hot food;
3. Range of the delivery menu;
4. Loyalty program (promotions, bonuses, discounts);
5. Possibility of ordering through aggregators (Yandex food, Delivery club, Foodtaxi).

The second stage covers the semantic space and keywords through text mining. At this stage, the keywords included in each factor that were used in online customer reviews to articulate and emotionally express the experience gained from using the restaurant service are extracted from the text reviews to establish are grouped according to the established factors in the first stage. Online reviews include user-generated content reviews on TripAdvisor for 242 restaurants that are part of the largest chain restaurant companies in St. Petersburg.

In order to identify keywords (or Kansei terms) and shape them into certain factors, a keyword detection method, based on the probability of n-grams, was implemented. N-grams of text documents are widely used in text mining tasks. They are essentially a collection of matching words in a given window, and usually one word is moved forward when calculating n-grams. If the likelihood that a certain set of matching words in the corpus is high, this means that the set of matching words is likely to be the most popular term for the factor. This was followed by a check for the presence of keywords in text reviews, using the QDA Miner Lite program, to determine the frequency of mentioning the keywords of each of the factors, and to group semantically identical words and terms according to their relationships.

The sample was selected from user reviews of more than 50 words from 201 restaurants, and were written during from 2011 to 2020. Each review was categorized according to positive or negative text sentiment to understand overall customer satisfaction with the restaurant service provided. Reviews were classified as 1 (positive review, “recommended”) or 0 (negative review, “do not use this restaurant”), depending on the text emotional orientation and the indicated n-grams associated with a positive or negative attitude: waiting time, taste of food, loyalty program and cost of food, easy availability of service and customer support. For example, online reviews in which customers reported long wait times at a restaurant were categorized as such by the use of keywords such as “waiting” and “long”, while positive and negative terms related to the loyalty program and the cost of dishes (for example, “specials”, “discount”, “cheap”, “affordable”) and the quality of dishes (for example, “tasty”, “juicy”, “hot food”) were also binary classified according to the different keywords. Directional keywords were used to classify explicit recommendations: for example, “come back” and “try” designated positive recommendations and were classified as a category of positive text direction (“recommended”). Terms such as “cannot recommend” and “do not plan to return” with negative recommendations were classified as negative text category (“not recommended”).

At the third stage, the relationship between the space of the semantic core and key factors is identified, for the formation of significant factors of the value proposition of the service format and the construction of a multivariate analysis of variance MANOVA for the analysis of the relationship. The calculations were performed using the SPSS 24.0 software package. Sentiment is calculated and the factors of service format according to customer opinions in their online reviews, which are classified according to the degree of significance and weight. It is in this sequence that managers need to pay attention to factors in the formation of a value proposition. MANOVA analysis tests the influence of five qualitative factors and quantitative star ratings in online reviews on negative and positive customer sentiment.

3 Results

The profiles of reviewers on TripAdvisor are presented in Table 1. Most respondents (61.2%) have 1–4 years of experience with the online review platform. 87.6% had left at least 1 detailed review of more than 50 words.

Out of the total sample of 201 reviews, 17,091 words of online reviews (53.4%) contained a positive directionality of the sentiment of the text, and 14,895 (46.6%) were negative (Table 2). This sample follows a distribution skewed towards positive sentiments, which is consistent with empirical findings in similar studies.

In accordance with the five factors described above, Table 3 shows the significant factors of the value proposition of the online restaurant delivery service format in the online reviews of St. Petersburg customers and determines the tone of each of them, showing the degree of significance of the factor. The higher the sentiment, the stronger the influence of the factor on its value for the reviewer.

After determining factors sentiment, the result was tested using the MANOVA test to identify the relationship between five factors that measure the direction of the sentiment

Table 1. Profile of reviewers

Characteristics		Frequency	Percentage (%)
Gender	Male	53	26.4
	Female	148	73.6
Residence	Saint-Petersburg	176	87.6
	Other Russian cities	25	12.4
Experience of participation on the platform (years)	1–4	123	61.2
	5–9	75	37.3
	10 and over	3	1.5
Number of reviews	1–100	176	87.6
	101–200	18	8.9
	201 and over	7	3.5
Number of review likes	0–50	173	86.2
	51–100	16	7.9
	101 and over	12	5.9

Table 2. Sentiment of online reviews of restaurants in St. Petersburg, 2020

The sentiment of online reviews	Number of words	% of words	Tonality
Positive	17,091	53.4	1.06
Negative	14,895	46.6	0.93

Table 3. The significant factors in the value proposition of the service delivery format of restaurants in online customer reviews of St. Petersburg, 2020

Factors	Number of words	% of words	Tonality
Time	6,982	21.8	1.09
Quality of the heat treatment of dishes	6,257	19.6	0.97
Range of the delivery menu	7,970	24.9	1.24
Loyalty program	3,036	9.5	0.47
Possibility of ordering through aggregators	7,741	24.2	1.21

of customer opinion regarding the qualitative description of the service format, and the quantitative star ratings (from 1 to 5) that accompany a text review (Table 4). Multilevel analysis allows the hierarchical structure of the online reviews to be taken into account in detail and a multivariate analysis of the sentiment of the text to be carried out.

Table 4. MANOVA analysis: testing the influence of the five factors and quantitative star ratings on the sentiment direction of online reviews

Multivariate results				
Factors	df	Wilks's λ	F	Sig
Time	112	0.219	7.707*	0.006
Quality of the heat treatment of dishes	81	0.219	2.546*	0.112
Range of the delivery menu	75	0.218	12.927*	0.001
Loyalty program	104	0.219	5.987*	0.015
Possibility of ordering through aggregators	89	0.220	10.123*	0.002

Note df—the number of degrees of freedom; Wilks's λ—Wilks lambda; F—the value of the F-criterion; Sig.—significance
*$p < 0.05$

Table 4 shows that the delivery menu ($F = 12.927$, $p < 0.05$), the possibility of ordering through aggregators (Yandex food, Delivery club, Foodtaxi) ($F = 10.123$, $p < 0.05$), and delivery time ($F = 7.707$, $p < 0.05$) have a significant impact on the negative and positive sentiment of online reviews and significant importance for customers when choosing a restaurant service. It also confirms the results obtained when identifying significant factors in the value proposition of the service delivery format of restaurants in online customer reviews (Table 3). The loyalty program (promotions, bonuses, discounts) has the least impact ($F = 5.987$, $p < 0.05$), while the quality of the heat treatment of dishes ($F = 2.546$, $p < 0.05$) is not an independent significant variable.

4 Discussion

Digitalization in logistics has a number of advantages in the field of technology optimization, simplification of production processes, organization and application of company knowledge. It affects significant components in the online delivery restaurant business value chain: collaboration, interconnection, adaptability, integration, autonomous control and interaction marketing improvement.

This research reveals the most discussed topics about text mining method in online customer reviews since the scientific community began using text mining technology for big data analytics in the hospitality and service industries. Method helps to uncover the most significant factors that are relevant to a value proposition from a consumer perspective. Through text mining, this study complements and contributes to the literature, revealing the most important factors in the service value proposition format. It also helps online review analysts to manage a company's business model based on data from reviews. Managers can effectively select the formats that will achieve the desired effect.

The delivery menus, ability to order through aggregators and delivery time are the most important factors predicting the presence of a positive or negative recommendation sentiment in a review. Choice and speed of online delivery are likely to be deciding factors in determining the purchasing intent of potential customers when deciding whether to use an e-commerce service. Logistical needs are becoming more demanding and complex, including a combination of factors and the service market is becoming more and more competitive.

The obtained results of the research shows that text mining is an effective and useful method for structuring a huge amount of previously unstructured data in tasks such as analytics of online customer reviews. In other words, text mining can help in identifying significant factors for the formation of a restaurant value proposition, which should be used as a basis for delivery service increasing demand strategy. Conducting text mining method, followed by multivariate analysis of variance, can be a way that assist researchers to examine correlations between multiple factors and group them by topic, before embarking on a deeper statistical analysis between online consumer reviews and value propositions of restaurant delivery systems.

5 Conclusions

For the value proposition of the restaurant business, the question of how to increase customer loyalty and attract new customers is an urgent problem. This study used a data mining approach to analyze the relationship between service format factors and the emotional perception of customers (Kansei engineering), the sentiment direction of online reviews, and identified the importance of service format factors from the point of view of consumers, which is a useful analysis for shaping a company's value proposition. By identifying service factors and keywords used by customers, this study integrated text mining analysis of online content into a traditional expert knowledge approach to improve overly subjective opinions of reviewers. Moreover, text mining technologies have also been used to establish associations between service format factors and customer experience. The results were compared using multivariate analysis of variance, which made it possible to contribute to the development of a method for operational value proposition analysis. This study proposes a design procedure for identifying significant service format factors that can be applied to a variety of service industries where customers use delivery and e-commerce systems and share their experiences online.

As with any research, there are some limitations. The study was limited to one source of information (TripAdvisor) and one type of service business (the restaurant industry). Further research to develop this work could confirm the results using alternative review platforms, or shift the focus to other logistics services in the hospitality and tourism sector. In future articles, it would be possible to identify whether a particular experience (for example, waiting time) influences certain factors of the service format (for example, the quality of the logistics), which will help managers quickly recognize and respond to changes in the loyalty of potential customers, predicting consumer behavior.

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The Maturity Evaluation of Procurement and Logistics Processes in the Value Chain

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Abstract. The performance of logistics and purchasing processes in the value chain is crucial, especially in the terms of digitalization and trending technologies. The management of these processes has a great impact on overall sustainability of the company and contributes to its success on the market. The article aims to present an approach to assessing the level of maturity of procurement and logistics processes in the value chain. The developed approach is based on the requirements and recommendations of standards and on the methodology of the level of maturity of processes assessment. Several Russian State Standards (GOST) in the field of lean manufacturing and information technology were analyzed. Thus, the presented approach is meant to help to determine the strengths and weaknesses of procurement and logistics processes to eliminate risks. The article is relevant for the management of logistics, and the results of the research may be practically used in the organizations looking forward to digital transformation.

Keywords: Value chain · Procurement · Logistics · Process approach · Process · Maturity · Evaluation · Improvement

1 Introduction

In today's world, the overall sustainability and success of a company is linked to the efficiency of its processes. In this regard, the process approach has become widespread, and its merits are highly appreciated by both researchers and companies. The efficiency of logistics processes and procurement management plays an important role in the overall contribution to the company's activities. Therefore, the assessment of logistics and procurement processes is one of the priorities for the business, a task that must be successfully solved. Such an assessment should be based on a consistent and logical approach and have structured methodological tools [1].

In the literature, there are two main types of models for the study of logistics processes: a model based on measuring process performance, and a model based on measuring the maturity of processes. The first type offers general approaches or frameworks for

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assessing supply and procurement management, for example, SCOR or Balanced Scorecard [2]. However, a model based on measuring process maturity helps not only assess the current state of processes, but also suggests what actions need to be taken to move to the next level of maturity. Maturity assessment criteria are simple and understandable; therefore, they will not cause difficulties for management in the assessment.

The term "maturity" in the context of assessing the state of processes is understood as completeness, perfection, readiness of processes. On the contrary, "immaturity" is understood as an imperfect, unfinished process that requires optimization [3, 4]. The concept of maturity can be applied to the assessment of a company's processes to determine its effectiveness, ability and competence in managing processes. By improving processes, the company becomes more efficient, more profitable and competitive [5].

Thus, a maturity model is a tool used to measure, compare and describe the state of processes, consisting of a set of elements or criteria that describe the way to improve processes from immature and ineffective to qualitatively better, mature processes. Evaluation can be both qualitative and quantitative, and can be used to compare several companies with each other [6].

The authors of the study decided not only to base the developed approach on the process maturity model, but also conducted a deep analysis of State Standard GOST. Thus, the purpose of the study is to use the State Standard GOST, as well as an approach to assessing the maturity of processes and the concept of a value chain to create a more complete, understandable and practical approach to assessing procurement and logistics processes. The evaluation of the processes is crucial for the companies looking forward to the digitalization trend as it is impossible to integrate digitalization unless you are aware of the processes state in your company.

2 Materials and Methods

During the study, the following method was applied:

- Analysis. The requirements and recommendations of GOST standards are analyzed in order to develop an approach that would contain the most appropriate characteristics of each process. The authors base the approach on the attributes and descriptions stated in GOST and the five levels process maturity model [7].

Thus, the main materials used in the work are state GOST standards and a model for assessing the maturity of processes.

3 Results

In accordance with [8] value stream refers to all activities, both creating and not creating value, that allow products to go through all the processes from concept development to launch into production and from order acceptance to delivery to the consumer. At the same time, it is noted that the value for the consumer of products is created in the production processes and logistics processes.

Meaningfully, value in logistics processes is achieved by delivering products to the consumer at the right place, in the required quantity and quality, and at the right time. This formally corresponds to the achievement of target values in the system of indicators “quality-cost-time” using the appropriate methods of lean manufacturing [9] for sustainable development [10] and continuous improvement [11]:

- the effectiveness of customer value creation processes;
- characteristics (capabilities) of processes;
- values for the consumer;
- reduction of real and potential losses.

The effectiveness and efficiency of the digital transformation of procurement and logistics processes is due to their current level of maturity, for the assessment of which the approach stated in [12] can be used. The approach is based on a rating score relative to the selected base model for the following 9 attributes:

- process implementation attribute;
- implementation control attribute;
- work product control attribute;
- process definition attribute;
- process deployment attribute;
- process dimension attribute;
- process control attribute;
- process innovation attribute;
- process optimization attribute.

At the same time, to assess individual procurement and logistics processes, basic models of system’s life cycle processes can be selected [13], including the following description:

- acquisition process:

  – purpose: to obtain a product or service in accordance with the requirements of the acquirer;
  – outputs: a supply request is being prepared; one or more suppliers are selected; an agreement is established between the acquirer and the supplier; a product or service is accepted that conforms to the agreement; the obligations of the acquirer specified in the agreement are satisfied;
  – tasks (actions): define a strategy for how the acquisition will be carried out; Prepare a request for the supply of a product or service that includes specific requirements; communicate a request to supply a product or service to specific vendors; choose one or more suppliers; develop an agreement with a supplier that includes acceptance criteria; identify the necessary changes to the agreement; evaluate the impact of the changes on the agreement; negotiate and update the agreement with the supplier as needed; evaluate the implementation of the agreement; provide the data required by suppliers, resolve problems in a timely manner; Confirm that the delivered product

or service meets the agreement; provide payment or other agreed action; accept a product or service from a supplier or other party as agreed; close the agreement.

- delivery process:
  - purpose: to provide the acquirer with products or services that meet the agreed requirements;
  - output results: a response to the acquirer's request is made; an agreement is established between the acquirer and the supplier; a product or service is being supplied; the supplier's obligations specified in the agreement are satisfied; responsibility for the purchased product or service is transferred in accordance with the agreement [14];
  - tasks (actions): define the existence and identity of the acquirer who has a need for a product or service; define a delivery strategy; evaluate the request for the supply of a product or service in order to determine the feasibility and content of the response; prepare a response that satisfies the request; negotiate an agreement with the acquirer that includes acceptance criteria; identify the necessary changes to the agreement; evaluate the impact of changes to the agreement; negotiate and update the agreement with the acquirer as needed; execute the agreement in accordance with the established project plans of the supplier and in accordance with the agreement; evaluate the implementation of the agreement; supply a product or service in accordance with the criteria of the agreement; provide assistance to the acquirer in maintaining the delivered system or service as agreed; accept payment or other agreed action; transfer the product or service to the acquiring party or another party in accordance with the agreement; close the agreement.

- transfer process:
  - purpose: to establish the ability of the system to function according to the specified requirements of the interested parties in the operational environment;
  - output results: transfer constraints that affect system requirements, architecture or design are identified; any supporting systems or services required for transmission become available; the site of the location is being prepared; the ability of the system installed at its operational location to perform its functions is ensured; operators, users and other interested parties required to use and maintain the systems are trained; the installed system is activated and made ready for operation; traceability of transferred elements is established;
  - tasks (actions): define the transfer strategy; identify any necessary changes to fixed assets or the site of the location; Identify and organize training for operators, users, and other interested parties required to operate and maintain the system; Define system limits due to transmission for inclusion in system requirements, architecture or design; identify and plan actions regarding the required supporting systems or services that must support the transmission; obtain or purchase access to the provisioning systems or services that will be used; Define and organize the shipment and receipt of system elements and support systems; prepare the site for operation in accordance with the installation requirements; put the system for installation at a

certain place and at a specified time; install the system at its operational location in conjunction with the environment; demonstrate proper installation of the system; Provide training to operators, users and other interested parties required to use and maintain the system; perform system activation and control; Demonstrate that the installed system is capable of the requested functionality; Demonstrate with support systems that functions are performed by the system in a sustainable manner; analyze the system for operational readiness; take the system into operation; record the transmission results and any deviations you encounter; record operational incidents and problems and ensure they are resolved; Maintain traceability of transferred system elements; Maintain the underlying information objects that were selected for the baselines.

The results of the assessment characterize the current capabilities of the process, corresponding to one of 5 maturity levels, for the determination of which the authors offer the following meaningful description [15]:

1. Implemented process (reached its destination):

   a. certain process outputs are achieved.

2. Controlled process (requirements for input and control parameters are defined):

   a. process objectives are identified;
   b. implementation of the process is planned, monitoring is in progress;
   c. process execution is adjusted to fit plans;
   d. responsibility and authority for the implementation of the process is defined, allocated and communicated;
   e. resources and information necessary for the implementation of the process are identified, available, allocated and used;
   f. interfaces between the parties involved are managed to ensure effective communication and clear allocation of responsibilities;
   g. requirements for the work products of the process are defined;
   h. requirements for documentation and work product control are defined;
   i. work products are identified, documented and controlled;
   j. supervision of work products is ongoing.

3. Established process (integrated into the system, requirements for the parameters of the mechanism are defined):

   a. sequence and interaction of the process with other processes is defined;
   b. the competencies and roles required to carry out the process are identified;
   c. infrastructure and working environment necessary for the implementation of the process is identified;
   d. methods of monitoring the effectiveness and applicability of the process are defined;

e. process is deployed based on a suitably selected and linked standard process.

4. Predictable process (statistically controlled):

   a. information needs of the process are established;
   b. process measurement objectives are defined;
   c. quantitative goals of the process are established;
   d. means and frequency of measurements are identified and determined;
   e. measurement results are collected, analyzed and reported;
   f. measurement results are used to characterize the implementation of the process;
   g. methods of analysis and control are defined and applied;
   h. controlled limits of variation are established for the normal implementation of the process;
   i. measurement data is analyzed;
   j. corrective actions are being taken;
   k. controlled limits are reset after corrective action.

5. Optimizing process (continuously improved):

   a. process improvement objectives are defined;
   b. data to identify common causes of variation in process implementation is analyzed;
   c. data to identify opportunities for good practice and innovation is analyzed;
   d. opportunities for improvements resulting from new technologies and process concepts are identified;
   e. implementation of the strategy to achieve the goals of process improvement is established;
   f. implementation of all agreed changes are managed;
   g. the effectiveness of the process changes based on actual performance is assessed against specified product requirements and process objectives.

The collation between the classical CMMI model of the process maturity and the approach suggested by authors is presented in the Table 1.

In cases where basic models (system life cycle processes) are not known for individual logistics processes, a self-assessment approach can be used [16]. At the same time, self-assessment is understood as a comprehensive and systematic analysis of the organization's activities and indicators of the level of its maturity.

The key elements of self-assessment in relation to "Process Management" are the following [17]:

- definition of processes;
- responsibility and authority;
- management and relationships;
- maintaining the achieved level and improving.

Table 1. The collation between 5 level maturity model according CMMI and the author's approach

	5 level maturity model according CMMI, [7]	5 level maturity model according author's approach
Level 1	Initial	Implemented process (reached its destination)
Level 2	Managed	Controlled process (requirements for input and control parameters are defined)
Level 3	Defined	Established process (integrated into the system, requirements for the parameters of the mechanism are defined)
Level 4	Quantitatively managed	Predictable process (statistically improved)
Level 5	Optimizing	Optimizing process (continuously improved)

At the same time, a 5-level maturity model is used with a meaningful description of the criteria for each of the above key elements. To simplify the self-assessment of the maturity level of "Process Management", the authors propose the following generalized scale:

1. policies and approaches to process management are not defined;
2. process criteria, policies and approaches to management are documented, information of the process passport is kept up to date [18];
3. the owner and participants of the process know the criteria of the process and the PDCA-management cycle, are guided by the relevant documents, the compliance of their knowledge is confirmed by the results of audits;
4. process criteria, policies and approaches to process management are consistent with corporate culture and strategic goals, risks and losses are analyzed, key performance indicators based on the PDCA process management cycle are applied, controlled conditions are supported [19];
5. self-assessment of the level of process excellence is regularly carried out, improvement initiatives are in progress, stakeholder satisfaction with the quality of process management is consistently high.

Thus, using the described approach to assessing the level of maturity of procurement and logistics processes helps to determine their strengths for dissemination as best practices and areas for improvement (weaknesses) to eliminate risks and losses during digital transformation.

4 Discussion

It is necessary for companies to control and manage the logistics and procurement processes in order to be able to compete in the market. To achieve strategic goals management needs to evaluate the state of the company as it is now and have a road map for the future development.

The proposed model for the evaluation of maturity is a convenient way to recognize strengths and weaknesses of logistics processes in the company. It also makes it possible to compare one's evaluation to the best practices or another company's processes. However, the results of the evaluation should be updated regularly in order to match the expectations on maturity definitions [20].

The proposed approach and the scale of criteria can be applied in different industries and companies as long as they have to deal with logistics and procurement: medicine, retail, construction, transport etc. Moreover, as the digitalization trend in logistics has a high impact on the processes, the assessment of the maturity should be considered as a high priority for the organizations willing to become digital.

5 Conclusions

Thus, the article identifies approaches stated in State standard GOST; analyzes basic model of system's lifecycle processes including its main purpose, output results and activities; links the results to the 5 levels of maturity model and proposes a generalized scale to assess the level of maturity of procurement and logistics processes effectively. This scale guarantees an appropriate approach to the evaluation due to its basis on the well-known maturity model as well as State standards used for the achievement of sustainability and success. The approach is of high interest for the companies managing logistics process in the age of digitalization.

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Pharmaceutical Logistics: Features and Challenges

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Abstract. Pharmaceutical logistics is a mechanism by which the health system assures regular support, a supply of medicinal aids and tools, waste disposal, cleaning, sterilization, and other supporting activities related to support for the control process. The growth in pharmaceutical logistics complexity coincides with the structure and utilization of innovative supply chain plans and technology, particularly in the private sector. In the public sector, national pharmaceutical logistics, and the global community that supports them, have an opportunity to better their performance and a command to provide the right pharmaceutical goods in the right state, at the accurate time, in the proper place, and at the best supply chain cost. The study is devoted to pharmaceutical logistics. This article presents the features of pharmaceutical logistics and its organization, the main provisions, the features of the movement of medicinal products, and a description of the importance of managing medical supplies. The article also describes the importance of the availability and reliability of the supply of pharmaceuticals to pharmacies and later to customers.

Keywords: Healthcare · Logistics · Pharmaceutical logistics

1 Introduction

At present, the processes of integrating biotechnologies, medicine, and information technologies are actively developing in the world. The purpose of the article is to describe the key features of pharmaceutical logistics and the processes of its organization. The authors describe the peculiarities of the movement of medicines and highlight the importance of managing medical supplies. The main directions in the development of innovative drugs are going in parallel with the development of diagnostic systems to personalize medicine. Logistics is a branch of the economy in which the heads of logistics departments need to ensure high clarity of procedures, the coherence of logistics business processes, and the precise timing of logistics operations by all supply chain [1]. However, there are areas of logistics activities that are the most difficult to organize efficient operations and achieve logistics' main objectives. Among such industries, one can single out logistics activities for pharmaceuticals, medicines, and vaccines [2].

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The organization of logistics activities of companies should consider the industry specifics in which they are carried out. For some companies, it is essential to take into account the time factor when organizing supplies; for other companies, the most important is price parameters; for companies in the pharmaceutical industry, the most important is compliance with temperature, economic, customs, and other regimes when moving goods along the supply chain. Today, logistics is considered as a fundamental management tool that provides to the achievement of strategic, tactical, or operational purposes of a business organization through useful in terms of reducing overall costs and meeting the requirements of end-users for the quality of products and services, management of material and service flows, as well as the accompanying information flows, and financial resources [3]. In contrast to the traditional approach, which provides for the leading equipment's continuous operation, maintaining a high utilization rate, the most extensive possible stock of material resources is available to ensure uninterrupted customer service. The fundamental difference between the logistic approach to management is the rejection of traditional sales management and switching to end-to-end material flow management. From the standpoint of organization management, logistics can be viewed as strategic management of material flows in the supply process: purchasing, transportation, sale, and storage of materials, parts, and finished inventory. Different logistics systems are used depending on the specifics of the company's activities [4].

Pharmaceutical logistics includes the management of drug flows both between facilities and indoors. In modern conditions and with the requirements that are put forward for pharmaceutical logistics, from the point of view of guaranteeing the quality of logistics services to consumers and ensuring reliable, clear and efficient functioning of logistics systems, networks and supply chains, logistics should be:

- operating and adequate;
- adapted and flexible;
- operational and integrated;
- optimal and balanced [5].

It is generally accepted that this environment consists of a complex set of functioning, parallel, intertwining material, transport, capital, financial, money, labor, information, service, and other flows, as processes of their transformation, continually occurring in commodity distribution channels, through which communication and interaction are carried out between all constituent structural objects and subjects. The pharmaceutical industry is no exception to the general rule. Analysis of the current stage of logistics development showed that there are currently three main classical approaches to the formation of logistics systems in the pharmaceutical business [6].

1. The operational approach lies in the fact that when organizing and carrying out logistics operations in the pharmaceutical sector, the main emphasis is on improving the material flow management process in logistics systems with appropriate information and financial service support and support. Those this approach is aimed at improving various processes, operations and activities in logistics systems.
2. The operational approach is that international, regional and national logistics should be adequate, adapted to each other, as well as to external environmental conditions,

flexible, transparent and capable of quick, prompt response to possible changes in production and the environment under the influence of innovations, scientific and technological progress, investments and in market solvent demands of consumers.

3. An integrated approach focuses the attention of managers involved in pharmaceutical logistics on the integration and adequacy, harmonization and coordination of the end result of the work of all participants in the logistics chains and links [7].

2 Materials and Methods

Within the framework of the article, the method of analyzing the current state of pharmaceutical logistics was used, the main advantages and disadvantages were identified, and the importance of managing consumables for medical purposes was described. General scientific methods, methods of comparative analysis, methods of clustering the peculiarities of the development of pharmaceutical logistics are used.

3 Results

In the pharmaceutical business, importing products is essential. International global pharmaceutical logistics must meet all the requirements for pharmaceutical logistics in the domestic, national market, but in addition, it has to cope with the much greater uncertainty of world markets caused by increased distances, different modes of transport and vehicles, requirements for them, fluctuations in consumer demand, language barriers and free options for translating business information, a variety of rules of state, customs and legal regulation, forwarding and insurance support, execution and provision of documentation in different languages. The main goals of international pharmaceutical logistics are to implement the following areas [8]:

1. Organization, provision and support of: foreign trade commercial and non-commercial operations, international exchange of all kinds of necessary economic resources, including financial, informational, innovative, integrated, harmonious, effective connections with regional logistics and national logistics of the states—partners in foreign trade, evolutionary and organically integrating them in stages into the international pharmaceutical logistics system. Also, it is the reliability of transportation and transshipment of goods of any kind and type necessary for the pharmaceutical industry, levels of complexity, danger, dimensions, parameters, characteristics, operational movements of a diverse range of tangible and intangible commodity products within contractual terms to consumers between continents from one state to another.
2. Optimization of resource, time, service and financial costs for the delivery of commodity products from the manufacturer to the consumer: effective logistics flows of commodity products, cargo, information, financial and intellectual resources, investments, services between countries and continents, as well as modern and high-quality, environmentally safe, in accordance with sanitary and hygienic standards of containers, packaging and stowage, cargo units and vehicles [9].

The entire path along which the goods pass can be divided into separate sections or links [10]. Warehouse links through which the goods pass. The selected distribution channels affect the speed and time of delivery of products from the manufacturer to consumer and its safety and cost. The distribution channel is considered direct (zero) when the goods from the manufacturer are delivered to the consumer, i.e., there are no intermediaries. Thus, the zero-level channel is characterized by the presence of only two participants [11]. Figure 1 shows a zero-level diagram of pharmaceutical logistics.

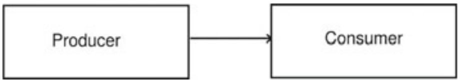

Fig. 1. A zero-level diagram.

When intermediaries are included in the distribution channel, it becomes indirect (multilevel). If there is only one intermediary, the channel is the first level. Figure 2 shows the first level diagram.

Fig. 2. A first-level diagram.

Therefore, in the presence of two intermediaries—a second-level channel. Distribution channels can be vertical (manufacturer—distributor—retail sales—consumer) and horizontal (among companies of the same level). It is typical for large pharmaceutical companies to use all distribution channels to bring products to consumers [12].

The movement of material flows in the supply chain is impossible without the concentration in certain places of the necessary stocks, for the storage of which the corresponding warehouses are intended. The movement through the warehouse is associated with living and materialized labor costs, which increases the cost of goods [13].

In modern distribution logistics warehouses, combinations of different types of storage are most often used. This is explained by the variety of commodities and the type of warehouse with its specific features. If, with the organization and management of flows of a transformation of tangible assets, finance, services between pharmaceutical organizations within one state, the problems are gradually being solved, then with international pharmaceutical logistics, they still exist [14]. The increased pharmaceutical market leads to boosted sales volume and forcing in producing nations throughout the world. This suggests that the need for warehouse management cannot be overemphasized. The pharmaceutical industry must rely massively on logistics services for this task. The more attractive markets expanded visibility in the supply chain, and reducing costs have made this need even more of a reality.

One of the problems of international pharmaceutical logistics is the quality transportation of medicines. A vehicle breakdown leading to the shutdown of temperature-maintaining equipment, a delay in loading or unloading without the use of thermal insulating containers, storage in unsuitable warehouses can turn a pharmaceutical, medical product, or vaccine into a life-threatening product. Therefore, such drugs and vaccines should be disposed of immediately to violate storage and transportation regimes. Freezing and overheating are both detrimental to vaccines, biologics, and many other pharmaceutical and medical products. Many logistics companies need to offer temperature-controlled freight options, as Diversified Transportation Services does. The transportation of medicines belongs to the category of moving fragile goods. Therefore, there are many requirements for the service that relates to the complete safety of the transfer. The goal is to deliver drugs without losing their primary characteristics while maintaining their properties. The state of vaccines and solutions is monitored, packaging integrity, quantity, and the shipped batch [15]. There are basic rules for the transportation of medicines, any logistics company that has taken responsibility for the delivery of a pharmaceutical batch is obliged to fulfill the established requirements.

Pharmaceutical logistics is becoming a major area during Covid-19, when many countries are actively preparing for mass vaccination of the population. It is very important to assess the readiness of the infrastructure for the storage and competent transportation of a large volume of drugs. The global logistics industry is facing an unprecedented challenge. In the next year or two, she will have to ensure the delivery of about 10 billion doses [16].

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The main task to be solved by all countries in the delivery of vaccines is to comply with the temperature regime. All vaccines against Covid-19 were created relatively quickly and scientists are not sure about the stability of the formula. They may not be able to withstand temperature changes during transport and change their properties. Therefore, at present, logistics companies, like scientists, are entrusted with the highest responsibility, therefore it is so important to find out what risks exist when organizing vaccine logistics and how to make sure that the drug reaches the recipients in its original form. To implement the competent transportation of vaccines, you need to consider the main steps of action.

3.1 Preparing

If for most vaccines the optimal storage temperature is from 0 °C to + 5 °C, then for the Covid 19 vaccine, the optimal temperature should not exceed minus 18 °C. And this is not a record low figure, the vaccine from the representatives of Oxford University will have to be transported at temperatures ranging from minus 60 °C to minus 80 °C. This temperature difference is explained by the unknown stability of the vaccines. The stability of the vaccine is the ability to withstand temperature extremes without changing the formula, which means maintaining its pharmacological properties. The next stage of preparation is packaging. Vaccines can be produced from production in conventional ampoules, in flasks made of glass or composite materials with the use of plastic, or even directly in disposable syringes. The number of vaccine doses in the thermal container determines its model. On average, hundreds of doses [18].

The packaging mechanism is the storage of boxes in one row, in one layer, so that they are not crumpled or deformed during transportation. Vaccine boxes should never be stacked one on top of the other, as this could cause damage. The last stage of preparation is the selection of a container for transportation. The choice of container is based on their ability to store temperature and also depending on the size of the transported batch. The modern insulated container is a self-contained unit with a thermostat. It maintains the temperature either using thermostats, or by the implementation of a phase transition. Figure 3 shows the types of containers for transportation.

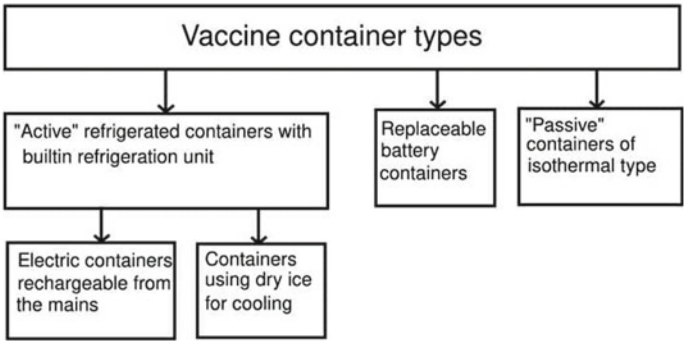

Fig. 3. Vaccine container types.

3.2 The First Stage of Delivery

Preparing the required amount of vaccines is the first step, the next is delivery. There are 3 options for transporting the vaccine:

- delivery from production directly to the end consumer;
- shipment to a single distribution hub, with subsequent distribution to regional centers;
- combined model.

The first option, delivery directly to the bed fund to the consumer, works only over short distances, for example, for delivery to a neighboring city: a specially equipped car carries the vaccine from point A to point B. In order to choose which option is suitable, it is necessary to estimate the volumes of batches and directions delivery. The initial stage of transportation of a vaccine is its delivery from the place of production to a single distribution hub or any other point of changing the mode of transport. From the place of production, the vaccine is delivered to the car, thermal containers with the material are loaded into the refrigerator. The most important task when loading a car with vaccines from production is the observance of the cold chain: along the entire route of the product. This task can be solved with the help of refrigerating chambers, sluices, vestibules and other devices that allow you to maintain the temperature.

3.3 An Intermediate Stage of Delivery

The last stage is the choice of transport for the longest stage of vaccine transportation. Basically, goods are transported using trucks, trains, cargo ships, aircraft.

Of course, the selection criterion is the distance between points, but the preferred option is an airplane. Firstly, the plane can carry about 100 containers with vaccines, and secondly, temperature sleeves and dermo-loaders are used at the airport, which make it possible to move containers with vaccines from car to plane without disturbing the temperature regime. And for Covid 19 vaccines, this is the main goal and condition.

3.4 The Final Stage of Delivery

The last stage of delivery is the transportation of vaccines from the airport to the medical facility by car. At the last stage of delivery, as in the previous stages, the main task remains to comply with the cold chain. From a technological point of view, this is achieved by the same means as in the first stage. When delivering by air to the airport of arrival, the thermal containers are unloaded from the plane, and they go to the terminal. Even if there are no refrigeration locks and vestibules at the airport, thermal containers allow the vaccine to be transported from the aircraft to the terminal, and then to the refrigerator body without the risk of disrupting the temperature regime.

The transportation of the Covid 19 vaccine is a difficult task from the point of view of pharmaceutical logistics, this task is influenced by many factors, but the main goal is to maintain the temperature regime, in order to avoid changing the vaccine formula, regardless of the batch quantity. As a result of this article, the safest sequence of transportation and the use of technological supplies for the delivery of the Covid 19 vaccine to any country, region was provided.

4 Discussion

As part of further research, it is planned to shape the business processes of a medical organization, considering the key aspects introduced by the pharmaceutical industry.

5 Conclusions

It can be revealed that one of the main features of the logistics of pharmaceutical products is adherence to all storage and transportation regulations, as well as the high responsibility of all participants in the movement of goods from manufacturer to consumer. This type of cargo can be called one of the most difficult to transport. The result of the article is a description of the features of pharmaceutical logistics and its organization, the main provisions, the features of the movement of medicines, as well as a description of the importance of managing consumables for medical purposes. The article also describes the importance of the availability and reliability of supply of pharmaceuticals to pharmacies and then to customers. The article also presents the sequence of transportation of vaccines from Covid 19 in compliance with all new vaccine delivery rules, which are significantly different from the delivery of other medicines.

Therefore, we can say that pharmaceutical logistics is one of the most critical logistics areas because the management of the procurement, storage, and distribution of pharmaceutical goods is one of the most important management issues in the healthcare sector. Indeed, the impact of mismanagement, expressed either in a shortage or in perishable products, negatively affects additional costs and the patient's health. Thus, the availability and security of pharmaceuticals' supply are critical factors to ensure useful and timely service to meet the pharmacy requirements and recommendations for medication reconciliation, ensuring that medications are confirmed and received with the patient at each transition in care.

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Tourist Cross-Flows of the Museum Clusters

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Abstract. In this article, the cross-flow phenomenon is considered from the approach of the analysis by digital footprint method, based on geotagging. The goal of the study is to test the cross-logistic approach to characterize the tourist flow of the museum clusters, based on TripAdvisor data. The empirical database included 221 museums united into 36 museums clusters. During the research, hypotheses concerning the dependence between the logistic flow value indicators and locations of the museums in the cluster were verified by Spearman's rank correlation test. The identification of the hub system type, based on the logistic flow model of each museum cluster, was determined by the graph method in Gephi. As a result, it was found that the intensity of cross-flow does not depend on the proximity of museums in the museum cluster. However, the average distance between cluster museums make potential effect on the cross-flow intensity. Moreover, it has been proven that the museum cluster is based on the hub system in terms of managing the tourist flow. Four models were identified: two-node, triangle, single and mixed hub. Two-node model of the museum cluster, based on the line strong connection between 2 museums, has been identified as the most common logistic structure.

Keywords: Tourist flow · Cross-flow · Temporal movement · Museum clusters · TripAdvisor · Digital footprint analysis

1 Introduction

Understanding the tourist movement is efficient for a wide range of purposes: from the formation of a tourist product to the regeneration of the city district. In this context tourist flows should be interpreted as a collective movement of tourists from one location to another for achieving the ultimate tourist goals (educational, health, cognitive, sports, etc.). To date, a pool of versatile studies has been formed, in attempt to identify patterns of tourist flows [1–3]. These model-base formations have been considered based on the example of modeling the tourist flow around the country, region, and city. However, modeling of the tourist movements on the micro-level, for example of the museums cluster, has not been adequately reflected upon by the researchers representing the according field. In its turn, museum clusters as "physical concentration of museums in one place" [4] viewed as a driver of local district development, are capable of concentrated income due to the stable tourist flow.

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It is essential to take into account that the majority of the studies concerning the research of the logistic tourist flows were based on the classification of the tourist movement models, characterized by cyclical flow. At the same time, the cross-logistic approach is not very popular among the researchers.

As for the ways to analyze flows, among methods appropriate in the field researchers construct the modeling by the results of questioners [5, 6] and interviews [7]. With the development of telecommunication technologies, the movement tracking data has become possible to be obtained by geographic information systems (GIS) [9] and global positing systems (GPS) [9], based on geo-temporal checking. In scientific literature the application of the security camera as an autonomous method for tourist flow analysis is referred to as a particular case of "tracking to locate people and to create models of people's appearance" [12]. With regard to the mobile technology development, the first efforts to fix tourist behavior spatial and temporal patters were provided by personal digital assistants (PDA) [11, 12]. Nowadays, this approach has been transformed into modeling the flows based on the mobile phone signals [13].

As an innovative alternative for the listed methods of fixing tourist flows, researchers are currently considering the method of digital footprints, based on geotagging. It means that empirical data of this method is collected within various media elements that have geographical identification metadata (latitude and longitude coordinates. Text content in post format [13] and visual content formats such as photo [14–16] which are known to be regularly geotagged. In this case, the sources of information most in demand are social networks and travel blogs. However, travel service TripAdvisor that is technically arranged as a simple social network or blog (unique pages of users with information about own travel experience, pages for each tourist objects like as museums and etc.), supported by visual and text geotagged information.

In view of the existing research gaps, this research is aimed to test the cross-logistic approach to characterize the tourist flow of the museum clusters, based on TripAdvisor resources. In this research cross-flow is meant to be perceived as tourists' visit of two or more museums included into the cluster. In the context of analyzing the features of tourist movements, the following study hypotheses are put forward: the intensity of the tourist cross-flow depends on the distance between museums of each cluster (H1); the average distance between museums of each cluster influences the condensation of flow's graph (H2); tourist cross-flow models of the museum clusters correspond to the hub system (H3).

2 Materials and Methods

2.1 Sample Creation

Museums clusters, as an object of the presented research, are formed by the following measures. Clusters were selected by a three-step algorithm. First, the list of the cities that focused on cultural tourism was formed. The provisional sample included all rural destinations that were represented in one of the competition nominations of "Travel Awards" for 2019: "City Destination"; "City Break Destination"; "Cultural City Destination".

Second, among selected cities there was chosen the top of destinations, where more than 50 museums are located accordingly to the category "Museum" of the travel platform TripAdvisor. The city-based sample of the second stage included 30 cultural destinations.

Third, the ultimate sample of museum clusters was collected based on 2–4 museum clusters of each cultural destination. The selection was provided by two composite parameters: unity territory and marketing identification as a cluster. The unity territory means that all cluster-based museums are located within walking distance (no more than 20 min). The unity territory was the passing parameter for choosing clusters for analysis. As a result of collecting, the initial sample of museum clusters was formed by 90 clusters submitted by 490 museums.

The last interaction of sample creation was provided by checking the marketing identification of each museum as a cluster element. Verification of the attachment to cluster was conducted by following parameters:

- a single site of several museums;
- a site of a museum consolidation in addition to the existing individual sites of each museum or a mention of the museum consolidation on the official websites of the city;
- a mention of the museum consolidation's name on the site or the placement of the museum consolidation's logo on the websites of its museums;
- a mention of the names of museums collaborators on the sites of the nearby museums;
- a possibility of purchasing an entire ticket.

It is necessary to take into account, that the identification of the museum as a cluster object was based at least on one of these parameters. Therefore, the total ultimate sample included 36 museums clusters with 221 museums from 24 cities.

2.2 Dataset Creation

TripAdvisor as a travel platform has become a resource of collecting empirical quantitative data. The dataset of this research has included only technical information that is essential for statistical flow modelling:

- tourist's username for identification, repeated visits of the same tourist;
- user's location for identification only, internal and external tourists, except the cities;
- date of the review posting for the control of the data upload period.

The unloaded data has been provided over the period of 5 years (01.01.2015–31.12.2019).

For data uploading R-based code was put into use. Due to the open application programming interface (API) of TripAdvisor, the data of the tourists' movements unloaded by the following algorithm. First, the R - based program code was referred to the TripAdvisor's page of each museum. Second, it unloaded text meanings of the research parameters (tourist's username, user location, date of review), referred to the html-codes of each element. Used R-based program code was provided by a page-hop function if it was necessary due to the numbers of the tourist's reviews. Unloaded material was formed into the table. The R-based program code was written with the usage of the "rvest", "stringr ", "xml2" and "writexl" packages.

Due to the existing language limitations of TripAdvisor's API, it was then decided to upload reviews in the following languages:

- English, Spanish, French, German, Italian, Russian, and Chinese (simplified)—because of their great usage;
- the language of the museum's country if it is not included in the list above.

For improving the relevance of the received data, it was crucial to provide data-based pre-processing in accordance with the selection criteria. The total dataset included 390 739 fixed tourist's visits in the last 5 years of 221 museums, united in 36 museums.

2.3 Methods

The data preparation included the following measures:

- the calculation of cross-visits between two or more museums from each museum clusters by R-based code with using of the "rvest" package;
- the calculation of the direction between museums from each museum clusters by R-based code with using package;
- the calculation of the condensation of flow's graph with the Gephi software.

The analysis was separated into 2 stages: data normalization and direct calculation.

First, the Shapiro–Wilk normality test was applied for data normalization that was checked as a zero hypothesis that should be formed in a following way: "The analyzed sample, derived from the population, was characterized by normal distribution".

Second, for correlation analysis the Spearman's rank correlation test was applied to checking the hypotheses.

3 Results

The hypothesis checking was provided by using the following algorithm. First and foremost, it is fundamental to provide the normal data distribution test to ensure that the sample was consistent with the absence of extreme emissions. On the second stage, the measurement was carried out in accordance with the developed methodology and objectives.

3.1 Analysis of the Connection Between the Cross-Flow Intensity and the Distance Between Museums of Each Cluster

During this stage, the test of the hypothesis, regarding the dependence of the cross-flow intensity on the distance between museums within a cluster, was provided. The sample included 624 pairs of statistical observations: cross visits of the cluster's museums; the distance between museums measured by kilometers.

First of all, the normal distribution test was conducted in order to check that the conditions of the normal distribution were satisfied in respect to the values of the studied variables. The statistical results of the Shapiro–Wilk normality test demonstrated that the data of cross visits as well as the territory length were not in accordance with the normal distribution. The test consequences confirmed the analysis results due to the less resulting probability value than the accepted significance level: the normality-based coefficient of cross-flow is 0.12 within the p-value–less than 0.05; the normality-based coefficient of museum's locations was 0.90 within the p-value–less than 0.05.

Conversely, it led to refute of the standard zero hypothesis regarding the normal dissemination. Because of this fact, it was appropriate to use the Spearman's rank correlation test for checking statistical connections.

The results of the Spearman's rank correlation demonstrated relationship between the intensity of the cross visits of the cluster's museums and the distance between museums is virtually non-existent (rho = 0.0478). Moreover, the test results were not statistically significant due to the exceeding of the accepted significance of the p-value p (p-value = 0.23, p-value > 0.05).

Therefore, the hypothesis (H1) was not proven. In turn, it means that distance between the museums didn't influence the tourist's choice of visiting the museums that were located near each other inside the cluster.

3.2 Analysis of the Influence of the Average Distance Between Museums of Each Cluster on the Condensation of Flow's Graph

On this stage of the test of the hypothesis the consideration of the dependence of the cross-flow intensity on the distance between museums within a cluster was conducted. The sample included 36 pairs of statistical observations: the condensation of flow's graph; the average distance between museums.

During the checking of the normal distribution of the observation groups, it was discovered that in the values of the average distance between museums in one cluster, the normality condition was satisfied. In this case, the condition was not satisfied within the respect to the second density of the graph.

The test results showed that there was a weak positive relationship between the average distance between museums of each clusters and the condensation of flow's graph with a low statistical significance (rho = 0.11).

It means that the distance between museums within a cluster can have a potential impact on the degree of cross-flow coverage of museums in one cluster. At the moment, it is not possible to fully confirm the hypothesis (H2) that has been put forward due to the non-normalized distribution of the values of the variable average density of the graph (Fig. 1).

3.3 Museum Cluster Hub System

The results of the previous stage were demonstrated the potential differences between the traffic model of the museums clusters with the density of the graph, other than 1.0. Among the total sample of the museums clusters 21 consolidations were chose. For

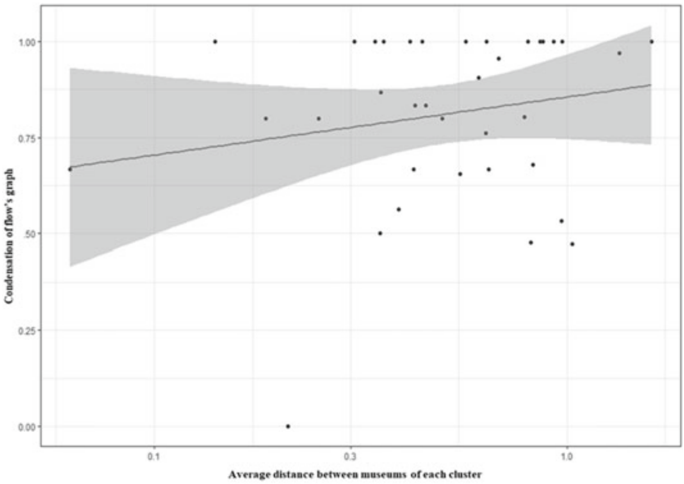

Fig. 1. The influence of the average distance between museums of each cluster on the condensation of flow's graph (author's figure)

checking this task the graphical method that realized by Gephi was used. The modeling of the tourist cross-flow model was based on the weighed degree of nodes as a number of node connections divided by the total number of connections in the graph. As a result the following models of the museum clusters were identified (Fig. 2):

- Single hub. This model was characterized by the existence of a central hub that connected all objects of the museum cluster into a single system.
- Two-node hub. 57% of researched cluster models were characterized by availability of the line strong connection between 2 museums that established the additional connections with other cluster objects.
- Triangle hub. It means that the largest concentration of the tourist flow was focused on the 3 museums and diversed between their edges. Three museum clusters were characterized by this type.
- Mixed hub. These type of cluster model was defined the availability of 1–2 hubs with strong and weaker connection between nodes. It is important to take into account of the availability of mixed connections.

Accordingly, the hypothesis, concerning the tourist cross-flow models of the museum clusters corresponds to the hub system, was proven.

4 Discussion

This study makes a relevant contribution to the data-base science and cultural tourism studies in the following aspects.

The significance of the research results is expressed, first of all, by the creating of the comprehensive methodology for analyzing tourist flows at the local micro-level.

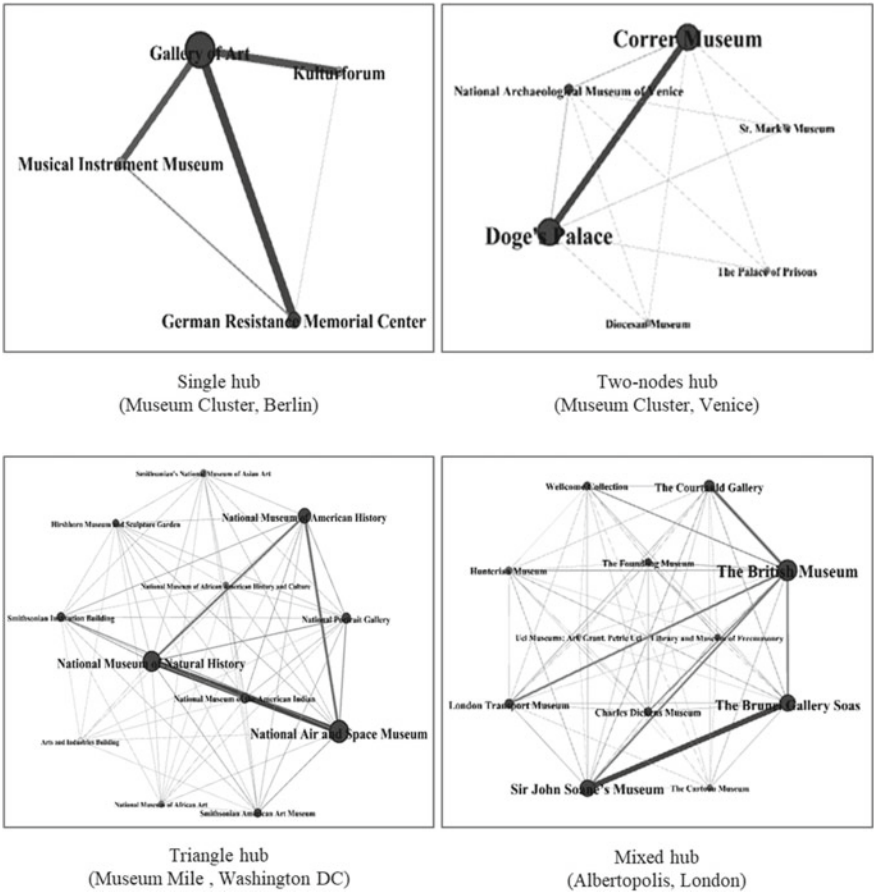

Fig. 2. Types of the hub systems based on the tourist cross-flow models (author's figure)

At a time when science studies are focused on the evaluation the tourist movements of the tourism districts [19, 20], the current research demonstrated the opportunity of analyzing at a lower and more specific level - at the level of museum institutions, united in a museum cluster.

Secondly, the current study was aimed at taking attention to the phenomenon of cross-flow of tourists. The applied method of modeling logistics flows within the museum cluster limits, based on digital data of the tourist movement between museums, on the one hand, allows museums to assess the effectiveness of cooperation in order to increase the flow of visitors. On the other hand, the assessment of logistics flows within the urban space makes it possible to identify the most popular tourist trajectories of movement. This, in turn, provides a basis for the development of infrastructure and local business in the identified territory.

Thirdly, the study has successfully tested the use of TripAdvisor data as a base for analyzing and studying tourist flows. Differing from the related works, TripAdvisor can also use as an alternative empirical database for estimating travel flows, because the aggregator consolidates metadata about user movements in the same way as social networks [13–15].

In addition, the proposed approach to the analysis and modeling of tourist flows within museum clusters can be scaled to other local consolidation formats of cultural institutions, as well as other scales of cultural and tourism space.

5 Conclusions

The current research revealed that the geographical distance of collaborative museums from each other does not affect the flow rate. However, the proved low statistical connection of the average distance between cluster museums and cross-flow intensity may reflect the influence of other factors on the effectiveness of collaborative interaction.

Moreover, it is necessary to take into account that the identified distribution of flows in the museum cluster space is not harmonized. Therefore, the analysis of the organizational and legal structure of museum clusters in order to determine the role of each museum in the cluster system is considered as a prolonging direction of research. It is anticipated that a desk study of cooperation agreements between museums will be required, as well as a survey among the heads of departments responsible for external communication with museum stakeholders. The research results are intended to explain the distribution of the logistics burden for each museum. The quantitative results of the current study should be the basis for the qualitative evaluation of the inner structure of the museum clusters. The identification of specifics of the flow distribution within the museum cluster should take into account during the forming a strategy and tactics for attracting tourists.

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Features of Digital Modeling of the Northern Sea Route Flows

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Abstract. The article is devoted to the description and analysis of the history of development of the Arctic and the Northern sea route. It raises questions about equipping expeditions from the very beginning and creating prerequisites for creating a transport highway through the Arctic (Amundsen, Nansen). Using digital technologies based on historical examples that determined the development of Arctic waters, as well as the safety of the first Arctic expeditions (Amundsen, Nansen). These examples justify the need to apply logistics methods and models in the development of the Northern sea route in the following years. The article also discusses the features of the operation of a particular equipment, as well as the problems of correlating the volume of equipment and equipment of the expedition with the need for its transportation in the Far North. The article also presents variants of models that can be used in the formation of routes in arctic conditions.

Keywords: Far North · Arctic · Logistic · Knapsack problem · Expeditions North · Transportation

1 Introduction

1.1 The Development of the Arctic Spaces

The history of logistics development in the extreme north. In accordance with the definition of the Great Soviet Encyclopedia:

> The Arctic—a single physical-geographical area of Earth adjacent to the North Pole and includes the continental margin of Eurasia and North America, almost the entire Arctic Ocean islands (except the coastal islands of Norway), as well as adjacent parts of the Atlantic and Pacific Oceans.

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You can see that the definition includes the word “single". Now we know that conditions in the Arctic are unique.

The Arctic includes the North Pole and territories and zones of eight countries: Russia, Canada, USA, Norway, Denmark, Finland, Sweden, Iceland.

The total area of the Arctic zone is estimated at 22–27 million square kilometers. It is a big, very big territories [1].

Nowadays the Arctic is an area rich on energy and other natural resources as well a potential cargo transit corridor due to the global warming. Therefore, it attracts a lot of research. Countries united in the Arctic Council cooperate in joint research projects aimed in creating new knowledge, applying known theories, formulating research problems, developing methods and tools to study cases and common issues related to the present Arctic and its history. They deal with Arctic natural resources and climate conditions, as well as Arctic current and future development from social science, geopolitics, economics, management science and natural sciences perspectives. Our research is conducted in the field of Arctic logistics, related to the logistics and environmental management of the development and transportation of natural resources in the Arctic zone. The main focus of this work is on logistics issues and issues related to the early passage of Russian and Norwegian vessels in Arctic waters, including the Northern sea route, as the main transport route in the Arctic [2].

The subject of the research is the logistics of historical Arctic sea expeditions, analyzing which we are forming a modern view of the TRANS-port routes in the Arctic. The problem under study is the logistics planning of transportation. The research format can be classified as in-depth qualitative comparative case studies [3, 4]. The main goal of the study is to determine what logistics problems historical Arctic explorers faced when passing the sovereign sea route and the secondary goal is to find the reasons for their success or failure. As a research approach, we use the basic principles and methodology of modern logistics theory, which is applied for the purposes of comparative analysis and classification.

Russian Russian explorations of the Northern sea route began with the voyages of the Russian Pomors, followed by the expeditions of Brunel and Barents in the 16th, Dezhnev and Popov in the 17th, Bering in the eighteenth centuries, and then continued with the expeditions of the Swede Nordenskiold, the Norwegians Nansen and Amundsen, as well as Russian expeditions of the first half of the twentieth century on the schooner Zarya led by Toll, on the icebreakers Ermak, Taimyr, Vaygach, “Malygin”, “Sedov”, “Alexander Sibiryakov, research vessel” Perseus”, steamship” Chelyuskin”. the analysis considered the main scientific Arctic expeditions of the late XIX—early XX century, and we use as a reference point the expedition of Fridtjof Nansen to FRAM, started in 1893.

1.2 History of Formation

Transportation path. Northern Sea Route. Through the Arctic extends cross-polar air bridge (the shortest route between North America and Asia) and the Northern Sea Route—the shortest sea route between East Asia and Europe.

Cargo transportation route using the Northern Sea Route and alternative route through the Suez Canal.

The Northern Sea Route, the Northern Maritime Corridor—the shortest sea route between the European part of Russia and the Far East; Russian legislation is defined as "historical national unified transport communication Russia in the Arctic."

It is taking place on the seas of the Arctic Ocean (Kara, Laptev, East Siberian, Chukchi) and part of the Pacific Ocean (Bering). Administrative Northern Sea Route (NSR) is limited to the western entrance to the straits of Novaya Zemlya and the meridian passing to the north of the Cape of Desire, and in the east to the Bering Strait to the parallel of 66° W. and the meridian of longitude 168° 58′37 "W. g. [5] The length of the Northern Sea Route from the Kara Gate to the Providence Bay—about 5600 km. Distance from Saint Petersburg to Vladivostok along the Northern Sea Route is more than 14 thousand km. (Via the Suez Canal—more than 23 thousand km.).

The Northern Sea Route serves Arctic ports and large rivers of Siberia (the fuel import, equipment, food, timber export, natural resources).

An alternative to the Northern Sea Route—transport arteries passing through the Suez or Panama canals. If the distance traveled by ships from the port of Murmansk to Yokohama Port (Japan) through the Suez Canal is 12,840 nautical miles, the Northern Sea Route—only 5770 nautical miles.

Organizational Northern Sea Route is divided into:

The western sector of the Arctic—from Murmansk to Dudinka, served by icebreakers Rosatomflota.

Eastern sector—From Dudinka to Chukotka, served by icebreakers of FESCO.

The main stages of development of the Northern Sea Route. The beginning of the development of the Northern Sea Route in Russia can be considered as the years 1616–1620. During these years the king Mikhail Fedorovich prohibits sales to people under pain of death to travel by sea from Arkhangelsk to Mangazeya [6]. This was done for political reasons, to protect the region against the penetration of British and Dutch sailors. Later in 1648—Semyon Dezhnev opened the Strait that separates Alaska from Chukotka.

Subsequently equips the first Kamchatka expedition to confirm the existence of a strait between Asia and America from December 1724 for 1729.

For the second quarter of the XVIII century, the Great Northern expedition, including a number of geographical expeditions along the Arctic coast of Siberia to the shores of North America and Japan.

The study and development of the Northern Sea Route is also actively involved the Swedes and British, so in 1874 the English captain Joseph Wiggins is navigating on the boat "Thames" from Sunderland to the Yenisei Gulf [7], and in 1875 under the leadership of the Swede Adolf Nordenskold whaling schooner "Previn" is navigating from Norway to the island Dixon Yenisei Gulf [6].

In 1877, the steamer "Louise" Irkutsk merchant AK Trapeznikova carried out from London to Tobolsk sailing through the Kara Sea, and in the years 1878–1879—A. Nordenskold expedition on the barge "Vega" vpervyee passed the whole route NSR [6].

First through voyage from east to west, with wintering in the Taimyr Peninsula, made Hydrographic Expedition of the Arctic Ocean under the leadership of Boris Vilkitsky on the icebreaker "Taimyr" and "Vaigach" in 1914–1915. This voyage was also the first through-passage of the Northern Sea Route Russian expedition.

"Alexander Siberians" For the first time a navigation Northern Sea Route was passed by the expedition Otto Schmidt in 1932 on the icebreaker.

First through voyage from east to west in a single navigation in 1934 Icebreaker "Fyodor Litke" (Captain NM Nikolaev).

The first transport operation on the Northern Sea Route—Through the cargo timber floating "Vanzetti" and "Spark" from Leningrad to Vladivostok c 8 July to 9 October 1935.

But the development of energy production began in the 70 s:

1971—Norway began gas production in the North Sea.

1975—Britain began oil production in the North Sea.

The cases we consider differ in goals, plans, and resources used. However, all historical Arctic research expeditions have common characteristics from the point of view of logistics theory. They can be classified as long-term business logistics projects with expected revenue in the form of politics (new lands discovered and claimed), Economics (natural resources found), and knowledge (ice characteristics, hydrogeology, nature, climate, indigenous people, maps, new experiences). For each of them, spatial and temporal start and end points were determined, driving distances and resources needed to achieve the goals were estimated. Some of the expeditions studied were successful (like FRAM), and some were not [8, 9].

Indeed, the logistics planning of p at that time was a really difficult task. First, there were problems with logistical resources, such as vehicles and other resources needed for travel, such as energy, water, food, ammunition, medicine, navigation and scientific equipment, etc. In many cases the characteristics of the vessels were underestimated: the vessels had limited traffic in the winter, as they could not withstand the forces of ice, had insufficient cargo capacity for long journeys, and some of them had insufficient navigation equipment due to lack of funding. Without accurate maps, the sailing routes and exact travel distances were unknown. Due to the lack of experience in navigating harsh climates and uncertain weather conditions (ice thickness, icing, fog, darkness), travel time was difficult to estimate in advance. To have enough energy, water, and food for the entire trip, these items had to be stored in the inventory in sufficient quantities [10]. But even at known levels of daily consumption, questions arise when planning: how much energy is needed (and what kind of energy), how much food is needed(whether there is a possibility of replenishment), how much ammunition, medicines and medical equipment is needed. In addition, safety and health issues are particularly important in such cases: emergency preparedness for ship and equipment breakdowns, weather and nature impacts such as polar storms, limited treatment options, consequences of isolation and conflict, etc.

2 Materials and Methods

Using the knowledge of digitalization, logistics theory, namely resource management, inventory management, vehicle routing and logistics of emergency preparedness, we can define the logistical planning problem for cases under study as a knapsack problem (which items and in which quantities to select based on their values and dimensions with limitations on space and weight), a newsboy problem (how much to take of those items that can't be refilled), and a vehicle routing problem (vehicle and route choice under uncertain travel times) integrated in a simulation model which simulates ship movement under uncertain (limited available) and inaccurate data on route alternatives, weather conditions (ice draft, wind), with incorporated resource actions including reaction on accidents and ad hoc situations.

We applied our model on the case of 1893–1896 Nansen expedition on polar ship Fram, which lasted for three years, returned as expected, and no one died. Even at that times with unavailable and limited information and lack of experience and communication, the careful and effective planning of expedition has resulted in building of a ship of "that can withstand the forces of the ice and accommodate a crew of 25–30 men for 4–6 years" (Nansen, 1897), in choice of right resources in right quantities, in right calculation of travel time, in right selection and accommodation of crew, and in fores ought for unforeseen events and accidents.

The study addressed several key issues, including a perpetual inventory. Inventory quantities are updated after each transaction [11, 12]. We know exactly how many items were sold. We know exactly how many items are left. The other problems is the news boy problem (this problem was formulated in 1951). The newsvendor model is a mathematical model in operation management [13]. This model used for determine of optimal inventory level.

The standard formula of the model can also be used in analyzing the problems of stocks for Arctic expeditions. The formula for calculating the optimal value of reserves is as follows:

$$E[\mathit{profit}] = E[p\min(q, D)] - cq$$

where D is a random variable with probability distribution F representing demand, each unit is sold for price p and purchased for price c, q is the number of units stocked, and E is the expectation operator. The solution to the optimal stocking quantity of the newsvendor which maximizes expected profit is:

Critical fractile formula:

$$q = F^{-1}\left(\frac{p-c}{p}\right)$$

The first situation unfortunately does not apply to our reality in the Arctic, because we do not have inexhaustible reserves.

The novelty of the results in the application of logistics theory to the problem of logistics planning of transportation along the Northern sea route. The value of the research is the analysis of transit cargo transportation along the Northern sea route (NSR) [6] and logistics planning of research expeditions in the Arctic. The modern logistics infrastructure of the Russian Arctic is represented by 17 ports, four of which are connected to the railway system. Even navigation on the NSR is mostly seasonal, and traffic is mainly associated with the transportation of natural resources and projects, the use of the Arctic for cargo transportation is increasing. However,even today, when Tris-class vessels can move through the Arctic seas without icebreakers, replenishment of resources along the NSR routes is quite easy, communication with modern it technologies is present and in most emergency situations it is possible to escape, there are still many logistics problems: remoteness, long distances, almost complete lack of infrastructure, fogs even in summer, the darkness of the polar night, low temperatures, seasonality of the ice situation, moving ice accumulations, wind affecting the ice situation, insufficient accuracy of data for navigation [14].

In that part of the methods that relate to the development of logistics, it is necessary to consider the amount of resources. The needs and resources of management, that is, logistics in the Arctic, came with the opening of ways and resources.

The need at the present stage of international cooperation in the field of logistics arose in connection with the territorial division of the Arctic waters. Currently, a serious problem is the division of the resource base and as a consequence of environmental problems on a territorial basis.

3 Results

The implementation of the modeling of such processes can be realized using modern technical means. Using fast analytics allows you to significantly reduce decision-making based on historical data, and get effective results.

The assessment of indicators for the Northern Sea Route will be in the following main directions [15–17]:

- weather forecast
- forecast of water conditions
- forecast of ice movement
- calculation of the optimal loading of ships and other vehicles used for transportation.

Based on the analysis of the history of the development of the Arctic and the Northern Sea Route, regularities were formulated that must be taken into account when equipping expeditions to the Arctic zone.

In addition, the optimal loading of the vessel under certain weather conditions (winds, wave height, etc.) was determined on the basis of weather data for different ship tonage.

Specific results of the study include the construction of a model of the formation of the equipment of vessels for the implementation of the Arctic expeditions in modern times with the utilization, and building models caseload during the forecast based on weather conditions. The main determining factors in the calculation of load models are the driving characteristics, maneuverability of ships, displacement of cargo. When assessing weather conditions, the forecast of ice thickness on the route of ships, the forecast of winds are taken into account.

4 Discussion

The study provides a detailed analysis of the main problems encountered by the alien encounter with the first Arctic expeditions. The reasons for their occurrence, which can be both removable and unremovable, are analyzed in detail. Many problems can be caused by improper planning, as well as the uncertainty of conditions that occurs during the trip and cannot be predicted in advance.

The analysis of historical expeditions (cases studied) was carried out using modern methods of analyzing logistic problems, such as Methods of operation research in particular methods of inventory theory, knapsak (selection and allocation problems), vehicle routing and decision making under uncertainty.

The use of modern methods of analysis of the logical component of any expedition revealed those factors (risks) that were minimized with the correct use of modern logistic methods. It also allowed to determine the risk factor, which remained unchanged.

Currently, there is not much research on generalizing the experience of historical expeditions. This study analyzes the experience of historical expeditions and research on this topic. The experience of Arctic expeditions of the nineteenth and twentieth centuries is mainly considered. Research on these expeditions was carried out, including by the leaders of the expeditions themselves—Amudsen, Nansen. A number of problems that arise in these studies can now be eliminated using modern techniques, such as logistics methods, linear programming methods, backpack problems, and other methods.

5 Conclusions

When creating a transport highway through the Arctic, it is necessary to consider a variety of environmental factors and take them into account when modifying conditions. These calculations substantiate the need to apply logistic methods and models in the development of the Northern Sea Route in subsequent years.

The modeling also takes into account the peculiarities of the operation of this or that equipment, as well as the problem of correlating the volume of equipment and equipment of the expedition with the need for its transportation in the Far North.

Evaluation methods are also seriously influenced by the presence of international interaction. It is impossible to ignore which in the calculations and modeling of transport models in the Arctic.

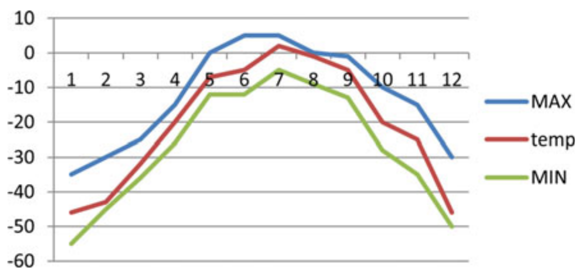

Fig. 1. Building a temperature forecast in the Arctic region

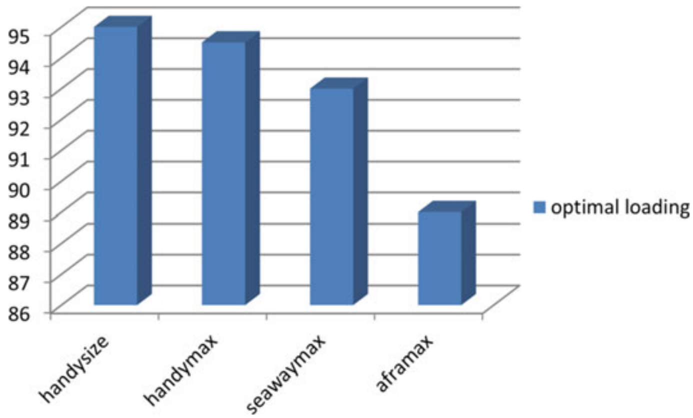

Fig. 2. Calculation of the optimal loading of ships and other vehicles used for transportation

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Digital Technologies in Supply Chain Management of Sheet Metal After Cutting

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Abstract. Improving the tools of material and information flows management based on the principles of lean production in micrologistic processes using digital technologies allows managers of producing enterprises to increase the economic efficiency of their activities and competitive advantages. One of the production processes at many engineering enterprises is the sheet metal cutting, in which it is necessary to solve the problem of increasing the utilization rate of material resources for increasing enterprise economic efficiency and careful use nature resources. The purpose of the research is to develop tools of material resources management in lean production for sheet metal cutting at engineering enterprises with single or serial production types. In the study, the toolkit is being developed based on information technologies in order to make reasonable and operative management decisions when sorting sheet metal after cutting, organize warehouse logistics and ensure production of timely delivery of the required amount of materials. At the previous stages of the research a situational analysis of sheet metal cutting at engineering enterprises was conducted, the main provisions of the sorting method of sheet metal after cutting were defined, approbation of certain aspects of the method was carried out. In this article, the causal relationships of the identified problem are described in more detail, the internal supply chain of the process is determined, and practical recommendations for management of material and information flows after cutting are proposed. Further research tasks of development the sorting method and warehouse accounting of material resources after cutting are identified.

Keywords: Lean production · Micrologistics · Management accounting · Sheet metal cutting · Business material resources · Sorting method

1 Introduction

In an innovative market economy, at manufacturing enterprises it is necessary to master production management tools, which are aimed at continuous improvement of operating activities and ensure the formation of enterprise competitive advantages [1–5]. At

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engineering enterprises, where sheet metal is the main material resource, within the framework of the organization of lean production, managers are faced with the task of increasing the utilization rate of the material in order to reduce technological costs, optimize the cost structure and increase net income. For solving this task, it is required to master a certain toolkit for managing material and information flows in micrologistic processes through information technologies.

The object of the research is engineering enterprises with single and serial types of production. The subject of the research is the managerial relations arising in the material resources management in the process of functioning and developing lean production at engineering enterprises. The purpose of the research is to develop tools of material resources management in lean production for sheet metal cutting at engineering enterprises with single or serial types of production.

Domestic and foreign researchers developed mathematical methods to organizing the rational cutting of industrial materials from the point of view of optimal location of blanks on a given material resource and optimal choice of a material resource for producing blanks from it. However, it is paid not enough attention to the questions of reasonable sorting, transportation and storage of sheet metal residues after cutting.

In previous works, the main provisions of the sorting method of sheet metal MR after cutting were determined, approbation of certain aspects of the method was carried out. Also, the main provisions for designing of a decision support system (DSS) for the management of MR after cutting are determined. In this article, the causal relationships of the identified problem are described in more detail and practical recommendations for management of material and information flows when organizing management accounting of business and non-business sheet metal MR after cutting are proposed. Management accounting in combination with lean production, logistics and information technology will provide managers of the enterprise with reliable and timely information for making reasonable operational and strategic decisions.

2 Materials and Methods

The theoretical basis of the study are theory and practice of lean manufacturing, management accounting, material resource management. At this stage of the research, it has been revealed that rational cutting of sheet metal is carried out using rational cutting methods, which have been widely studied by researchers: L. V. Kantorovich, V. A. Zalgaller, E. A. Mukhacheva, I. V. Romanovsky, V. M. Kartak, Yu. G. Stoyan, H. Dyckhoff, G. Wascher, H. Haubner, H. Schumann and others. The special group ESICUP (Euro Special Interest Group on Cutting and Packing) and a scientific school in Ufa work on the questions of rational cutting [6–12].

Methodological basis of the research are based on the concept of lean production, which is related to the concept of supply chain management. In the work, micrologistic processes are considered between participants of the supply chain (warehouse, blank production, technologists, management accounting and specialists) which interact in material and information flows (sheet metal from supplier, business and non-business sheet metal MR, management accounting the values of indicators characterizing business and non-business MR in information system (IS) of enterprise). At the same time, some components of supply chain management are considered as the part of the tools of sheet metal MR management (for example, demand forecasting, inventory management of sheet metal, visualization of information about sheet metal residues taking into account classes of business and non-business MR) [13].

It should be noted that the developed toolkit provides for the need to master it using information technologies that contribute to the development of the digital economy. At the same time, a variant of DSS modeling using neuro-fuzzy logic was considered, the relevance of which is reflected in the works [14–20].

The empirical base of the work consists of production processes at engineering enterprises, analytical materials presented in the studied literature.

General scientific research methods were used: analysis; synthesis; formalization.

3 Results

The conducted situational analysis of sheet metal management accounting in the cutting process at Vologda engineering enterprises which specialize in production of capacitive equipment made it possible to draw the following conclusions:

– the sheet metal cost in the cost structure is approximately 70%, the utilization rate of sheet metal is approximately 0.8, which confirms the relevance of the task of increasing this indicator;
– sorting of sheet metal MR after cutting into business and non-business is carried out empirically, which can be reflected in the increasing of material costs (business MR can be classified to the non-business group), storage and transportation costs and procurement works (non-business MR can be classified to the business group);
– there are no marking equipment and procedures for marking business sheet metal material resources after cutting, which complicate their accounting;
– sheet metal accounting is carried out in the context of the original nomenclature of materials received from an external supplier, in kilograms, which is make it impossible to see data on the actual residues of source sheets, about variety of business MR and their characteristics, about formation of non-business sheet metal MR in the information system. It also complicates the operational designing of cutting cards taking into account business MR, planning the correct purchase of MR;
– there are no industrial scales at the MR warehouse, which is reflected in an increase of inaccuracy of sheet metal accounting;
– information support provides for the possibility of organization a more detailed sheet metal accounting, however, the managers do not draw up the required documents and the necessary actions are not determined;
– there is no approved procedure for accounting of sheet metal MR after cutting.

A diagram of the causal relationship of absence of data about business sheet metal MR in the accounting system was built for the purpose of graphic interpretation and more concretization of the identified disadvantages of the management accounting of sheet metal MR after cutting. The diagram is shown in Fig. 1 based on the provisions of the Ishikawa diagram, which is one of the lean production tools for evaluating the causal relationships of the research problem and improving enterprise activity.

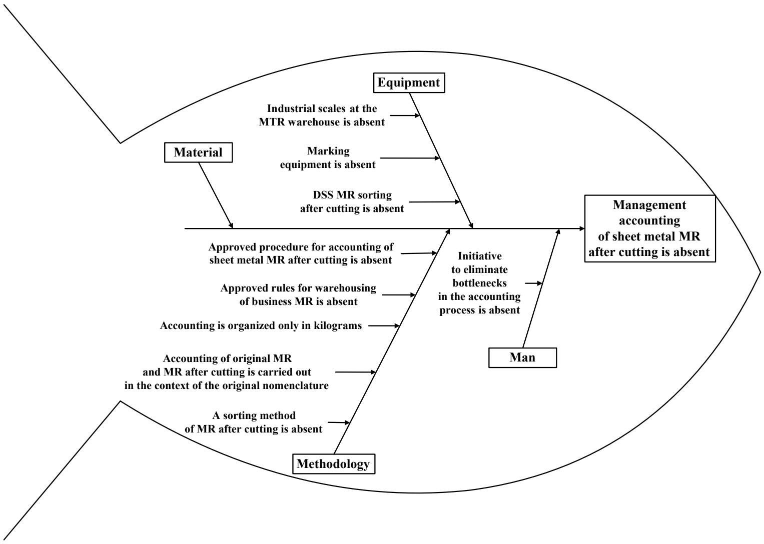

Fig. 1. Diagram of the causal relationship of the absence of management accounting of sheet metal MR after cutting

Based on the constructed diagram, it can be concluded that the main reasons of the disadvantages of management accounting of business MR are related to the accounting methodology and equipment for organizing the process. Therefore, it is necessary to adjust the existing management rules of material and information flows within the framework of the accounting process of sheet metal MR after cutting.

Quantitative and qualitative accounting. At this stage of the study, it is proposed to account MR after cutting not only in kilograms, but also in pieces in order to separate initial and generated after cutting MR and design cutting cards using business MR. Also, the requirement of accounting of measurements and properties of materials is presented on the automation of blank production. This requirement is especially important for business MR of sheet metal after cutting, since each MR is unique. At industries where the composition of subsequent production batches is not always known, and where it is impossible to organize the flow of sequential use of residues of one cut in the next cut, the organization of such accounting is a difficult task. In this connection, it is advisable to consider MR after cutting as semi-finished products, which, together with products, are produced from the original material or previously produced semi-finished products, and the nomenclature of which will correspond to the MR classes. In the framework of the developed sorting method, the MR class is a set of interchangeable MR, allocated on the basis of their similarity in terms of the estimated indicators in a certain range of values. The accounting of business MR by class will allow dividing the nomenclature and the number of initial MR of the 0th level (MR received from the supplier) from business and non-business MR, which will allow obtaining from the information system the necessary operational data on the structure of the remaining sheet metal MR, the consumption dynamics of the corresponding classes of business MR, which are necessary for making reasonable decisions.

Metrological support and marking equipment. It is necessary to have industrial scales at the warehouse for accounting in kilogram, since sheet metal can be transferred to production in various volumes (from one business MR, a solid sheet to ten solid sheets or more. It is necessary to use marking equipment that puts a barcode on the MR in order to take into account business MR after cutting in the context of certain classes and search operationally a corresponding MR indicated in the cutting card.

The main participants in the research process and their main actions are identified in the study from the point of view of the process approach and supply chain management. Based on previous studies, it is considered that the participants of the process use ERP system, CAD/CAM systems for rational cutting of materials and decision support system for sorting sheet metal MR after cutting.

Based on the description of material and information flows after cutting, a graphical representation of the management accounting of sheet metal MR after cutting is built in Fig. 2. There are the main participants in the process at the corresponding "activity paths", the accounting procedures of employees, their interaction with other participants in the process, material and information flows at the diagram.

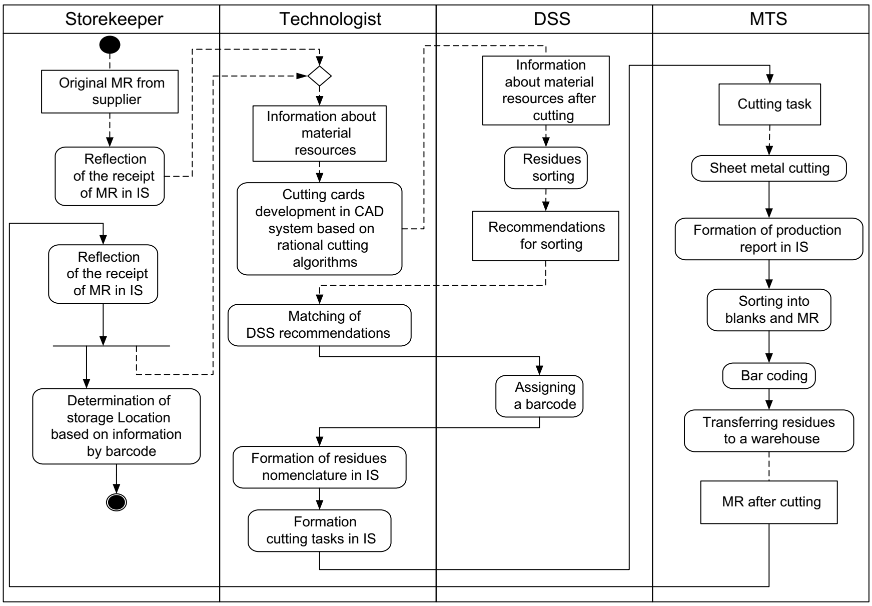

Fig. 2. Graphical representation of management accounting for sheet metal MR after cutting

A storekeeper is responsible for reflecting MR movements in the accounting system of the enterprise, which occur at the stage of receipting the MR from an external supplier or from the manufacturing-technological system (MTS) of the enterprise and during the transfer of MR to production. During these actions, the storekeeper fixes the weight of the MR using industrial scales.

A technologist designs cutting cards using the automatic rational cutting system take into account information from the ERP system about the nomenclature of available MR at the enterprise. In this case, it is necessary to provide safe transportation of business residues. It is solved by placing additional technological cuts on the cutting card in order to exclude sharp corners of the MR after cutting. The received cutting cards are loaded into the DSS of sorting, which offers recommendations for sorting the MR obtained after cutting into groups of business or non-business MR according to the corresponding classes based on analyzing the values of indicators, which are characterize the MR after cutting. Based on the feedback from the technologist, the DSS assigns the corresponding barcode for the received MR, which contains information about the group and the class. The barcode will allow to build operational internal logistics and management accounting when moving MR between production and warehouse. Integration of the DSS of sorting into the ERP system will allow to form in the ERP system the cutting task and the nomenclature of MR after cutting.

Based on the task for cutting and after receiving the MR from the warehouse, a worker of MTS carries out the necessary actions for cutting sheet metal on the appropriate equipment strictly according to the cutting cards that are reflected in the task. After technological operations, the worker in the ERP system confirms the corresponding production stage, on the basis of which production documents are formed in the ERP system about the release of products and MR after cutting (business and non-business MR). Next, the worker sorts the result of cutting into blanks and MR, puts the appropriate bar code on the MR after cutting with the help of marking equipment, transfers the products to the next technological stage and MR to the warehouse.

The storekeeper draws up the receipt of MR after cutting from the MTS: determines the weight of the received MR; forms in the ERP system the corresponding nomenclature of MR, information about which was previously defined by the DSS and is contained in the barcode, reading the barcode from the MR with a scanner; further, according to a certain storage scheme of the MR, the storekeeper determines the storage place of the MR, also reflecting these actions in the ERP system.

From the point of view of evaluating costs in value terms, it is proposed to account business MR at the price of returnable residues approved in the accounting policy of the enterprise (at the corresponding price of the original MR or a reduced price), and non-business MR at the approved scrap metal price (estimated selling price). This costs reflection allows to reflect the fact operating costs correctly.

With the aid of obtained operational data of sheet metal material costs in natural and value terms the managers of the enterprise will can to analyze the bottlenecks of the cutting process in relation of sheet metal utilization rate and make corrective management decisions aimed at improving the processes at the enterprise in order to create a continuous flow value for the consumer and the formation of competitive advantages in the products market.

4 Discussion

During the complex automation of blank production taking into account the use of business MR, it is necessary to solve the problems of transporting material resources after cutting to storage places, their storage and timely deliveries of original material and business MR to production, along with solving the main tasks (planning the blank production obtained during cutting from the original material; forming optimal cutting cards; accounting of materials and products obtained as a result of cutting). Storage locations and production places can be geographically remote from each other, herewith timely provision of production with the required volume of materials is a strategically important task for the enterprise.

One of the indicators of the work of warehouse logistics is the level of supply, which is evaluated as the ratio of the amount of materials provided on time from the warehouse to the total amount of materials requested. At the same time, the interaction between the warehouse and production is characterized by the level of provision of cutting tasks, which is defined as the ratio of the number of cutting tasks, for which the material was delivered from the warehouse on time, to the total number of cutting tasks requiring receipt of the material. Careful control of these indicators allows to timely determine the required volume of warehouse stocks.

Consequently, an important indicator is the projected consumption of MR of a certain class (Qsm, pieces/month), when managing material resources of sheet metal after cutting with the use of DSS of sorting. It is proposed to make a decision on sorting MR to the group of business or non-business MR taken into account this indicator within the framework of the sorting method. When assessing the required amount of residues by class, it is necessary to have a stock at warehouse sufficient for the uninterrupted operation of blank production in the period between new receipts of MR of certain classes. At this stage of the study, an evaluating method for its is being formed.

A variant of Qsm evaluation based on the number of priority choices of the corresponding classes by the cutting program is considered. However, in the future, when the MR is assigned to the business group, the costs of storage and transportation are changed. Storage costs depend on the space, taken up in the warehouse, equipment that ensures the movement of materials at the warehouse and equipment for accounting, labor costs of participants of warehouse accounting and other general business costs. Therefore, when assigning MR after cutting to a business MR group, it is necessary to optimize the warehousing process.

In order to improve the decisions for sorting, it is proposed to accumulate statistics on the receipt and consumption of business MR of the corresponding class in the accounting registers of the ERP system. Based on the accounting registers, it will be possible to generate reports reflecting the statistical experience of storing and using MR after cutting. It will allow to determine the time of MR storage and the volume of filling storage bins, in which business MR are stored.

From the point of view of material resource planning, it is important in the ERP system to provide possibility of reserving business MR when designing cutting cards, in order to reflect its status, which will not allow taking into account the same MR in several developed cutting cards. Also, when determining Qsm, it is advisable to determine a safety stock of business MR, which can be taken into account in the sorting

DSS when checking the demand on MR (comparing the consumption volume with the current quantity in the bin and the volume of the safety stock).

5 Conclusions

Thus, the following research results are obtained in this article:

- the causal relationships of the absence of data on the sheet metal MR after cutting are determined;
- proposals were formulated for the management of material and information flows in terms of organizing the management accounting process of sheet metal MR after cutting: it is proposed to use a DSS for MR sorting, metrological support and marking equipment, accounting for business MR by allocated classes, MR bar-coding after cutting at the production stage, sorting and determination of the storage place of MR after cutting at the warehouse by reading the barcode. As a result of the study, a graphical description of the internal supply chain of sheet metal MR after cutting is presented (participants, actions, flows).

The using an integrated automated enterprise management system with DSS elements makes it possible to solve the problems of managing material and information flows when organizing a sheet metal cutting process at a blank production taking into account business MR. The assimilation of the research results based on information technologies at engineering enterprises with a single or serial production types will make it possible to design cutting cards taking into account business MR, provide the enterprise management with operational and reliable information about the existing structure of sheet metal MR, about the actual material costs for sheet metal. On the basis of this, the managers of the enterprise will be able to make informed management decisions about assigning the MR after cutting to the group of business or non-business MR, design cutting cards taking into account the business MR, make timely decisions on the purchase of the necessary MR.

In further research, it is necessary to develop a methodology for assessing the potential demand for classes of sheet metal MR, develop practical recommendations for organizing the process of storing MR after cutting.

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Digitalization of the Oil and Gas Research Infrastructure

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Abstract. The results of scientific and methodological research on the development of elements of the infrastructure of scientific activities of the oil and gas complex based on digitalization are considered. The factors limiting the competitiveness of work on the identification, preparation and development of hydrocarbon deposits are identified. System effects of implementation of digitalization technologies in the activities of research and design organizations of the oil and gas complex are highlighted. The structure of priorities in digitization of research activities in the exploration and training of specialists is defined. The authors substantiate the options for implementing digital technologies in EA: Big Data, artificial intelligence (AI) and It technologies; corporate information system (CIS); immersive learning; platform approach and suggest options for forming the optimal structure of scientific activity. Elements of the CIS for a scientific organization that includes information support, information and project management subsystems, as well specialized applications, a security system and end-to-end information search with the implementation of all software on a fault-tolerant cluster solution are presented.

Keywords: Scientific infrastructure · Digital technologies · Indicators of the digital economy · Geological exploration · Big Data · Intelligent systems · Artificial intelligence · Scientific activities · Training of specialists · Corporate information system · Integrated scientific and technical cluster

1 Introduction

In modern conditions of increasingly complex geological exploration for oil and gas, the effectiveness of solving problems will be determined, first of all, by the capabilities of new technologies at all stages and stages of exploration.

New technologies are based both on the amount of accumulated knowledge and information, methods of their processing, and on the application of fundamentally new solutions determined by theoretical developments and practical research.

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The purpose of the cycle of research results presented in the article was to develop basic elements of the infrastructure of scientific activities of oil and gas companies and organizational cluster approaches for their implementation.

In the context of critical import substitution of NGC technologies, comprehensive development of scientific activities, its infrastructure, training of specialists and effective commercialization of scientific results in exploration processes.

2 Materials and Methods

To solve these problematic issues, the authors proposed a method for functional optimization and complex transformation of the main business processes of scientific activities of the oil and gas complex and organizational structures, taking into account the introduction of digital technologies.

During a cycle of research works of JSC VNIGRI together with the specialists of HSMB St. Petersburg Polytechnic University scientifically applied aspects of digitalization infrastructure for scientific activities were researched, together with exploration and service companies engaged in the forecast, searches and preparation of hydrocarbon reserves [1].

The most dramatic effect for the oil and gas industry, of course, can be obtained with the introduction of digitalization technologies, including the use of artificial intelligence in the management of oil and gas fields, the construction and use of permanent models (hydrodynamic, geological, etc.).

The integral effect that can be obtained from digitalization in geological exploration is the ability to accumulate, save and quickly process large amounts of data, leading to a reduction in time losses, cost of work, efficiency of managerial decision-making and increased productivity of specialists [3, 4].

This effect becomes especially relevant against the background of modern geological and technological challenges of exploration and oil and gas Geology, which include the qualitative complication of the geological conditions of fields involved in development, as well as the change of the paradigm of searching and developing hydrocarbon sources to non-standard and non-traditional ones (Fig. 1).

Effective exploration can be achieved by a deep transformation of the main business processes with the introduction of innovative technologies [5]. The review of such developments conducted by the authors made it possible to highlight among the priorities the introduction of knowledge bases with artificial intelligence, decision support systems, the use of new remote methods of searching for fields, etc. (Fig. 2.).

The factors that limit the competitiveness in Hydrocarbon research and exploitation are the nonlinear growth of accumulated information and its predominantly destructible nature. Under these conditions, the development of digital technologies allow for the efficient accumulation, transmission and use of databases for forecasting the main design parameters at the stages of exploration and production of hydrocarbons.

The main constraining factors for the digital breakthrough are the technological restrictions of the Russian oil and gas companies are before all caused by sanctions, as well as a number of subjective reasons (Fig. 3).

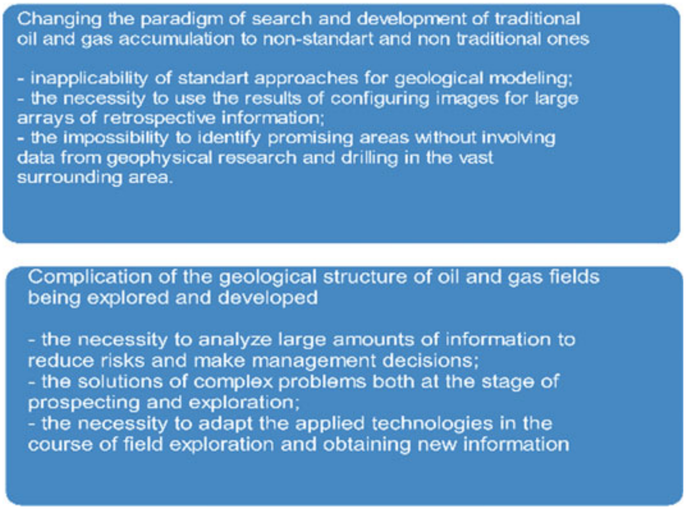

Fig. 1. Basic geological challenges [2]

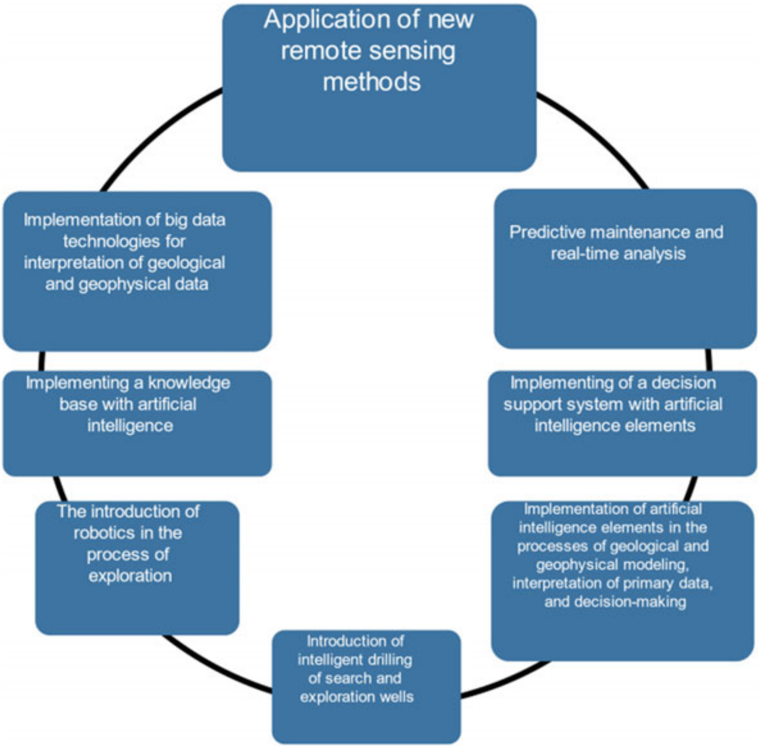

Fig. 2. Innovative exploration technologies

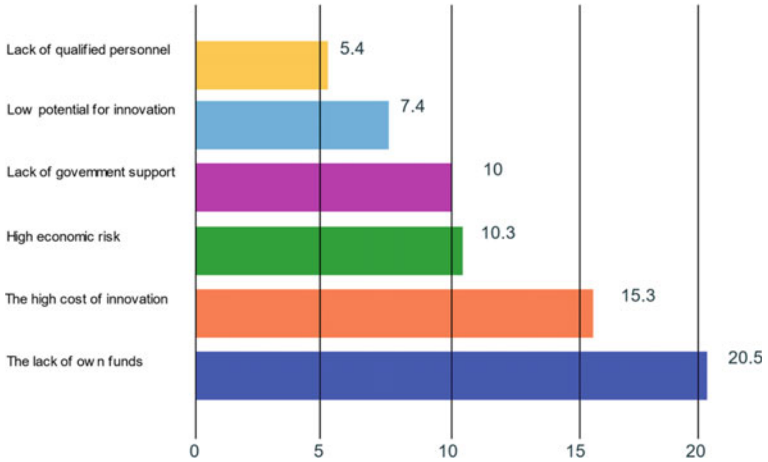

Fig. 3. Main factors hindering innovation, % (based on data [4, 6])

Digitalization of the exploration process it is not only the transition from analog to digital forms of information, but first of all the introduction of digital automatic registration of primary data, their online transmission to processing centers with the possibility of automated management, including adjusting the observation systems and applied techniques of current field work in order to achieve the most optimal result. Such a process can fundamentally change the paradigm of geological exploration currently employed in Russia. For example during the recent seismic surveys commissioned by subsurface user companies, the company Vinki often employs a standard technical task based on the experience of previous studies, but does not take into account the individual characteristics of the study area or objects of attention.

By automating the receipt of digital information, processing data in online mode and including the possibility of making adjustments to both surveillance systems and surveillance networks, a qualitatively better result of sequential optimization and tuning can be obtained directly in the conditions of reception of primary data.

Digitalization involves innovative science-based development of technology, applied technologies, organizational structures, organization of production and service work, as well as effective management solutions and business models based on breakthrough digital technologies [7, 8]: big data; neural networks and artificial intelligence; distributed registry systems; quantum technologies; new production technologies; industrial Internet; components of robotics and sensors; wireless communication technologies; virtual and augmented reality technologies.

Leading companies in the oil and gas industry are already actively working on various options for digitalization: an intelligent geologist's workplace; a digital core; machine learning in core interpretation; machine learning in GIS interpretation; machine learning in lithology forecasting; a virtual experiment laboratory; cognitive tools for geological analysis; an expert data verification system; an expert system for searching for missing intervals; an expert research planning system; a digital twin of seismic data, etc.

3 Results

The Analysis of industry information allowed us to determine the structure of priorities in digitization of research activities in the exploration and training of specialists. These include Big Data and IOT technologies—22%; development of technologies for implementing business processes Upstream—58% of investment projects implemented by oil and gas organizations.

One of the most important and urgent tasks for obtaining important information by re-processing seismic data from previous years and using more advanced computing devices is the analysis and re-processing of large data arrays using Big Data technologies. With the use of artificial intelligence and IoT technologies, we proposed to create systems for supporting management decisions, geological and geophysical modeling and data interpretation, etc.

The introduction of immersive (mixed) learning technologies will bring the training of corporate specialists in the oil and gas industry and the training of geologists and engineers in specialized Universities to a new level. The training processes should actively use the effects of presence, immersion, and simulation of real processes, i.e. augmented and virtual reality AR/VR (virtual environments, simulated environments that simulate the real world, etc.).

By 2022, the global market for training based on corporate VR/AR solutions may grow to $6.3 billion, according to a report from the research company ABI Research.

The development of the scientific activity of the GRR should be complex and cover three levels: the direct level to the research scientist; the level of organization and the level of interaction of scientific organizations. It should be structured and its funding should include three sources: Federal budget; commercial work with a background territorial consolidation and internal budget holding at fixed research in all phases and stages of exploration.

Researchers today do not have enough simple to use digital services, therefore their effective formation, development and cooperation are recommended to be implemented within the framework of a digital platform for internal interaction and with external information resources, both on the domestic market and at the international level. The platform should provide a single information space with various forms of access. Options are already being worked out both at the regional and Federal levels.

The Automation of organizational and technical business processes of daily research activities in the Geological Research evidence that is most appropriate to implement the information support on the basis of the corporate information system of the organization [9–11].

The process of R&D activities offers key benefits for the scientific organization, including information systems, information management and projects, as well as specialized applications, system security and end-to-end information retrieval with the implementation only on a failover cluster solution with virtualization technologies.

As an organizational form of effective scientific activity in the exploration industry, we propose to use an integrated scientific and technical cluster with a single constantly updated database of information, software and technical support (Fig. 4). The strategic goal of the NTC is to provide comprehensive scientific, methodological and informational support for the geological study of the Russian Federation's subsurface resources in order to ensure the conditions for sustainable reproduction and rational development of the country's mineral resource base of oil and gas resources, taking into account its long-term socio-economic development priorities.

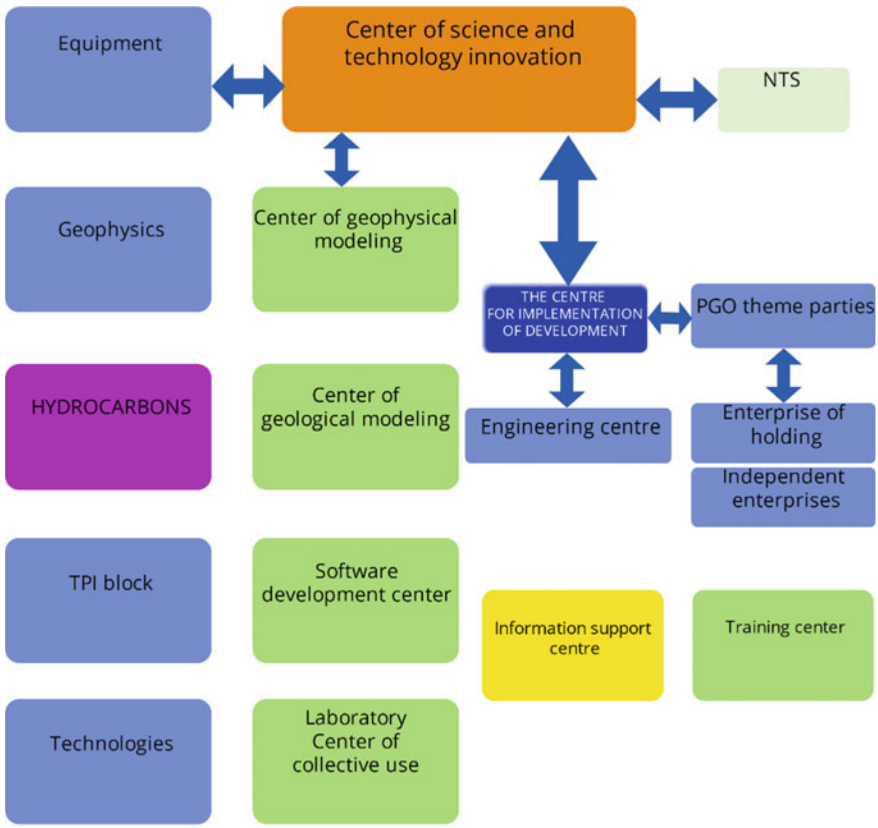

Fig. 4. Organizational structure of NTC GRR

The Organizational structure developed to integrate scientific and technical clusters should be the Central industry holding JSC Rosgeologiya. This will allow for the integration of tasks and the development of methods, technologies and competencies within the same network structure, ensuring the growth of competitiveness of the company and assuring consistent technological development of the sector (Fig. 5).

The principal idea of the creation of the Oil and Gas Technological clusters consists on becoming a global player in the sphere of technological innovation which could guarantee the fulfillment of all scientific and technical tasks relevant to the industry and foment stable procurement of the raw mineral base of hydrocarbons of our nation. The integration of entrepreneurial clustes (scientific, commercial, educational and Production Sector) will enable the development of Rosgeology by a 20% increase its market share of Geological exploration in a short time. The key competences for this increase are the

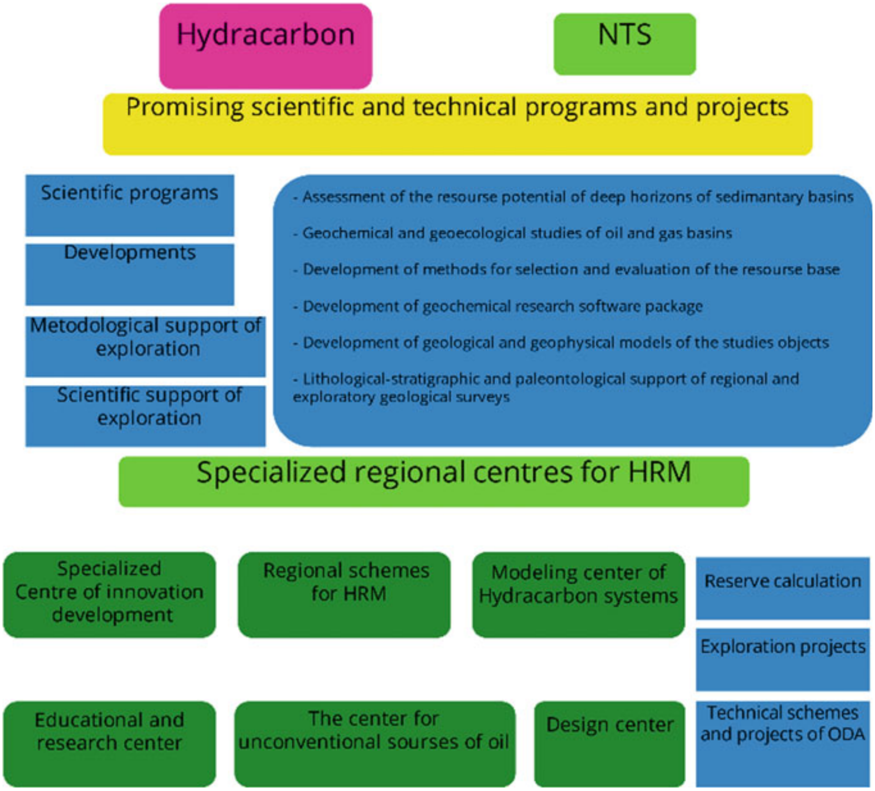

Fig. 5. Organizational structure of HRM

internal reorganization, the synergistic effect, the cost optimization and the expended use of advanced technologies.

For state-owned exploration companies, such integration within the cluster being formed is the most economically feasible and strategically justified option for development corresponding to the basic concept of the holding and the main provisions of the strategy for the development of the geological industry of the Russian Federation until 2030.

Financial and industrial development strategy of the STC should be based on maximizing the vector criterion of efficiency of functioning of the hydrocarbon clusters, components of which are the performance criteria of the elements of the system-margins.

The main target in the Oil and Gas Technological cluster in the market and plans for the development of Rosgeology is the Geological Research and Exploration of Oil and gas. Today this represents more than 70% of the total Russian market for Geological Research and Exploration Projects. At this time the distribution of the enterprises holdings do not correspond to the market dynamics and has a slightly different proportion than expected (Hydrocarbons are more than 47% share of projects). The Financial-Productivity strategy of development for the Oil and Gas cluster is to be defined by the maximum vector criteria of the effective function of the Oil and Gas clusters, where the element representing the criteria of effectiveness in this case is the coefficient of profitability.

The main expected results of creating a cluster are: improvement of the quality of scientific-geological and methodological support of the activities of the Federal Agency for subsoil use "Rosnedra"; optimization in exploration companies included in the vertically integrated structure; the increase of competitiveness on the market of geological services; a guarantee of sustainability of the enterprises and the diversification of R&D; the development of new types of activity in the market of geological services.; the improvement of the quality of geological tasks performed and research; the improvement of the efficiency of the use of scientific, methodological and human resources of individual enterprises; improvement of the level of competence of qualified personnel.

4 Discussion

The main directions and conditions of the application of digitalization in geological exploration have been analyzed, taking into account the possibility of accumulation, storage and operational processing of large data sets.

The structural effects of digitalization on the Upstream stage have been defined as a significant improvement in quality of information, which should provide a more accurate forecast of all the parameters (development of oil and gas bearing strata, lithology, and reservoir properties, the conditions and criteria of petroleum potential, phase composition and other geologic characteristics).

This research defined and developed elements of the Corporate Information System for a scientific organization, including subsystems of information support, information management and projects, as well as specialized applications, security and end-to-end information search with the implementation of all software on a fault-tolerant cluster solution with virtualization technologies.

The proposed concept is a single vertically integrated scientific and technical cluster, providing increased efficiency of scientific-technical support to the functional tasks of exploration and production of the hydrocarbon l resource base.

Promising areas for further development include the preparation of effective "cluster strategies" and the justification of business activity centers that have proven their competitiveness.

The successful implementation of digital technologies in scientific activities and the processes of optimization of its infrastructure will make it possible to achieve the following results in geological exploration in the near future:

- Increase in efficiency and efficiency of decision-making in geological exploration processes by 30–50%;
- Geological exploration of territories and water areas, as well as the reliability of the results will increase by 10–30%;
- Geological and geophysical modeling and construction of sections with complex intelligent analysis in real time;
- Expenses for exploration work and their terms will be reduced significantly.

5 Conclusions

1. The results of scientific and methodological research of the infrastructure of scientific activity of the oil and gas complex were presented, the problem field and systemic priorities were determined.
2. A method of functional optimization and complex transformation of the main business processes of scientific activity of the oil and gas complex and organizational structures, taking into account the introduction of digital technologies, has been proposed.
3. The authors substantiate the options for implementing digital technologies in GR: Big Data, artificial intelligence (AI) and IT technologies; immersive learning; platform approach and suggest options for forming the optimal structure of scientific activity.
4. The architecture of the corporate information system (CIS) has been developed for the optimal functioning of scientific activities in exploration organizations. Successful implementation was realized in JSC "VNIGRI".
5. The concept and structure of how to form an integrated scientific and technical cluster with a single constantly updated database of information, software and technical support is proposed.
6. This concept of an integrated scientific and technical cluster is already partially implemented in JSC Rosgeologia, while the competence of specialized and regional centers for the implementation of scientific and technical programs and developments in the oil and gas complex is highlighted.

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Re-Engineering of Logistics Business Processes Influenced by the Digitalization

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Abstract. In the economic sphere, qualitative changes are taking place as a result of new digital technologies development. Digital technologies are gradually being integrated into all areas of enterprise management, requiring the digitisation of operational business processes aimed at providing the management processes of the organisation with the necessary infrastructure and data processing technologies. Such technologies as the Internet of Things, Blockchain, Process Analyst, Cloud Technology, 5G Technology, Big Data, which have become the sphere of interests of big business, are no longer the future, this is the present. The market economy and its digital development require that modern business be able to adapt quickly to changes, optimise its work in the shortest possible time, and change dynamically under the changing conditions of the external environment. The paper addresses the topical subject of digitalisation of the business and the use of digital technologies in logistics, and the direction of development of logistics infrastructure under the influence of digitisation. The concept of re-engineering and its role in the modelling of the business processes were considered. The work reviewed the principle of developing the business processes of the organisation and re-engineering the business procurement process. The business processes modelling and core notation software aspect were also highlighted.

Keywords: Digitalization · Business process models · Reengineering · Modeling · Purchasing · Transport logistics

1 Introduction

High dynamism associated with continually changing market needs, continuous improvement of production methods and severe competition are the main factors that characterise modern business. In such an environment, the emphasis on the management of individual resources is shifting to the organisation of business processes in general, intending to improve the quality and quantity of performance and competitive advantage.

Improving logistical business processes involves a systemic integration approach. The modelling of business processes across the supply chain while improving delivery, production, marketing, transportation, and warehousing could appropriately implement

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this integration. The modelling of business processes makes it possible to improve the interaction of different units, visualise the sequence of work, track the flow of information, identify the participants of work and technology.

Business engineering techniques help to execute a modern approach to the creation of business processes models. Business engineering is a modern technology of formal, accurate, complete and comprehensive description of the activities of an organisation by building basic information models (primarily the models of organisational and functional structure and business processes) [1].

The first step in digitisation should be the improvement of business processes in an organisation. Automating an inefficient business process often fixes it for a long time and does not improve the quality of management. Re-engineering of business processes should precede their digitalisation. The use of digitalisation for itself and not for enhancing governance and organisational efficiency creates a rather dangerous situation.

Re-engineering is a method of improving the management of an organisation by improving the business processes and organisational structure of the organisation. Re-engineering of business processes can help if an organisation is in crisis, the industry has changed significantly, a strong competitor has emerged, and the organisation needs to improve its performance quickly. Re-engineering conducted by even one key player on the market creates a new benchmarking level that all competitors must meet [2].

The Russian Federation supports the method of business digitisation at the state level—the government has prepared The Russian Federation digital economy programme and has created the strategy for the information society development in the Russian Federation for 2017–2030. Digital communications is an important sector of economy. This type of economic management influences not only the development as a whole but changes the ways of social interactions and structure of economic relations [3].

The introduction of digital technology makes it possible to obtain and process in an expeditious manner sizeable volumes of relevant information, to use artificial intelligence and predicate analyst to manage logistics in enterprises, to control the actions of all parties in the supply chain.

Within each process, there is a transformation of any resources (material, labor, financial, production, etc.). To make a management decision, each process must have an informational reflection. Thus, in management there are always two streams, the first is the resource flow, and the second is the informational reflection of this flow, which makes it possible to make a decision on the state of the resource and, if necessary, to change this state. Obviously, the effectiveness of the decisions made by the management depends on the quality of the information used [4].

Process analyst (Process Mining) plays a significant role in the digitisation of business—this approach of business process re-engineering is based on analysis of the received metrics, events, information from the systems in which employees work. As the CEO of ABBYY Russia notes: If earlier conclusions about the state of a business process were made based on fragmented information from different information systems, now market leaders do it centrally, relying on the totality of data. Business process re-engineering itself from analogue becomes digital [5].

The future direction of supply chain management is the development of the Internet of Things (IoT). The term Internet of things is related to combining a growing number of devices and objects with the help of the information-telecommunication Internet network [6]. This technology reduces costs and increases the transparency of logistics operations, which is mainly required among retailers with their own distribution centres and logistics services. Vehicles connected to the Internet by sensors allow automatic traffic control systems.

The COVID-19 outbreak led to an unexpected and unintended disruption of supply chains for all organisations of the Russian Federation: borders with foreign countries were closed, and the leading Chinese factories were seriously disrupted. This has led many organisations to seek new suppliers quickly. The pandemic has reflected the instability of the supply chain system, in which organisations are dependent on suppliers in a particular region, and has created momentum for the diversification of production and supply chains.

The spread of innovative digital technologies has brought about significant changes in the competitive landscape and challenged the competitiveness of existing products and services. To remain relevant, companies must transform [7]. Modelling and designing changes expected in business processes and assessing the impact of their design are the primary tools for justifying the costs of upgrading in the face of increasing investment in the information technology infrastructure of institutions [8].

2 Materials and Methods

The vast majority of organisations in the modern market in Russia use a functional approach to management, maintaining a strict vertical of power. With the adoption of the ISO 9000 version of the year 2000, the so-called process approach is officially based on the construction of the organisation's quality management system. Modern approaches to quality management involve defining the network of business processes of an organisation and then working to improve them [9].

According to the National Standard of the Russian Federation Quality Management System ISO 9001–2015, the process approach is one of the seven quality management principles. [10]. The main idea of the process approach is to isolate the business processes that exist in the organisation and manage the system of these co-interacting processes. The fundamental aim of the process approach to the management of an organisation is to quickly and efficiently restructure the interrelated operations of the enterprise, taking into account changes in the external or internal factors of the environment, by improving already constructed business process models.

The modern organisation is a complex system in which many (sometimes tens of thousands) interrelated and mutually influencing processes are carried out. Business process modelling allows to describe processes in the organisation as they are at the time of model creation and to identify the bottlenecks in the received models based on analysis, after which to create a business process model as it should be or an ideal model to be pursued.

Organisations often have problems with logistics due to the lack of prescribed and regulated business processes. The problem of illiterate planning is particularly acute when the organisation is engaged in international procurement, and the delivery of materials takes up to several months. It is necessary to move to the process approach of management, describe and structure business processes with the aim of putting order in work, identify bottlenecks, reorganise business processes and improve the functioning of the organisation to maintain the competitive position of the organisation.

The study examines the process of creating a business process model for procurement as a critical process for achieving both current and strategic objectives, as virtually all organisational processes are related to the movement of goods and materials procured.

It is first necessary to choose a suitable modelling tool to develop business process models. Increasingly, CASE tools (Computer-Aided System Engineering) are used to build business process models. A comparative analysis of the modelling tools should be carried out to select a suitable one. In practice, the following business process modelling tools are often used: CA Allfusion Process Modeler, ARIS Toolset, Rational Rose. In the framework of the research, the work was carried out in the instrumental business-modelling environment CA Allfusion Process Modeler. This choice is justified by the fact that this CASE tool makes it possible to create diagrams in notations IDEF0, IDEF3, DFD and in the simulation process to switch from IDEF0 notation to any branch of the notation model IDEF3 or DFD and create a mixed model if necessary during the study.

The next question is what methodology for developing business process models will be used. The methodology (notation) for the creation of a business process model(s) is the set of ways in which real-world objects and their relationships are presented in the form of a model [11]. The main thrust of the methodology is that any user must have a defined and standardised algorithm for performing the task. Each methodology has its own notation—a set of graphical elements and rules for their use. The popular methodologies for constructing and describing business process models are structural type models, workflow description methodologies and data flow description methodologies. The most widely used business process modelling methodologies are IDEF0, IDEF3, and DFD.

Note that in the current modelling approach, there is a desire to combine, integrate different modelling methods [12]. These techniques are called integrated modelling techniques, and they combine different types of models, such as structural analysis techniques, simulation models and object-oriented models. Business model technologies are continually evolving. Simulation models such as AnyLogic are the most obvious in describing business processes, but their construction requires special training from the user. Integrated methodologies combining the capabilities of object-oriented programming, animation and simulation (example—Gensym's G2 toolkit) [11] appear.

Creation of the model as it is is a preparatory stage for further improvement of the business processes of the organisation. The organisation's business process models include top-level models and detailed remote business process models. Each particular top-level business process model is a crucial component of an organisation's corporate architecture. Top-level processes are generally referred to as the 1–3 level of aggregation (generalisation) business processes. Based on such a model, an integrated business process model of an organisation is constructed, including more detailed models with decomposition [13].

First, a top-level model or context diagram is developed, which is a description of the system level of the investigated organisation that has the most significant abstraction compared to other levels and reflects the system's interaction with the environment. This level (A-0) is the most general, reflecting the primary function of the organisation—operating in the market. At the control level, the context diagram is decomposed into several functional blocks representing the main processes. The activity of the Inventory Items Procurement Organization consists of five main business processes: customer search, preparation of a business proposal, conclusion of a contract with the client, receipt of the order from the suppliers and providing the customer with the goods.

The functional block Procurement Implementation of the management level is decomposed to the division level. The process of ordering and importing goods is described. The business process model Purchasing from a foreign supplier is presented in Fig. 1.

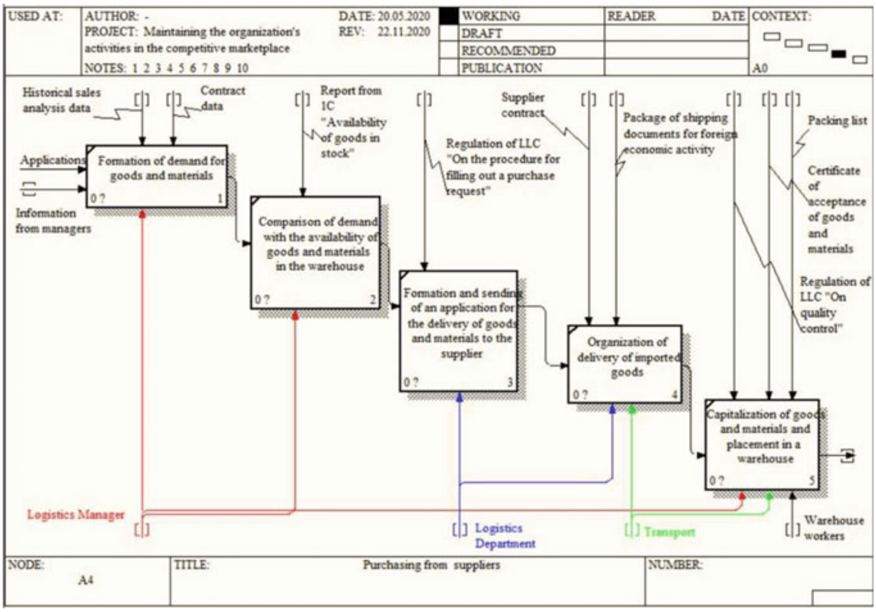

Fig. 1. Decomposition of the Procurement business process

The problem of illiterate planning became clear after analysing the created model of procurement. Ordering of products that is done based on approximate calculations of the Logistics Department, with no planning taken into account, causes considerable problems. Managers often order products based on intuitive assumptions. As a result, a batch of products received several times exceeds the volume of its sales. The products are kept in storage, and this surplus stock becomes frozen money.

Conversely, the Logistics Division did not receive information about the planned contract with an extensive list of items, and importing is a lengthy procedure, so the goods do not arrive on time, and the failure of the contract deadlines becomes the result.

Apparently, logistics isn't handling the workload. Managers decide to appoint a new staff member to the post of procurement specialist, to eliminate the bottleneck. This person will synchronise the supply of materials with their consumption, keep operational records of the availability of goods in the warehouse, manage the inventory. An important point is the further development and operation of a particular calculation methodology for the purchase of goods and materials based on statistical forecasting methods, rather than planning based on subjective expert estimates of sales department and managers. For example, extrapolation of time series of actual material consumption data (trends in average, moving average and other). The procurement specialist will carry out supply planning and, if necessary, manage changes of this planning in response to urgent orders or, conversely, waivers of the declared purchase of inventory items, as well as one will shorten the supply plan.

Procurement activities cause disruptions and (or) additional costs in subsequent phases and poor performance across the supply chain [14]. Errors in determining the need for materials, selection of an unreliable supplier, refusal of the supplier to supply materials (a striking example is an embargo on the import of many goods due to the economic isolation of the Russian Federation), shortages and other irregularities in the procurement, will only increase in the future. Moreover, they will create a wave effect on the whole supply chain up to the delivery of finished products to the consumer.

The evaluation of the business process of the as it is model showed the existence of a problem in the functioning of business processes. We reorganised the model taking into account the identified bottleneck. In the functioning of the process, a new decomposed unit Formation of the need for inventory items for order.

3 Results

The work proposes a project to improve the logistics of the organisation. We discussed the main approaches to management, errors and logistics problems in modern organisations. The study analysed tools and methodologies for business process modelling. We have also developed and analysed the models of the business-procurement process functioning at several levels of as it is decomposition. Analysis of these models revealed a problem of poor planning within the organisation, and a procurement specialist had been appointed to solve it. This decision made it possible to arrange deliveries of foreign suppliers, which reduced the shelf life of the products and freed storage space. In response to the changes, a revamped model of the business procurement process has been established.

As a result of the study, a model of the functioning of business processes in an organization at the management level was developed, presented in Fig. 2. The diagram reflects the interaction of key business processes and highlights the role of the new process of forming a demand.

The business process models developed have practical meaning: the business process becomes structured and visible, it reflects the entire sequence of work and allows for the identification of those responsible for the actions. The primary tool is the ability of business process models to reflect the organisation's bottlenecks for further improvement.

An essential aspect in the development and regulation of business processes is the further digitalisation of business and the introduction in the organisation of an information system for the collection and analysis of large volumes of data (e.g., CRM system).

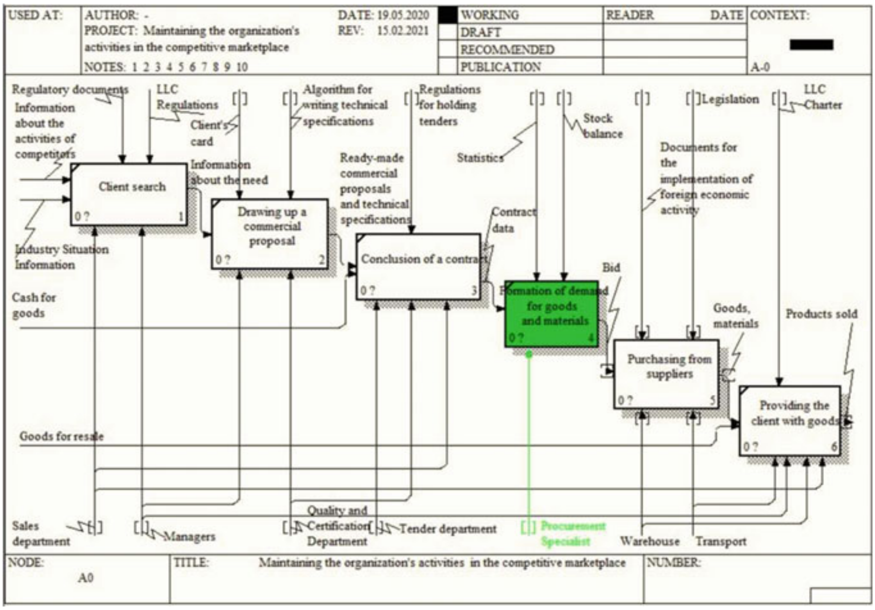

Fig. 2. Model of business processes of the organization at the management level

The research methods used were general research methods: content and comparative analysis, as well as specific research methods: specialised business process modelling methods, project performance evaluation methods, identifying elements of a logistics implementation mechanism.

4 Discussion

For the introduction of digital technologies, business process modelling and re-engineering are necessary. Automating a wrong business process often makes it fixed for a long time and does not improve the quality of management. The danger is that digitalisation is done for itself and is not used to improve governance and the effectiveness of organisational activities.

During re-engineering of business process, it is essential to define precisely the range of activities that make up this business process, the order in which they happen, the division of responsibilities, and the resources that this process consumes. It is also crucial to understand the interactions between the staff involved, assess the effectiveness of communication between them; establish the movement of information (paper or electronic) during the process, determine its necessity and rationality [15–17].

Concerning aspects that are not yet fully disclosed in this field, we should note that the issues of methodical support of through business process development management remain not thoroughly researched and require further elaboration. There is quite a lot of literature written on the subject, but the practical significance is not always obvious. It is important to emphasise that business process modelling in organisations is a modern trend, and some organisations describe business processes but do not apply models in practice.

5 Conclusions

A project to improve the logistics of the organization was proposed. The purpose of the study was to develop a business process model for the functioning of the international logistics activities of the organization, identify the existing problem in the process, and develop a justified way to solve it.

The study examined the theoretical aspects of business process modeling in the organization. The concept of business process the concept of the process approach of managing an organization, its main provisions are considered.

The modern theory of organizational management and modeling business processes, and modeling techniques were considered while writing this paper.

A decomposed model of the organization was reviewed. At the department level, a model for purchasing from foreign suppliers was developed as is The analysis of the model revealed the lack of a demand and stock planning system in the organization. Based on the identified problem with the operation of the logistics business process, a new staff member was selected.

Business process models greatly simplify the adaptation of new employees and reduce the dependence of the enterprise's work on the human factor. Re-engineering, aimed at redesigning business processes to achieve radical improvements in business performance, along with digitisation, is one of the most modern tools of this type.

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Balanced Scorecard as the Basis for Global Container Shipping Line IT-Architecture Modeling

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Abstract. Companies in the container liner shipping industry actively introduce digital technologies, which have a significant impact on all business aspects of a company. New technologies could become drivers for new business models. The digital transformation requires changes of company IT-architectures, cultures, and organizational frameworks. Monitoring and planning digital transformation processes require a method that allows evaluating the changes in the company's IT-architecture in the context of their compliance with the company's strategic goals. The Balanced Scorecard normally is used as a tool for the strategy implementation assessment. This article proposes the Balanced Scorecard application to measure and plan IT-architecture changes, using it as the basis for the company's digital twin. This tool could provide substantial support for global container shipping line digital transformation planning and monitoring. For the purpose of current study, the authors use the multi-level matrix comparing and linking indicators and IT-architecture models of the global container shipping line.

Keywords: Digital twin · Container shipping line · Enterprise architecture · Balanced scorecard · Digital transformation

1 Introduction

As the authors of this paper described before, "analysts define seven trends of digital transformation, which are capable to change the container liner shipping industry: blockchain, electronic platforms, Internet of things, predictive analytics, artificial intelligence, autonomous vessels and robotics, and cyber security"[1].

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In accordance with [2–4], the shipping industry invests heavily in technologies that can transform established business models. Such new technologies relate to ship operations, as well as strategic decisions and day-to-day operations, and also issues like automated navigation systems, cargo tracking systems and digital platforms that facilitate operations, as well as trade and data exchange. This can help reduce costs, facilitate interaction between different actors and raise the supply chain served by maritime transport to a new quality level.

The authors proposed an architectural approach concept to the information systems formulation as well as strategic alignment of business and IT-architecture of the global container shipping line on the basis of the formulated Balanced Scorecard [5].

Strategic alignment is a continuous process of adaptation and change in which organizations try to create synergies between their position within their competitive environment and the design of the appropriate structure to support the execution [6]. This process for global container shipping lines is impossible to maintain without a special tool designed to provide adequate assurance that objectives are being accomplished.

The purpose of this paper is to propose a company digital twin concept, which could provide substantial support during the global container shipping line digital transformation.

2 Materials and Methods

The Enterprise Strategic Alignment Method (ESAM) represents a cross-domain approach to the company business and IT architecture alignment in order to achieve its strategic objectives. This method combines such discipline approaches as Strategic Management, Capability Based-Planning, Enterprise Architecture and Enterprise Portfolio Management [7].

ESAM presents the company's business model as a subject area, allowing to coordinate all the company's transformation strategic stages in accordance with its changes. ESAM defines ten strategic stages, for the purposes of this paper the following were considered during the stage of strategic measurements and metrics and their changes during the company digital transformation. Reference models of the Balanced Scorecard strategic maps have been developed and ontologies have been proposed to be the basis for the global container shipping line "digital twin" creation.

The digital twin is a virtual model of a product, process or system and represents complex multidisciplinary mathematical models with a high level of adequacy to real objects [8–10]. This technology becomes an effective tool for high-tech product development and real-time enterprise or process management.

A multi-level matrix of targets and resource constraints (real, financial, technological, production) is an integral part of the digital twin development. Another part is artificial intelligence, which as a computer science discipline uses statistics methods as well as machine learning and deep learning instruments.

For this paper the multi-level matrix comparing and linking indicators and IT-architecture models of the global container shipping line was developed and using of ontologies was suggested. These tools enabled to ensure information support and to track the impact of IT-architecture changes on company's performance.

3 Results

The Balanced Scorecard for a global container shipping line digital transformation was previously described by the authors [5]. For the global container shipping line Balanced Scorecard formation, the concept of shareholder value added management (SVA), formulated by Rappaport [11, 12], as well as Norton and Kaplan Balanced Scorecard were adopted [13, 14].

The Balanced Scorecard financial perspective represents the goals of the company's operational, financial, and investment activities, in addition, strategic goals for the company financial position are defined, too. The digital transformation strategic goals are defined, their achievement will increase the global container shipping line shareholder value. These goals are divided into strategic goals for each perspective—customer, internal process, learning and a growth perspective with the help of drivers that influence each perspective strategic goals achievement.

The customer perspective drivers reflect current trends in the supply chain marketing environment. To define the customer perspective strategic objectives, it is necessary to apply the Marketing-Mix strategic model and metrics of strategic and digital marketing [15, 16].

The internal process perspective is based on Supply Chain Operations Reference Model, the reference framework, recommended by The Supply Chain Council [17, 18]. The internal process perspective drivers according to the SCOR model are defined as performance, processes, practices, people; strategic goals are determined as strategic characteristics of supply chain performance: reliability, responsiveness, agility, costs, and asset management efficiency.

SCOR provides an opportunity to analyze supply chain processes and to correlate internal process perspective indicators with other Balanced Scorecard indicators therefore the SCOR model becomes an effective tool during the company's digital transformation. Besides, the internal process perspective was supplemented by indicators of the BIMCO Shipping KPIs Standard, IMO Standard, capacity management metrics [19, 20].

Learning and growth perspective drivers are people, infrastructure and technology, and culture. During the global container shipping line digital transformation, it is necessary to define strategic indicators, initiatives and challenges of the IT-architecture and ensure that changes to the IT-architecture are implemented and monitored through the necessary organizational structure and expertise. The COBIT standard and the ITIL library, as well as existing frameworks, standards and quality control systems, can provide significant support in this regard [21–25].

The developed reference models of the Balanced Scorecard strategic maps are able to not only assess the impact of the IT-architecture change on the financial, customer and internal process perspective, but also to provide project management during the global container shipping line digital transformation.

Figures 1, 2, 3 and 4 represent the digital transformation strategic goals and drivers for each perspective of the global container shipping line Balanced Scorecard, which are broken down then into strategic indicators.

Software lifecycle management standards and methodologies place great importance on metrics collection and management. IT-project metrics are indicators that reflect their individual characteristics, measurement, or combination of measurements performed

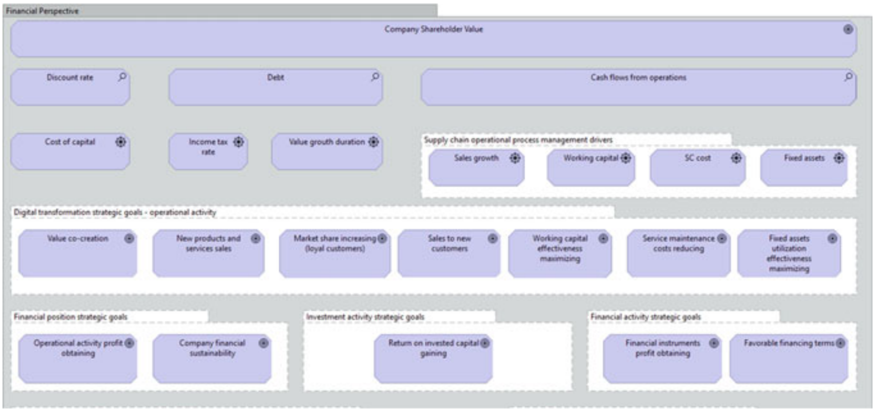

Fig. 1. Financial Perspective: Strategic goals and drivers of the company digital transformation

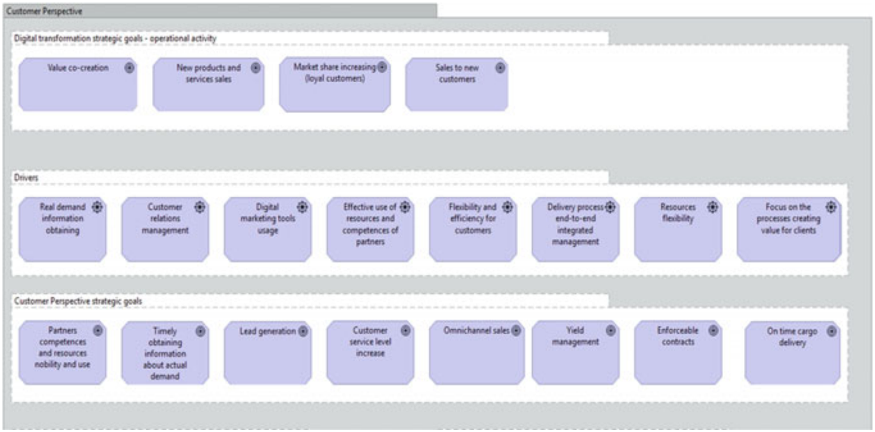

Fig. 2. Customer Perspective: Strategic goals and drivers of the company digital transformation

within IT-project or IT-process. Nowadays the IT-project management problems could be defined as following: the ambiguity and complexity of selecting indicators for tracking; the difficulty of interpreting the results and the obtained data usage for the IT-project development prognosis.

The metrics collection itself is practically useless without thoughtful implementation—it is necessary to correctly interpret the results, to identify IT-project risks, to determine corrective actions and forecast metrics.

This paper suggests the use of ontology to standardize the knowledge collection and presentation approach. Ontology (in computer science) is an attempt to detail and comprehensively formalize a certain field of knowledge using a conceptual scheme. One of the main advantages of using ontology is the ability to combine information obtained from various information sources. The ontologies usage will create a unified

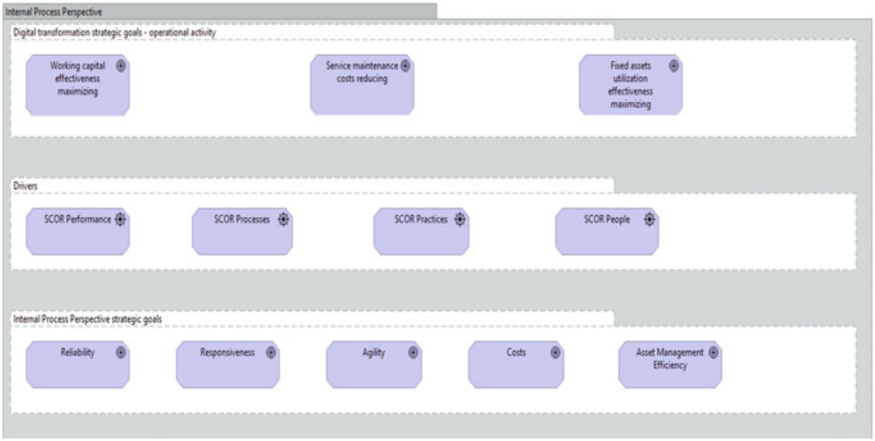

Fig. 3. Internal Process Perspective: Strategic goals and drivers of the company digital transformation

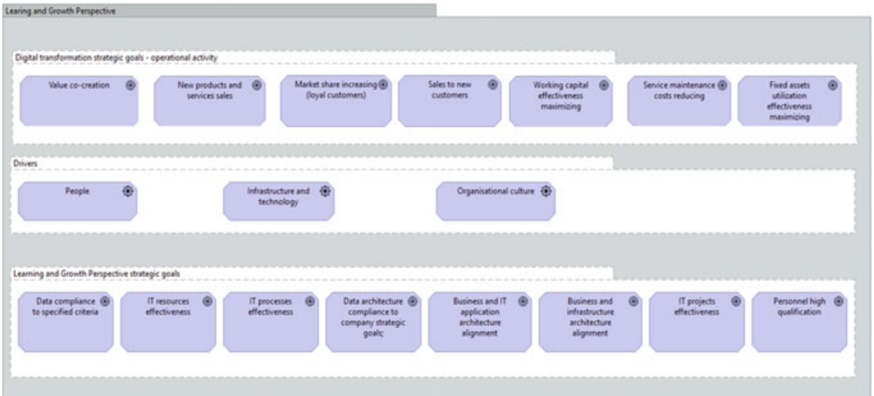

Fig. 4. Learning and Growth Perspective: Strategic goals and drivers of the company digital transformation

knowledge database containing information about IT-projects, and, in particular, metrics and experience with their use.

For the global container shipping line digital transformation control, the following ontologies are proposed:

1. the Balanced Scorecard metrics ontology. The main properties of metrics will be a list of primary indicators, recommended targets and critical thresholds, and a recommended frequency of reading. This ontology should be linked to the IT-project database through the metrics usage precedent database.
2. the risks and constraints ontology: categories of risks and constraints - technical, external, risks and constraints of the environment and project management, risks

and limitations of testing. The risks and constraints ontology through the history of risks and constraints database should be linked to the IT-project database.

3. forecasting methods ontology, associated with the IT-project database through the forecasting precedents database.
4. the IT-architecture reference models ontology, related to the IT-project database, as well as to the risks and constraints ontology through the history of risks and constraints database.

The proposed ontologies used are based on the developed reference models of the Balanced Scorecard strategic maps that can become a basis for the global container shipping line "digital twin" creation. A company's digital twin is a dynamic data-driven software model for representing and analyzing the organization's activities, its current business model, and which can be used to respond to changes in the external and internal business environment.

To create the company's digital twin, it is needed to correlate a large number of strategic indicators, risks and constraints, forecasting precedents and IT-architecture reference models. Figure 5 represents a multi-level matrix comparing and linking indicators and IT-architecture models of the global container shipping line as a whole and its business units and business processes.

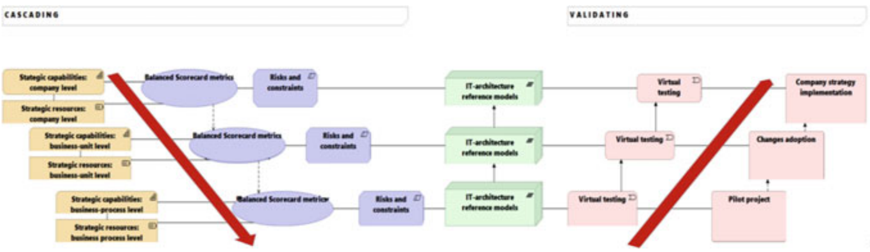

Fig. 5. Multi-level matrix comparing and linking indicators and IT-architecture models of the global container shipping line

As a result of this process, a large numbers of indicators and models balance is ensured, while initially they can "conflict" with each other.

The strategic indicators cascading takes place from the top down, from the company level to the level of the business process, since the global container shipping line implements a unified strategy for all business units. Balanced Scorecard metrics are correlated with risks and constraints, as well as with IT-architecture reference models. At each level, there can be several IT-architecture reference models depending on the technologies proposed for implementation.

The multi-level matrix should provide the ability to not only track the metrics, risks and constraints and IT-architecture models mutual impact, but also allow to make necessary changes and clarifications as soon as possible, to carry out operational management of the company digital transformation. For this purpose, the IT-architecture model is validated, from the pilot project of business process level to the strategic changes of the company IT-architecture. Validation occurs as a result of virtual testing using various forecasting methods. After the pilot project launching, the ontologies of strategic indicators, risks and constraints, IT-architecture models and forecasting methods should be refined and supplemented by comparing of prognosis and actual indicators.

This approach is an effective tool for planning, implementing and monitoring of the strategic changes in the context of the global container shipping line digital transformation, allows to avoid errors and inefficient management associated with incorrectly selected strategic indicators, as it will allow analyzing of the impact of a significant number of indicators on achieving strategic goals, as well as adjusting the strategy due to changes in external and internal capabilities and resources.

4 Discussion

This paper proposes the Balanced Scorecard as a basis for IT-architecture modelling, as well as multi-level matrix comparing and linking indicators and IT-architecture models as a part of the global container shipping line digital twin for the purposes of digital transformation. However, this study is not considering another part of digital twin technology: artificial intelligence methods, which could be applicable for analysis and prognoses during global company IT-architecture modelling and development. These methods are the subject for separate research.

5 Conclusions

Thus, the global container shipping line digital transformation requires digital technologies introduction in all aspects of the company's activities, the Balanced Scorecard can provide significant support in modelling and analyzing of the latest technologies introduction results. To align the company's business and IT-architecture, it is relevant to use ontologies of strategic indicators, risks and restrictions, forecasting methods and company's IT-architecture reference models as well as multi-level matrix comparing and linking indicators and IT-architecture models.

By using of the proposed in the current paper tools, it is possible to create a company "digital twin" that will ensure information support and tracking the impact of IT-architecture changes on company's performance.

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Use of Underground Gas Storage Facilities to Optimize the Logistics of Gazprom's Export Deliveries

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Abstract. This article focuses on the key role of underground gas storage (UGS) facilities (or UGSF) in the Russian gas export to Europe. The UGS system is overviewed from the point of view as the main tool for increasing the reliability and efficiency of gas supplies to consumers in European Union (EU). The dynamics are determined and the forecast of the gas storage capacities development of Gazprom Group in Russia and in European countries is made. The main UGS facilities used by Gazprom Group abroad are considered. An optimal solution for gas storage capacities with the active use of natural gas in the energy balance of countries are shown. The article analyzes and shows an overview of UGS capacities to cover peak demand by country, as well as an assessment of the gas filling of European UGS facilities. The leading countries with the largest storage capacities of gas reserves in Europe are shown. The article also traces the dynamics of changes in gas storage capacities of the main natural gas importing countries of Gazprom Group and countries of Central Europe for the period 2016–2020.

Keywords: Underground gas storage facilities · Natural gas · Capacity · Gas consumption · European gas markets

1 Introduction

Underground gas storage facilities (UGSF) are one of the most important tools for increasing the reliability, safety and flexibility of natural gas supplies to the EU.

UGSF, on the one hand, serve as a guarantor of the fulfillment of contractual obligations in case of repair or maintenance work on gas pipelines, incl. in the EU, on the other hand, they allow to actively respond to changes in demand for natural gas both during the day, weeks or month, and in the longer term, taking into account the seasonality of de he UGS system in this article is considered from the point of view of one of the most important tools for improving the reliability and efficiency of gas supplies to consumers of the European Union, which requires a systematic analysis of the current trends and strategic priorities of its development.

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The purpose of the article was to assess the transformation trends and problematic areas of development of natural gas exports carried out by the global energy company PJSC Gazprom to the European gas market. Solving this problem will allow identifying and optimizing promising areas of logistics schemes for natural gas supplies, taking into account existing and prospective underground natural gas storage facilities.

In the course of the study conducted by Peter the Great SPbPU together with the NGO "International Gas Union" and TP "NIUVS", the following tasks were set and solved; a systematic analysis of the value and use of UGS in the system of energy export supplies to the EU countries was performed; factors were identified and a forecast for the development of gas storage facilities of the Gazprom Group of Companies in European countries was made; the concept of the development of digitalization of UGS and the system of intelligent underground natural gas storage facilities was justified; The seasonal balance of gas storage capacities is analyzed and the necessary gas storage capacities are justified to cover the peak demand for natural gas importing countries. recommendations for their strategic development of Gazprom Group UGS in European countries.

2 Materials and Methods

The materials of this article are the results of a study conducted by Peter the Great St. Petersburg Polytechnic University together with the International Gas Union the following tasks were set and solved; a systematic analysis of the value and use of UGS in the system of energy export supplies to the EU countries was performed; factors were identified and a forecast of the development of gas storage facilities of the Gazprom Group of Companies in European countries; analyzed the seasonal balance of gas storage capacities and justified the necessary gas storage capacities to cover the peak demand for natural gas importing countries. recommendations for their strategic development of Gazprom Group UGS in European countries.

Gazprom Group is the largest gas exporter to the European gas market. By steadily increasing gas sales in European gas markets, the Gazprom Group's share in gas consumption by non-CIS countries in 2019 reached 35.6% (Fig. 1), down 1.2% after a record level of 201.9 billion cubic meters of gas supplies in 2018.

Continuing to improve the reliability of gas supplies to Europe, as well as to increase the efficiency of sales activities, the gas storage segment is at the heart of Gazprom's strategy to develop gas production capacities and gas transmission capabilities, including integrated processing. For this purpose, a program for the development of gas infrastructure, in particular UGSF, is being actively and consistently implemented both in Russia and abroad.

Currently, Gazprom Group is the world's largest company in the UGS sector. They are integrated into the unified gas supply system and are an integral part of it. At present, PJSC Gazprom operates 27 underground gas storage facilities in the Russian Federation: 8 of which are built in aquifers, 2 in salt caverns and 17 in depleted gas fields.

As of December 31, 2019, the total active capacity of Russian UGSF reached 75.01 billion cubic meters. Over 10 years, compared to the 2009/2010 gas withdrawal season, Gazprom has increased the potential maximum daily capacity of the Russian UGS network at the beginning of the season by 36%. The indicator has been brought to a record

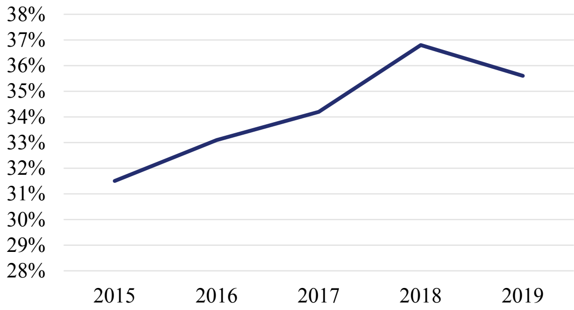

Fig. 1. Share of gas sales by Gazprom Group in gas consumption by non-CIS countries, 2015–2019, [1].

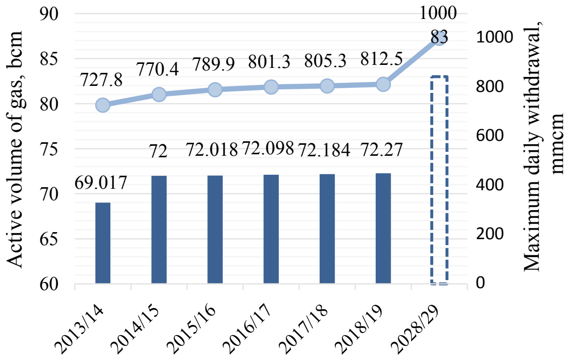

Fig. 2. Dynamics of storage capacities development of PJSC Gazprom in Russia, [6].

level in the history of the Russian Federation—843.3 million cubic meters. Work in this direction continues: by the 2030/2031 withdrawal season, it is planned to increase the daily productivity by another 200 million cubic meters. Among the key tasks in the field of UGS for 2020–2030—increasing the flexibility of the UGS system by creating peak storage facilities in rock salt deposits of a relatively small volume, but with high productivity.

3 Results

The results of the retrospective study show that in the last two decades, the European gas market has undergone significant changes in both the technical and organizational, as well as in the regulatory and legal spheres. This requires the development of a concept for the transformation of Gazprom's natural gas exports in order to increase its competitiveness in the face of high demand volatility and geopolitical actions to freeze new and ongoing gas transportation projects.

As part of its foreign activities, Gazprom Group systematically implements a strategy for developing its own UGSF in the neighboring countries and far abroad. The use of UGSF abroad makes it possible to ensure uninterrupted supplies of "blue fuel" to foreign consumers during periods of increased demand and repair work on gas transmission systems, as well as to realize additional gas sales.

In particular, Gazprom Group actively uses gas storage facilities in European non-CIS countries: Germany, Austria, Czech Republic and Serbia. 2006 to 2016 the volume of active storage capacities in the Gazprom Group's UGSF in Europe increased from 1.4 bcm up to 5 bcm, and withdrawal capacity from 18.2 mmcm per day up to 83 mmcm per day. By the beginning of the 2019/2020 withdrawal season, in European non-CIS countries Gazprom Group have created its own storage capacities in the amount of about 8.5 bcm of active gas which is in the range of 4 – 5% of Gazprom Group supplies to European gas market recently.

Thus, in August 2020, the construction of the Jemgum UGS facility in northern Germany was completed.

Jemgum is one of the largest underground storage facilities in Germany, set up in salt caverns. It consists of ten caverns up to 1.5 km deep. Their total active capacity is about 900 mmcm of gas. The construction of the storage began in 2008. Five years later, its first stage was put into operation. The storage facility is located a few kilometers from the border with the Netherlands. Due to its favorable location, it has a direct connection to the Dutch GTS and the German Gascade pipeline network, which provides access to two large sales markets at once. Russian gas is transported to UGS facilities via the Nord Stream and NEL gas pipelines.

In addition, work continues on expanding storage capacities at other Gazprom Group projects such as Banatskoy Dvor in Serbia, Katharina in Germany and Damborice in the Czech Republic [6].

Located at a short distance from the main gas pipelines, as well as near the points of delivery of Russian gas to European buyers, Gazprom Group's UGSs respond most quickly to changes in demand, as well as in other unforeseen situations. Figure 3 below shows a comparison of various options how long it takes to deliver natural gas to end consumers in the EU: using UGS facilities in the EU, delivering Russian gas via transit through Ukraine, and supplying American liquefied gas.

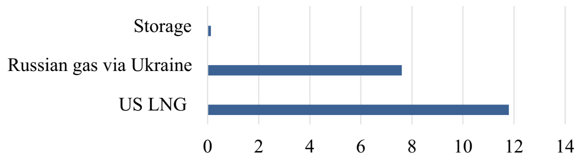

Fig. 3. Estimated number of days of gas supply to the European gas market, [2].

The high responsiveness that UGSF, especially salt storage facilities, can provide, also make a significant contribution to ensuring the smooth functioning of the gas market, including by minimizing price peaks in the EU gas spot markets.

According to expert opinions, with the active use of natural gas in the energy balance of the country, the most optimal solution is to create storage capacities in the amount of 20–25% of annual consumption. During the peak period of demand in 2016/2017

UGSF in the EU covered 32% of natural gas supplies to the market. A similar situation developed in 2017/2018 and 2018/2019.

Today, the European gas market has significant natural gas storage capacities that can cover demand during peak periods ranging from a few days to several months (Fig. 4). Taking into account the intentions of the EU member states to continue to increase the liquidity of gas hubs and the integration of domestic regional gas markets, the availability of storage capacity is a fundamental factor in achieving these goals. The availability of a reliable source of energy in the form of gas, which, in addition to diverse gas supplies to the EU, is also backed-up by UGSF, suggests that there are no other alternatives to underground storage facilities. The key feature of UGSF is a capability to act as a guarantor both from suppliers and consumers perspectives as well as the market itself.

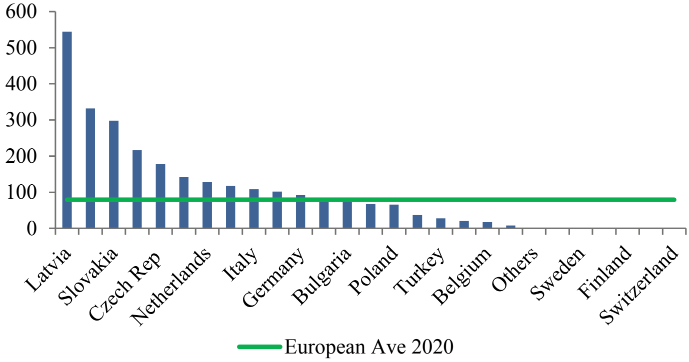

Fig. 4. The number of days of gas demand per year that the UGSF can cover in 2020, [2].

Underground gas storage system with a total capacity of 108 billion cubic meters (bcm) operates in Europe. Germany, Italy, France and the Netherlands account more than 60% of the total gas storage capacity, which makes them particularly important for the European gas market.

Total capacity has gradually increased by 5,5 bcm since 2014. It especially increased in Netherlands and Italy (by 2,4 bcm and 2,7 bcm).

The growth of UGS capacities in Europe and the drop of gas demand (associated with the relatively warm weather in winter and the spread of the coronavirus infection COVID-19) led to the fact that in August 2020 the reserves of natural gas in storage facilities in Europe reached 95 bcm [2], (88% of the total capacity of underground storage facilities). This is 29 bcm more than 5 years ago (compare with August 2016). In some countries (Germany, Hungary Italy and Poland) gas storage facilities are filled to the limit.

Figure 5 shows the changes in UGS capacities in countries that are large consumers of natural gas since 2014.

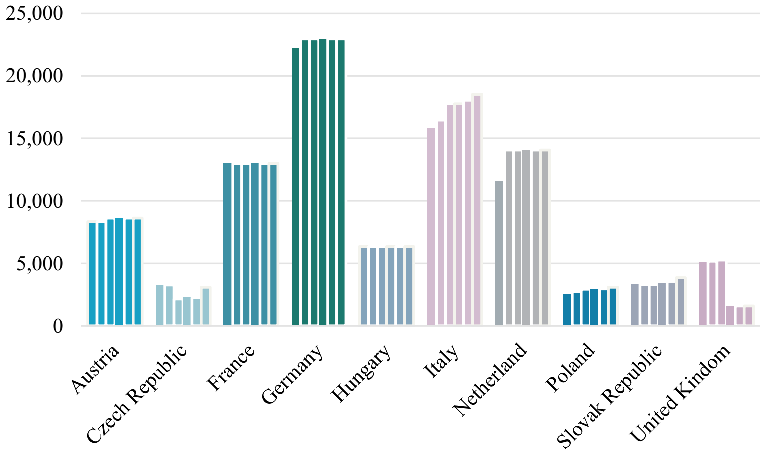

Fig. 5. UGS capacities in Europe 2014–2019, [2].

4 Discussion

Interpretation of the results of the analysis of the state and implemented projects for the construction of underground natural gas storage facilities in European countries allows us to determine the priority areas for their future development.

Priority directions for the transformation of the structure and capacity of underground natural gas storage facilities for the period up to 2030 can be determined on the basis of a systematic analysis of existing underground storage capacities and trends in the development of demand for natural gas. We will consider the possibilities of developing natural gas storage capacities in the main natural gas importing countries of Gazprom and the Central European countries for the period 2016–2020.

Let's consider the possibilities of natural gas storage capacities for the main gas importing countries of PJSC «Gazprom» and for the countries of Central Europe during 2016–2020.

Germany currently has the largest underground gas storage capacity in Europe. The total volume of the storage capacity is 23 bcm.

In August 2020 the total volume of gas injected into UGS facilities reached 22 bcm increasing the volume of reserves by 3.8 bcm compared with January 2020. It allows to provide 25% of the gas consumption in the country (in 2019 the level of consumption was 89 bcm).Gas injection began in April of this year and has reached 96% by the end of August.

Italy takes the second place of gas storage capacity in Europe. Gas storage capacity growth established from 15.8 bcm up to 18.5 bcm. Currently the gas storage capacity filling is 90% which amounts 16,7 bcm. Gas filling is capable of covering about 23% of the total gas consumption in the country, which in 2019 amounted 70.8 bcm. Gazprom does not have own natural gas storage facilities in Italy.

Since the beginning of the year, the Netherlands has increased gas reserves in underground storage facilities by almost 2 bcm. The gas filling in UGS is 74%. The total natural gas reserve for the 2020/2021 autumn- winter period is 10.4 bcm. that 0.8 bcm less than the same period 2019/2020.

The gas storage reserve covers more than 28% of the country's annual consumption (the consumption reached 37.4 bcm in 2019).In the Netherlands, Gazprom uses the Bergermeer UGS facility in the amount of 1.85 bcm.

UK's largest gas storage facility was closed in 2017. This fact led to a decrease of the potential capacity for natural gas reserves by 3.7 bcm (currently, the capacity is 2 bcm).The main places for gas storage are salt caverns, which are 86% filled at the moment.

France began to fill in gas storage facilities in April and as the result operating gas reserves have amounted to 11.2 bcm, in August (86% of the total gas storage capacity) The filling level allows to cover 26% of annual consumption (total consumption in France was 43,4 bcm in 2019).

Countries of Central Europe (Visegrad group)—Poland, Slovak Republic, Hungary and Czech Republic have filled gas storage facilities by almost 90%. By the start of the 2020/2021 withdrawal season, the operating gas reserves in this region totalled 15.5 bcm in this region.

By the end of the summer 2020 total volume of operating gas reserves at European UGSF is 95 bcm. This is 12.7 bcm more as compared to the average 5-year filling rate of gas storage facilities (Fig. 6).

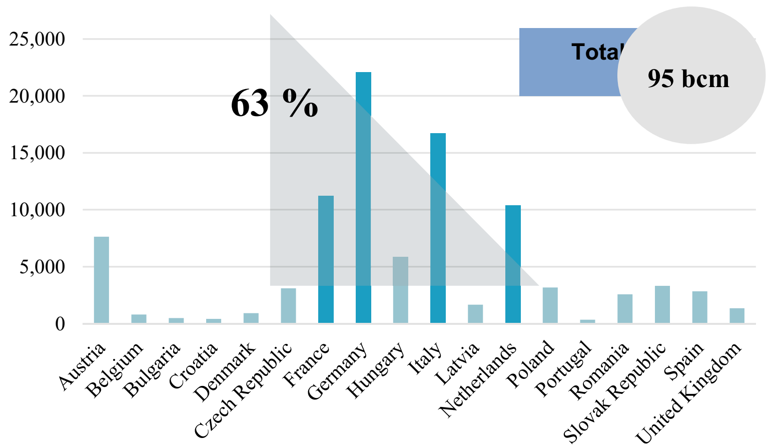

Fig. 6 Overview of the level of gas filling of European UGS facilities, [8]

To supply Russian natural gas to the EU, Gazprom Group has pumped about 9 bcm of gas into European UGS facilities [10]. In addition, on the beginning of the gas withdrawal period an operating reserve is 72.3 bcm was created by PJSC Gazprom in the underground storage facilities of the Russian Federation.

Despite the diversification of gas supplies to the EU, the integration of European regional gas markets, an increase in the liquidity of gas hubs in the context of the ongoing gas market globalization, UGS facilities continue to play a significant role in the chain of functioning of the natural gas industry.

The high level of gas reserves in European underground gas storage facilities, including the Gazprom Group, for the coming autumn–winter period will provide the most favorable conditions for the functioning of the EU gas market. That way will satisfy gas demand even in the event of unfavorable weather conditions during the winter and realize additional gas volumes in Europe and will strengthen the leading position as the largest gas exporter in the European energy market.

5 Conclusions

1. An effective tool for improving the efficiency of Russian gas supplies to the west is the integrated, interconnected development of production capacities for the production, transportation and storage of natural gas. At the same time, the functioning of the underground storage system allows not only to increase the stability of the supply of natural gas to consumers, but also to optimize costs in the development of gas transportation infrastructure and production capacities.
2. This fact is particularly relevant in the light of the European Union's desire to strengthen energy security, political differences with Russia's traditional natural gas transit countries, and economic sanctions imposed on new gas transportation projects. The results of the forecast allow us to conclude that despite the stagnation of EU gas demand in recent years, the value and capacity of underground gas storage facilities will increase at a higher rate than in the whole world.
3. Objective growth factors will be: a decrease in domestic gas production and, consequently, an increase in imports by the EU countries; an increase in the gap in the volume of seasonal fluctuations in gas demand, a decrease in the role of Ukrainian UGS against the background of a drop in the volume of Ukrainian transit, and others.
4. Under these conditions, and taking into account the growing external threats to Gazprom's exports, it is necessary to consistently develop the volumes and productivity of UGS while ensuring their logistical efficiency in terms of uninterrupted natural gas supplies.
5. The results of the analysis prove the effectiveness of the strategy for the construction of underground natural gas storage facilities near the points of delivery of Russian gas to European buyers. This allows Gazprom Group to respond most quickly to changes in demand, as well as in other unforeseen situations.
6. As a result of the conducted research, it is established that, taking into account the intentions of the EU member states to increase the liquidity of gas "Hubs" and the integration of domestic regional gas markets, the availability of storage capacity is a fundamental factor that in the future can have a positive effect on the functioning of markets, including reducing the cost of gas for end users.

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Digital Technologies in the Production Logistic Support System of the Arctic Fields

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Abstract. The fuel and energy complex of Russia is one of the most important industries in the country. Therefore, today the issue of large-scale implementation of digital technologies at enterprises of the oil and gas industry, including in the system of logistic support of the Arctic shelf, is very relevant. It has been found that, if properly applied, the use of modern digital technologies has a positive effect on the results of companies' work. Despite all the difficulties companies face, digitalization has several benefits. The development of new and the use of existing digital technologies at the enterprises of the fuel and energy complex makes it possible to increase the competitiveness of companies and the competitiveness of the country as a whole. The aim of this work is to prove the necessity of introducing digital technologies into the logistics of oil and gas fields, to analyze existing digital technologies on the market and to formulate barriers to their implementation. As a result of this work, the scale of implementation of various technologies in oil and gas companies was assessed.

Keywords: Oil industry · Digital technology · Logistic support

1 Introduction

Recently, the oil and gas industry has been paying increased attention to Arctic resources. Today, this direction in the oil industry is at an active stage of study and search for appropriate technologies for the development, production and transportation of hydrocarbons offshore fields. Implementation of offshore field development projects requires significant investments, which determines the existing economic risks. This is only one of the most important factors explaining the high cost of errors in the implementation of this type of projects. A kind of solution to this problem is the introduction of digitalization at all stages of oil production. One of the important components of the oil and gas industry is logistics, which ensures the movement of material flow. It is necessary to use the optimal, economically feasible way. This will reduce costs, reduce transportation time, and efficiently use production resources [1, 2]. Thus, optimization of the production process

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becomes an important task in the oil and gas industry. This is directly facilitated by the use of digital technologies. The aim of the work is to prove the necessity of introducing digital technologies in the production logistic support system of the Arctic fields.

2 Materials and Methods

2.1 Prerequisites for Digitization of Oil and Gas Industry Companies

Today 43 hydrocarbon fields have been discovered in the Russian sector of the Arctic. Each of them has its own characteristics: each has a different degree of remoteness from the shoreline, certain ice conditions. Important characteristics are logistic availability and technological capabilities of the field development. On the other hand, these are huge reserves of hydrocarbons, which by their characteristics surpassed the characteristics of oil of famous brands. And the main task for scientific and technical centers, oil and gas industry companies today is to find and develop new effective technologies for offshore oil production, including the use of innovative technologies, digitalization technologies aimed at improving the quality of work [3].

Economic risks. The main feature of oil and gas projects on the Arctic shelf is their high capital intensity. Economic risks also include a long payback period and significant investments. All this should be taken into account at the early stages of work on the project, it is important to predict the price dynamics for raw materials, calculate possible development scenarios so that there were reasons to believe that by the time the project is launched, the offshore field is put into commercial operation, at the stage of production and finally sales of products will bring positive economic results [4]. Digital technologies such as cognitive computing and artificial intelligence, intelligent content extraction, predictive and advanced analytics, joint portals visualization, crowdsourcing, 3D printing, robotization, blockchain, sensors and detectors, cyber-tracking, virtual reality and three-dimensional spatial analytics, etc. have already been applied for this purpose.

Ecological risks. Another major problem is environmental and industrial safety. The Arctic is a very fragile ecosystem: it is a unique natural resource that requires special treatment, as well as wide biodiversity, including many populations of global importance. This factor explains the impossibility of making mistakes in the implementation of oil and gas projects that entail negative consequences for the entire ecosystem of the region as a whole [5]. Therefore, all offshore oil production operations should be one hundred percent safe and exclude any negative impact on the environment. Innovative methods and digitalization technologies, designed to ensure safe controlled and efficient production, also come to the aid here.

Technological risks. Another very important issue is the technological capability to implement offshore projects in the Arctic. It is necessary to take into account the harsh natural and climatic conditions in which the work will be carried out—a squally wind, the most difficult ice conditions, logistics accessibility. Today, there are no standard publicly available and generally accepted technologies for industrial production on the shelf, and science and industry are faced with the urgent issue of creating fundamentally new technological solutions, including digital technologies [6, 7].

2.2 Analysis of Existing Digital Technologies in Logistics

Cognitive Computing and Artificial Intelligence, big data technologies. Such digital technologies as big data, machine training and artificial intelligence allow us to reach a fundamentally new level of data interpretation quality, including seismic exploration and offshore field logistics. The application of machine learning algorithms provides an opportunity to classify a great number of different information, often unrelated, unstructured, coming from different sources. If consider the logistics in the oil and gas complex, it can be, for example, different types of information about the supplier, posted on the website of the supplier, in magazines covering the oil and gas industry, in various Internet sources. These technologies symbolize new opportunities to work with “big data". Cognitive computing and artificial intelligence, big data technologies allow integrating any unrelated information into a single data source, which is constantly updated, thus allowing to use the collected information for further analysis and processing [8, 9].

VR, AR and 3D, 4D visualization, 3D printing. VR, AR, 3D, 4D visualization—these are digital technologies designed to improve the quality of solutions, which day after day, from project to project have to take industry experts in the development of oil fields, and especially important—decisions on the development of offshore fields, which are characterized by the complexity and the need to avoid errors for the absolute implementation of environmental standards. The essence of modern digital data visualization technologies is that they can transform information from ERP systems into a visual format in the shortest possible time, in a matter of seconds, and this, of course, simplifies the decision-making process, and most importantly, reduces the risk of managerial error [10].

3D printing allows you to accurately create an object from a digital model by adding layers to the material. Today in this way parts and prototypes are created in the industry, as well as prototypes of tooling for use in severe extreme conditions, including the Arctic shelf drilling sites. 3D production has several of undeniable advantages, including a significant reduction of time for the production of equipment, such as a failure; significant savings on production costs; avoidance of downtime in production when the equipment breaks down, etc. [11].

Predictive and advanced analytics. The system of predictive analytics in oil production on the Arctic shelf, by installing sensors that receive all sorts of information about the operation of the equipment, as well as the use of appropriate software that can analyze the data, allows you to predict the processes in production, for example, provides an opportunity to assess the quality of the equipment, its condition and, if necessary, the operator will make an accurate decision on repair work. As for the application of predictive and in-depth analysis in the process of logistics support of offshore fields, this technology provides buyers with the ability to make the most accurate forecast models, accurately develop probability cost/price scenarios, more accurately assess fluctuations in demand, as well as effectively manage procurement risks [12].

Sensors and detectors. In oil and gas logistics, sensors are widely used to obtain relevant information on the need, delivery, consumption of raw materials and supplies. Through the use of technologies such as GPS, radio frequency tags (RFID), bar codes, it is possible to obtain information in real-time with the latest changes, track any changes in status. This, of course, can significantly reduce uncertainty in the supply chain and noticeably improve the quality of planning.

Smart content extraction. There is a digital possibility, such as the use of OCR optical character recognition and learning algorithms that are configured to read information from unstructured sources, as well as sorting and retrieving the necessary data fragments, certain tables and the necessary information. This significantly reduces the time needed to collect and analyse information [13].

Crowdsourcing. This technology makes it possible to organization of efficient work of procurement companies in the logistics system through active use of mobile technologies. They gain access to the opinion of consumers and industry experts and monitor trends and trends that have a direct impact on supply chains and supplier policies.

Cooperative portals. An important part of the logistics system for oil and gas projects is occupied by platforms that provide access to information to both buyers and suppliers, ensuring transparency of all elements of the supply chain. Users can use the so-called 'cloud' for storing information, it is possible to analyse and manage various indicators, as well as identify and monitor risks in the supply chain [14]. Having access to joint portals for suppliers throughout the supply chain makes it possible to exchange information, reduce communication barriers, increase the speed of project implementation and improve the quality of services provided.

Robotics Process Automation. Robotic process automation in commercial procurement is used to perform routine operations through self-learning algorithms. The introduction of this type of technology can significantly improve the efficiency of P2P processes by reducing errors and risks. The use of robots in the office process system reduces the time it takes to perform frequently repeated actions and allows you to increase operational efficiency through two factors: firstly, by freeing up the payroll, and secondly, by reducing operational risks. The use of robots at all stages of oil production helps to increase efficiency and minimise the human factor.

Blockchain. A blockchain is a database that stores information about the actions of all participants in a "chain of blocks" format. The main feature is that the risk of fraud and poor use of information is reduced by confirming the truth of the information that each user contributes. The widespread use of technology such as block brokers in the procurement system is due to the use of so-called "smart contracts".

Cybernetics tracking. In logistics cyber-tracking technology is used to monitor supplier behaviour and evaluate supplier performance through real-time tracking—online or physical supplier activity. By integrating the information obtained through cyber-tracking with other data, it is possible to design trends and analyse purchasing risks [15, 16].

2.3 Practical Application of Digital Technologies: Opportunities and Barriers

The application of new technologies enables oil and gas digital companies to achieve the following results:

- expansion of the company's raw material base;
- increased oil recovery and production volumes;
- reduction in the number of accidents;

- increase in productivity and occupational safety;
- improving oil and gas production, transportation and refining operations.

The main indicators that determine the economic feasibility of all costs associated with the development of oil fields and the introduction and operation of digital technologies at oil fields include:

- annual economic effect;
- increase in profit.

Barriers to the implementation of digital technologies in the oil and gas industry.

The oil industry is a complex manufacturing process with a number of exceptional features. The introduction of digital technologies into production therefore breaks down a number of barriers:

- dependence on foreign technology supply and unpredictable geopolitical situation. It is necessary to have domestic developments and technologies;
- harsh Arctic conditions for digital technologies;
- threat of cyber-attacks;
- the high volatility of world oil and gas prices threatens digitalization projects at all stages of oil production, including logistics support for the fields;
- complexity and high cost of digital technology development [17, 18].

Experience in applying digital technologies in the logistics system for Arctic offshore fields. At «Gazprom Neft» IoT is actively used in the work of intelligent transport systems, which make it possible to determine the location of each vehicle and monitor its movement history.

Smart vehicle monitoring systems using GLONASS/GPS sensors make it possible to analyse and optimise traffic routes and ensure that vehicles are used for their intended purpose. At «Gazprom Neft», they are used in the chain of all types of transport services—from the delivery of equipment to the fields to the transportation of petroleum products.

The prototype of IoT in the logistics system was the industrial RFID technology—radio frequency identification, which allows wireless communication to transfer information contained in RFID microchips on goods and cargo.

An example of the introduction of digital technologies into the logistics system for offshore fields is the implementation of a pilot project for the use of a blockage system by «Gazprom Neft Supply» and «Gazprom Neft Shelf» for the delivery of shut-off valves to the «Prirazlomnaya» offshore ice-resistant stationary platform. Radio-frequency RFID tags were applied to the cargo and GPS sensors were installed so that movement data could be recorded automatically in the blockage. This digital solution has made it possible to automate all warehousing operations and also to monitor their implementation within the declared deadlines. Due to the fact that data entry in the network is fully automated, the possibility of errors, substitution or correction of records is eliminated, the logistics process has become as transparent as possible thanks to the introduction of digital technologies at all stages of the production chain [19, 20].

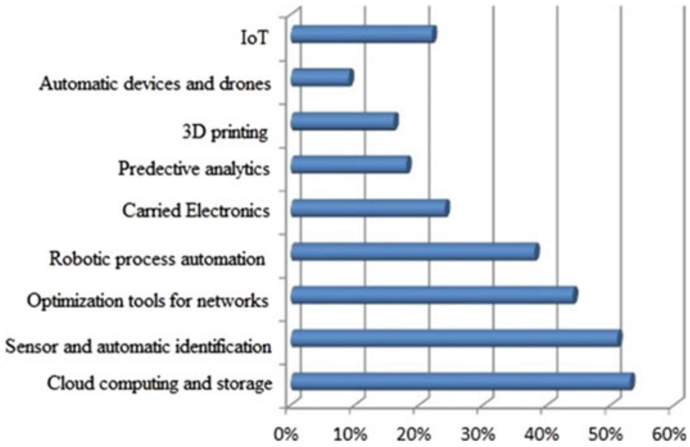

Fig. 1. Scale of technology adoption, % of companies surveyed

3 Results

As a result of the analysis it has been established that digital transformation in modern times at all stages of production in the oil and gas industry is no longer presented to company directors as an unavailable breakthrough transformation, but as a real opportunity to improve productivity and business development. The various digital technologies are characterised by the specific scale of their adoption by companies, and the percentage of companies surveyed is shown in the picture [21].

The picture shows that the scale of technology implementation in companies is quite large. This reflects the seriousness of companies in digital technology.

4 Discussion

However, in addition to the expected benefits and opportunities for companies in the oil and gas industry when introducing digital technologies at enterprises, there are certain risks that may arise in the context of the digitalization of the complex.

This is another urgent issue today that requires detailed study in order for companies to have the opportunity to implement large-scale digital technologies to optimize the production process, despite the existing barriers to their implementation.

In the near future, with the development of technologies and the market for these technologies, risks will decrease, which will give a powerful impetus to the development of digital technologies in oil and gas, but those companies that will be the first to carry out digital transformation will receive the maximum benefit and high competitiveness.

5 Conclusions

An analysis of the experience of introducing digital technologies at enterprises of the fuel and energy complex proves that, with proper application, the use of modern digital technologies has a positive effect on the results of companies' work.

The main results are as follows:

The fuel and energy complex of Russia is the most important industry for the country, to which much attention is paid. The export of hydrocarbons provides a significant part of the country's budget.

1. It was found that the introduction of digital technologies at the enterprises of the fuel and energy complex corresponds to the strategy for the development of the fuel and energy complex adopted at the state level;
2. According to the results of the analysis of the use of digital technologies in the oil and gas complex of Russia, it can be concluded that many Russian companies are already successfully implementing digital technologies in their work, due to which they have more competitive advantages in the Russian and world markets.
3. The implementation of digital transformation technologies in the field logistics support system within the framework of offshore projects solves a number of critical tasks: it allows to optimize work, improve key performance indicators of project implementation, ensure the required level of labor safety, and significantly simplify process management at all stages of the technological chain.

Of course, digitalization of enterprises in the oil and gas industry is today a priority for every company operating in the industry.

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Optimization of Logistics Through Introduction of Digital Technologies in the Company's Supply Chain

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Abstract. Each network trading company must adequately build the logistics processes and monitor the supply chain management, since the "chain" covers the entire group of intermediaries and suppliers who are involved in the production path, from the manufacturer to the ultimate consumer. At the same time, each individual product or product line may have its own distinct list of active contractors. The introduction of the compulsory product marking significantly influenced the organization of the company's logistics processes. This paper focuses on the process of logistics optimization with the network trading companies based on the introduction of digital technologies in the supply chain management. Throughout the course of the study, the interconnection between the company's main stakeholders with external and internal drivers is examined, thereby aiming to distinguish the estimates and goals corresponding to the "Optimization of the company's logistics processes" driver, at the same time, taking its decomposition into account. Special attention was paid to the introduction of compulsory product marking and its impact on the logistics processes of the network trading companies. As a result, the study articulates the basic principles for the optimization of the logistics processes based on the introduction of digital technologies, suggests the main stages of marking and tracking, develops the algorithm of obtaining and printing the product codes from the personal account in the Center for the Advanced Technologies, and highlights the most urgent problems of the network trading companies.

Keywords: Supply chain management · Logistics · Logistics system · Network trading companies · Retail · Optimization · Labeling · Product tracking

1 Introduction

Each network trading company must adequately build the logistics processes and monitor the supply chain management, since the "chain" covers the entire group of intermediaries and suppliers who are involved in the production path, from the manufacturer to the ultimate consumer. At the same time each individual product or line may have its own

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distinct list of stakeholders and companies. Thus, supply chain management in logistics is an indispensable process without which it would be impossible to establish timely delivery, organize large batches and reduce costs.

The introduction of the compulsory product marking has already had a significant impact on the company's logistics processes, which is manifested in changes in the volume of deliveries, procedures, deadlines, financial costs and other expenses of companies. According to the above mentioned statements, the research related to the optimization of the company's logistics activities based on the introduction of digital technologies in supply chain management is becoming more and more relevant.

The whole-scale goods marking is expected to be implemented in all the major groups of industrial products in the Russian Federation (from clothing and footwear to food) by the year 2024. The marking of goods was initially started back in 2005 by the Unified State Automated Information System, which was designed to control the volume of production and turnover of the ethyl alcohol and the alcohol-containing products. In addition to the alcohol labeling, the compulsory marking of the fur products has been active in Russia since 2016. All fur products are marked with the identification signs that contain a two-dimensional barcode and a RFID chip. Each identification mark has a unique number, which is stored in a single information database on the servers of the Federal Tax Service [1, 2]. This eliminates the chances for forgery and reuse of signs. When selling a fur product, the seller registers the transaction in the personal account on the information platform of the marking company. The introduced marking of the fur coats showed that in Russia the shadow market of fur products was twice as high as the numbers reported by the sellers. Since January 1, 2020, labeling of all medicines has been active as compulsory in Russia.

2 Materials and Methods

At the present day, an increasing number of mass-produced products undergo the labelling procedure, which implies the application of digital and written identification numbers, barcodes etc. that contribute to the product individualization. In addition to applying an individualizing number, in some cases the trademark of the state, region, manufacturer, is applied to the product. The number usually individualizes a specific piece of the product. Taking these conditions into account, an integrated approach to the assessment of information placed on the labeling carrier is advisable. This is explained by the fact that such an approach contributes not only to revealing inconsistencies of the information support, but also to determining the lack of compliance with safety, security and availability requirements.

This study uses the analytical methods, such as description, data grouping, causal analysis, evaluation. The methods applied made it possible to link separate facts about the condition of the logistics activities of the network trading companies in the context of the introduction of mandatory product labeling into a single system, which made it possible to identify current realities, problems and development trends in this sector of economy.

3 Results

The compulsory marking in Russia is currently affecting the growing number of product categories. Experimental monitor groups in 2020–2021 are operating in the segment of dairy products, wheelchairs and smoking mixtures. After testing the system, many groups switched to the category of products that are subject to the mandatory registration [3]. Among them, by the end of 2020, were shoes, medicines, some textiles, perfumes and tires. According to the adopted regulations of 2021, their sale without the DataMatrix code on the labels will be illegal.

Consequently, the introduction of mandatory marking can affect both the volume of shipments and transit times. DataMatrix codes must be applied to imported products before passing all the customs procedures. Thus, the codes can be applied either at the production site, or in the warehouse, or with the help of logistics operators who can provide such services. The key point in this process may be the level of automation of this operation [4–6].

Currently, the retail sector, like many other industries, is severely affected by external factors that have a huge impact on its further development. All this leads to adjustments in the operational and strategic goals of network trading companies and other participants in the supply chain. Let's look at the relationship of the company's main stakeholders with external and internal drivers in more detail.

According to Fig. 1, as the main internal drivers of network trading companies, it is advisable to highlight the optimization of logistics activities and increasing customer orientation, since in the current economic conditions, these functional areas contain the potential growth reserves, especially given the changes in the legal framework associated with the introduction of compulsory marking [7].

Table 1 shows the main estimates and goals corresponding to the "Optimization of the company's logistics processes" driver. The selected estimates and goals are presented separately in accordance with the decomposition of the internal driver "Optimization of the company's logistics processes" into the driver "Optimization of the warehouse logistics" and the driver "Optimization of the transport logistics".

Implementation of the presented goals corresponding to the "Optimization of the company's logistics processes" driver is possible only if the basic principles of optimization are observed. Let's look at the four main principles for optimization of the company's logistics processes based on the introduction of digital technologies. They include the following:

- Optimization of business processes should be carried out gradually. First of all, it is necessary to fix the current business processes in the form of models in order to build them again later, evaluate their efficiency and improve them.
- It is advisable to start optimizing logistics business processes by identifying, grouping and eliminating individual shortcomings. If necessary, it is possible to use the reverse approach and turn to reengineering.
- Integrated approach. Eliminating non-optimality for one business process can significantly aggravate the KPIs of other processes. Therefore, it is very important to evaluate all the consequences of optimization in order to make a well-grounded choice.

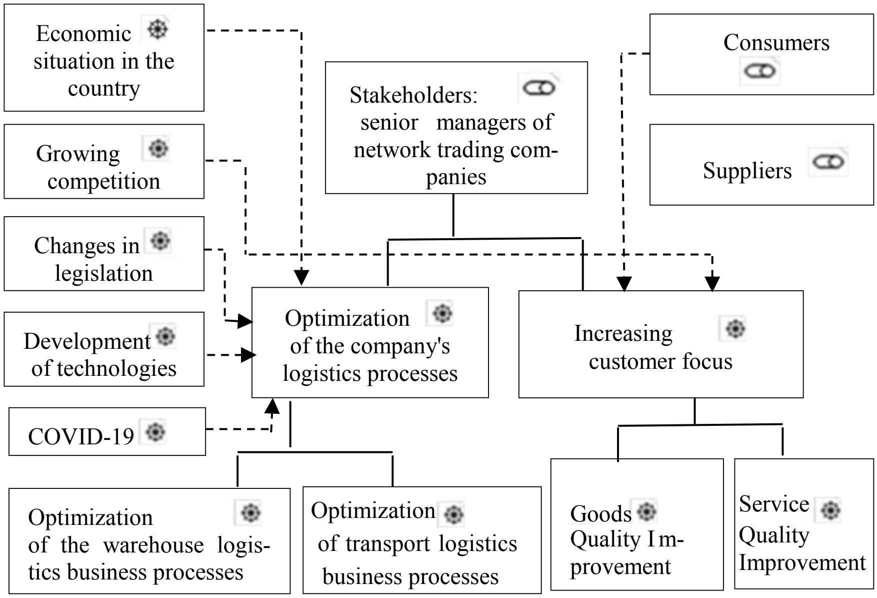

Fig. 1. Interconnection between the company's main stakeholders and the external and internal drivers

It should be noted that the optimization will result in the increased exploitation of specific performers, which will lead to some resistance from the company's staff.

We should not forget that supply chain management is a system of goods, information, and financial resources that move between organizations, their suppliers, consumers, intermediaries, and other companies that are somehow involved in the process of creating consumer value. The logistics supply chain management system is a system in which a manufacturer and a consumer successfully interact. Other individuals – distributors, dealers, or retail outlets can also participate in the network. Therefore, it is a mistake to consider supply chain management exclusively in the context of goods and raw materials, without taking into account the information and financial flows. In this paper we will suggest a more complete description of these elements of the supply chain management [8, 9].

Material and / or product flow is a smooth transition of goods from the producer to the recipient. This becomes possible with the participation of various dealer warehouses, distributors, and retail outlets. The main problem to be solved at this stage is the need to ensure the movement of products without stopping and delays. The sooner the product moves, the cheaper it will be for the company. The flow also works in the opposite direction. For example, when the company needs to make any kind of repair or replace a product with an expiring shelf life. In this case, the elements move in the opposite direction, from the buyer to the manufacturer. There is also movement within a particular company, between departments and workshops [10].

The information flow is a variety of paper and electronic documents. This refers to the information carriers, such as purchase orders, various charts or graphs, profit

Table 1. Estimates and goals corresponding to the "Optimization of the company's logistics processes" driver

Optimization of the company's logistics processes			
Optimization of the warehouse logistics business processes		Optimization of transport logistics business processes	
Non-optimal parameters of technological zones and warehouse equipment		Unproductive logistics partnerships within supply chains	
Business process modeling		Business process modeling	
Business process audit		Business process audit	
Reengineering and standardization of the warehouse business processes		Reengineering and standardization of business processes	
Lean production and staff training		Consistency of parameters of different vehicles in the transport chain	
Organization and control of product marking		Application of a single transportation technology adapted for all types of transport involved in the transportation chain	
Warehouse dispatching systems (status information)		Creating transport chains that may consist of links served by different means of transport	
Network schedule		Joint planning of the transport logistics within various divisions of the company;	
Process maps (information on modules and technical processes)		Automatic planning of regional / local delivery for a large number of requests	
Operational planning		Implementation of automated logistics systems that can provide summary data on all shipments for the required period	
Control, evaluation, and reduction of product distribution costs			

charts, and plans for further growth of the company. It is mandatory to analyze the information on volumes already sold in order to assume how much will be sold in the future. This also includes complaints of any nature—from customers, from employees, on quality or changes in technical performance. Supplier performance reports, profit and cost statements, invoices, and other financial documents are stored and reviewed.

Financial flows serve as the basis for the execution of all business processes of the company—the manufacturer issues invoices, the receiving side checks them and pays if everything is correct [11]. If there is a claim, it is also studied and the funds (partially) are returned to the consumer, and the defective product is returned to the supplier.

It is important to take into consideration that for any company to work effectively, it is necessary to properly build business processes in order to put the minimum effort to achieve the maximum effect. In accordance with this, it is advisable to highlight the main goal of optimizing the logistics business processes of the enterprise, such as control, evaluation and reduction of the cost of goods movement.

It should be noted that the above-stated main goal of optimizing logistics business processes, in the framework of monitoring, evaluation and reduction, applies to the following costs:

- transportation costs for the delivery of goods carried out by various modes of transport (loader);
- transport costs for loading and unloading of goods, as well as for possible transshipment on the way of the goods;
- the cost of assembly and storage of cargo during transshipment;
- transportation costs that are associated with the unproductive storage (damage at the storage location, theft at the storage location, loss of cargo, violation of configuration);
- expenses for the formation and maintenance of inventory of goods from intermediary companies;
- "Deficit costs", which are associated with the lack of goods in any parts of the sales chain, with a lack of ability to manage equipment, with the inability to fulfill an order, as well as with the unforeseen economic crisis;
- cost of unit marking, packaging, and related documentation;
- expenses for cargo insurance, forwarding operations, administrative operations, freight charges [12].

We will pay special attention to the process of introducing mandatory product labeling.

It is important to note that the DataMatrix codes were chosen for marking shoes on purpose, which is explained by the fact that the DataMatrix codes are much cheaper than the RFID tags. They can be identified even if they are partially damaged. DataMatrix codes store a large amount of information, but they take up little space on the package.

The DataMatrix code consists of:

- identification code that determines the position of the product in the unified product catalog labeling system (GTIN issued by the GS1);
- the individual serial number and a crypto code that protects against forgery. It is generated by a special system operator that must be installed for each legal entity;
- product identification—the first 4 characters of the code of the commodity nomenclature of the foreign economic activity of the Eurasian Economic Union. The system uses it to find out which product was marked [13];
- the "electronic signature" used to control the disposal of goods when selling using an online sales register—31 characters will be printed on the label. If there are problems with reading at the checkout, the seller can enter it manually.

Figure 2 shows the main steps in the product labeling and tracking process.

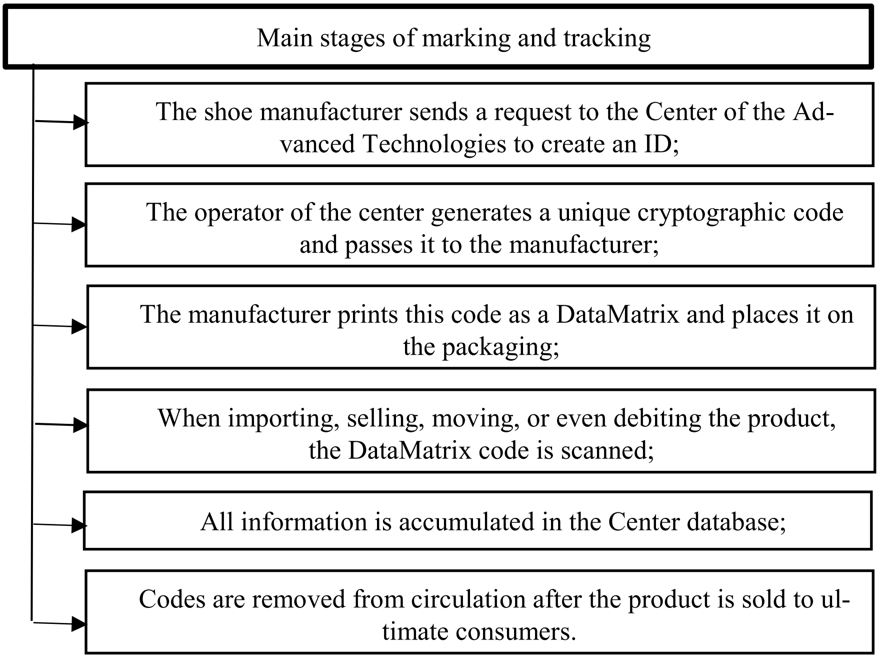

Fig. 2. Estimates and goals corresponding to the "Optimization of the company's logistics processes" driver

It should be noted that each product within the selected product groups must be marked with the unique code. It can be printed and used only once, with the exception of returning the product by the buyer.

Various programs have been developed for the integration with the Center portal, including the Easy Label program [14, 15].

Easy Label is a software solution for printing labels within the framework of mandatory product labeling, developed by specialists of the "Pilot" Group. It provides an opportunity for importers, manufacturers of goods and sellers to automate the process of obtaining ordered identification tools (brands) from the personal account of the Center and convert them into a corporate format for printing a full-fledged label.

Let's look at an example of automating the process of obtaining stamps from the personal account and converting them into a corporate format for printing using the BarTender—a program for creating and printing graphic and text signs for any industry.

Let's highlight the main problems identified by network trading companies to date due to early connection to the project:

1. Data processing speed is not high enough. This problem must be solved at the level of a single tagging operator, otherwise large retailers that, for example, need to receive 1 million or more codes at a time will simply not be able to do it on time. While

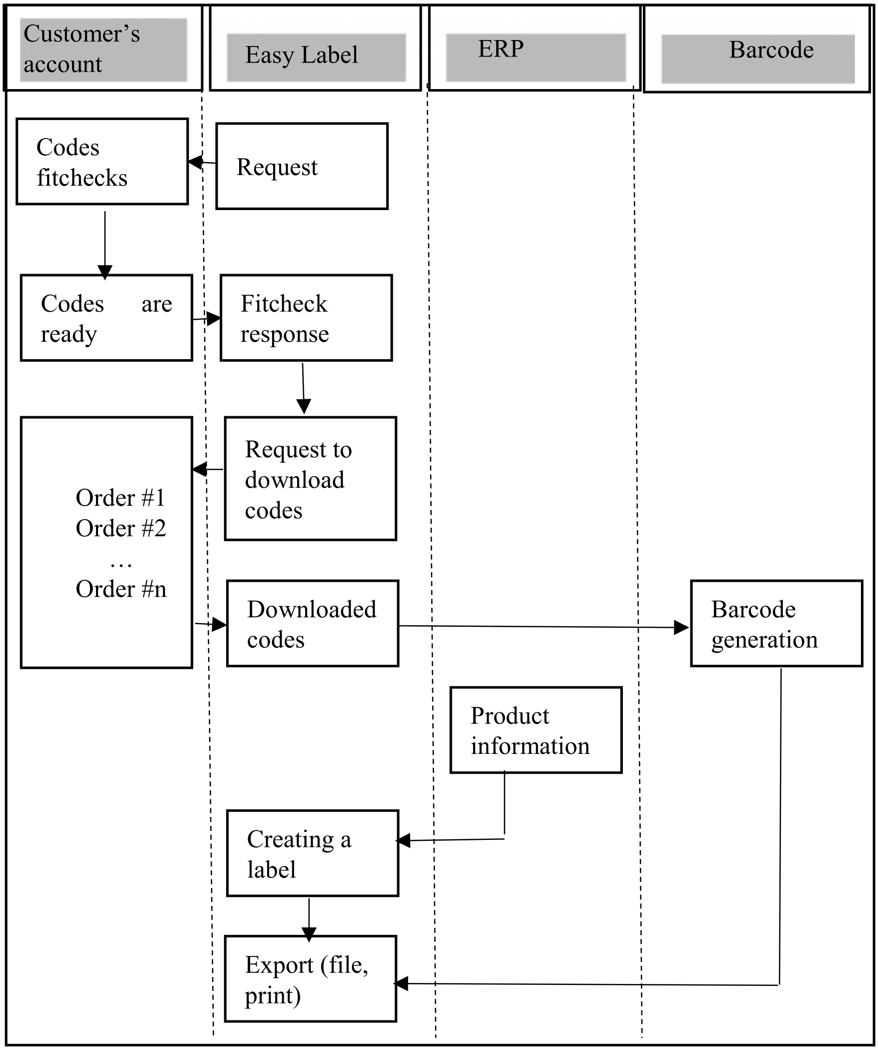

Fig. 3. Algorithm for obtaining labels from the personal account and converting them to a corporate format for printing

network trading companies solve this problem in the following way: the company orders codes in batches of 20–50 thousand pieces, so that the system has time to process the request.

2. Missing part of the required codes. For example, individual codes for each pair of shoes are generated in the system, but there are no two types of group codes that may be needed yet:

- 12 pairs boxes (usually shoes are packed in production);
- per lot, a truck that delivers goods through customs to the Russian Federation.

Since a significant part of the footwear is imported, the marked goods will be processed at customs. Therefore, each batch should have its own code, scanning which the service will get a complete list of what is in the truck.
While there are no such group codes, large retailers get out of the situation as follows: they generate their own group codes, which contain information about the batch of shoes, and transmit it to the unified operator of the marking project, and it stores this data at home [16–18].
3. It is not fully clear how the procedure for returning the product will take place. It can become much more complicated if the code on the box is erased and becomes unreadable during the time it is in the buyer's possession. To accept such a product, you need to generate a new code (you can't do this in the store: only one legal entity can access your personal account). The seller will have to make a request to the Central office, which, in turn, will send a request to the Center. The latter will create a new code for this product, and it will be sent to the store, where it will be printed and pasted on the box. And only then you can make a refund. The unified labeling operator has not yet clarified this point. For retailers, one thing is clear: nothing should change for the buyer, even if the company's internal processes are different. But still, there is a chance that the return period will increase.
4. Not all employees can quickly understand the new processes associated with the presence of DataMatrix codes, so they have to conduct constant training and work on errors. If you need an urgent sale or if the marking code is unreadable, the code from another product can be scanned. Sometimes there are cases when, if an individual box is defective, it can be disposed of together with the marking code, which subsequently leads to the impossibility of selling this product.
5. An important problem is that due to the continuity of sales, retail is faced with the inability to conduct operational inventory. Without additional investment in the development of accounting systems, it is also not possible to track the correct movement of marked goods between different retail outlets. Often, one mistake when working with marking codes leads to another, and without daily monitoring and reconciliation of data on product balances, there is a risk of encountering a large number of goods that cannot be withdrawn from circulation.

The above reasons result in the need to hire additional staff and introduce additional business processes.

4 Discussion

In order to implement new requirements in the context of a pandemic, network trading companies are forced to develop new hybrid schemes. All participants in product supply chains are required to meet certain conditions: logistics service providers are required to provide warehouse space, trained personnel, coordinated business processes, IT support, and secure communication channels.

On the part of manufacturers-transfer of marking codes and printing equipment. At the stage of launching a network marketing company has problems with cross-border transfer of data from the foreign offices of the counterparties. Printing new labels from suppliers' information systems was organized directly to printing devices in warehouses in the Russian Federation, since the responsibility for obtaining marking codes lies with the participants in the turnover (importers or manufacturers), the task of the logistics provider is only to print and apply labels with the DataMatrix code on goods [19].

In early July 2020, some companies experienced delays in receiving codes, but now the situation is more or less stable. From time to time, there are difficulties associated with integration between the supplier accounting system and the CRT (Center for the development of advanced technologies, operator of digital labeling and product tracking systems), most often they are solved at the level of IT departments. Problems were also identified when entering goods into circulation due to failures and errors in data exchange between the Federal Customs service and the Honest sign system.

In addition, it is difficult to obtain additional product data from suppliers and prepare descriptions for uploading to the national catalog. In essence, these are new operations that did not exist before, meaning additional staff or investment in it solutions is needed.

As for costs, the main factor here is the requirements of network companies for packaging and labels, as well as the price segment of products. For example, luxury customers receive requirements for the sterility of the workstation and the implementation of stickering operations in gloves. The degree of automation of the marking process and the format of reporting after it is completed are also important [19–21].

Currently, logistics companies often provide marking services at their own customs warehouses in the Russian Federation and in some European countries. The main role in choosing a location is played by the terms of reference and the wishes of their clients.

Russian importers are often concerned about the quality of labeling when performing operations by suppliers in foreign factories. This is due to the fact that not all suppliers can provide the service of proper quality, as well as perform post-verification of digital marking codes. For this reason, more and more companies choose marking in the territory of the Russian Federation, where it is possible to conduct audits and check the quality of operations, as well as the presence of representatives of the importer when the product is actually marked.

When working with a marked product, retail may need to update the software. The cost of such an update depends on the software provider, but practice shows that even in remote work, such issues are solved by network companies quite successfully.

Currently, in the face of the threat of the spread of coronavirus infection, the increased demand for medicines has led to some failures in the labeling processes of these types of products.

For example, in the Russian Federation, the medication labeling system is temporarily switched to notification mode, so that citizens can buy drugs without delay against the background of increased demand for drugs. At the moment, there are still problems related to the lack of technical readiness of distributors and some pharmacy organizations to work with labeled drugs. That is why, while the wholesale and retail trade is dealing with these issues, taking into account the peak of increased demand, the government decided to temporarily switch the drug labeling system to notification mode in the pharmacy and distribution segment, since this allows you to release the product immediately, without waiting for the response of the labeling system.

5 Conclusions

It is still too early to evaluate the results of optimizing logistics processes as a result of the introduction of mandatory product labeling, but it is already obvious that large network trading companies will significantly increase the volume of document flow, change business processes, primarily logistics, and there will be additional costs for purchasing equipment and expanding its capacity.

If at the initial stage supply chain participants did not have a complete understanding of how to work in the system—business processes were not described, technologies were not developed, then by the end of 2020 the situation has changed significantly.

The introduction of mandatory labeling has already pushed most companies, especially small ones, to automate processes and switch to electronic document management faster. This will allow them to simplify interaction with contractors, and the entire market to reach a new level of development [22, 23].

In addition, the introduction of labeling is also beneficial for end users of goods. When working with labeling, the movement of goods must be recorded at every stage—at a warehouse abroad, at customs, at the company's Central distribution warehouse, at regional warehouses, and in stores. At the same time, all processes must be automated and you need to track each code of a specific product.

Let's consider the business process of product labeling on the example of the product group "Shoes". Since many companies in the Russian Federation import shoes from China, they will most likely have to change their business processes in this country. Previously, all manufacturers marked shoes with internal codes directly at the manufacturing factory. Now this requires codes that come from the unified system from the Center for the development of advanced technologies. These codes are sent to the company's Central office. They are then sent electronically to manufacturing companies, where they are labeled on boxes. After that, all the shoes are flocked to the distribution center, where batches are formed for delivery to Russia. Each one is scanned using data collection terminals, after which the information is sent electronically to the company's accounting system, which, in turn, also generates all the necessary accompanying documents in electronic form. If necessary, you can print them at the distribution center before sending the product. Then the marked shoes with all the necessary accompanying documents (in electronic or paper form) are sent to customs. Then-to the company's Central warehouse, where storekeepers receive it using data collection terminals. There is already a map of the distribution of goods by city. At regional warehouses, shoes are checked again using data collection terminals, and they are sold to stores [24, 25].

Business processes at retail outlets are also changing. Previously, many retail outlets accepted goods manually, but now you only need to do it in automated mode. This means that you need to buy terminals for data collection—either the same as for warehouses (they are quite expensive), or look for a replacement.

Since retail outlets accept significantly less goods than warehouses, some companies use phones with a special mobile application that they developed themselves instead of data collection terminals. It is integrated into the corporate it system and understands and can process marking codes. The seller or administrator only needs to scan the received shoes using their phone, and all the information will be automatically sent to the unified data processing system.

The order of interaction with some counterparties, such as wholesale buyers, is also undergoing significant changes. Wholesale companies will also need to register in the unified system, since they will receive goods with codes from supplier companies, and then register them in their accounting system.

Wholesale companies should also translate all communication with suppliers into electronic form, including document management. In other words, those companies that were slow to automate for some reason will now be forced to do so. This is a positive trend, because interaction with counterparties will be significantly simplified and accelerated.

A significant increase in costs associated with the introduction of mandatory labeling should also be noted. Network trading companies were forced to purchase equipment such as data collection terminals for distribution warehouses (distribution warehouses in partner States, Central warehouses, regional warehouses), terminals for accountants and commodity experts who conduct audits, terminals for retail outlets and/or mobile phones with applications.

An important consequence of the introduction of labeling is a sharp increase in the volume of electronic document flow. Let's take the "Shoes" product group as an example. For comparison: if earlier, for example, you ordered a thousand pairs of size 40, this was reflected in one line in the invoice, now it will be a thousand lines. The size of each invoice will increase multiple times. Yes, all documents will be in electronic form, but the volume of information will increase dramatically, so we will need increased capacity of it systems to process it. So another possible cost point is to increase disk space for the it infrastructure. As for software development, most of the work can be done on your own, if the company already has an automated accounting system. However, in some cases, you only need to hire contractors to perform specific tasks, such as creating an application for working in a distribution warehouse in China.

Thus, optimization of logistics business processes based on the introduction of digital technologies in supply chain management will minimize costs and risks, improve the quality of work and increase the competitiveness of network trading companies in difficult economic conditions.

The result of optimizing logistics processes will be faster solutions to typical problems, lower production costs, increase the speed of product production and improve their quality, optimize customer service, and reduce employee training costs.

Logistics processes and operations cannot be implemented without centralized management. The latter requires regular optimization of the system, taking into account constantly changing environmental conditions or the activities of the enterprise itself. As a result of optimization of logistics business processes, time and resources are freed up, which can be directed to solving strategic or other issues.

To optimize the management of logistics systems, it is necessary to provide for interaction:

- design of logistics operations with the task and design of the company's activities;
- logistics operations with other system operations that are performed at the enterprise;
- information technologies with information support of the system.

The state is most interested in the results of the introduction of mandatory labeling of goods and the subsequent optimization of the company's logistics processes based on digital technologies, since the introduction of these technologies allows you to track the movement of all goods and increase the tax base. In addition to the state, this is beneficial to the end user—the buyer receives an additional guarantee of the quality of the product and eliminates the possibility of falsification. Third on this list are professional manufacturers and retailers. Competition in the market will become more open and fair, as unscrupulous companies, including disparate stores and clothing markets, will leave it. Network trading companies that will be able to maintain their niches in these conditions will only work in the legal field. At the same time, large manufacturers and network trading companies will be able to increase their market share.

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Methodology for Researching the Lifecycle of Arctic Logistics Systems

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Abstract. The article describes a research methodology and lifecycle management approach for a logistics system operating in the Russian Arctic region. The following types of Arctic logistics systems have been identified: a system for managing the country's Arctic space, i.e. the Arctic industry or area; holdings and other possible forms taken by multinational corporations operating in the Arctic; production associations, enterprises, individual divisions, households and associations operating in the Arctic; the Arctic territory of the country, large economic Arctic areas, economic clusters in the Arctic, administrative-territorial units (cities, districts, villages), local territorial production complexes in the Arctic; global, national and local corporate or enterprise networks operating in the Arctic region. A conceptual definition of the "Arctic logistics system lifecycle" is formulated. The methodology for research and management of the lifecycle of Arctic logistics systems is based on graph theory models and methods in combination with the Product Lifecycle Management (PLM) and Continuous Acquisition and Lifecycle Support (CALS) technologies for managing object data. A toolkit for the implementation of the research methodology and modelling of the Arctic logistics system lifecycle is described. A list of tasks that can be performed within the framework of the presented methodology is adduced.

Keywords: Arctic logistics systems · Arctic logistics system lifecycle · Alternative graphs · PLM and CALS technologies

1 Introduction

The Arctic logistics system comprises an emergent set of interconnected elements, which has the property of integrity, divisibility, the presence of connections between elements and the ability to perform specified functions in the Arctic.

In order to distinguish between types of Arctic logistics systems, the broad concept of logistics formulated at the First European Congress on Logistics, held in Berlin in 1974, is adopted. The definition interprets logistics as the doctrine of planning, management and

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control of the movement of material, information and financial resources within various systems [1]. An analogous definition was developed by Boris Anikin. He defines the term “logistics” as follows: “Logistics is the science of managing flow processes in the economy” [2. p. 7]. In various sources, we find broader definitions of the term, e.g.: “Logistics is the process of planning, implementing and controlling the efficiency of the flow of raw materials, semi-finished products, finished products and related information from the point of origin to the point of consumption in order to satisfy consumer demand” [3–5].

Based on the broad interpretation of the concept of logistics, the following types of Arctic logistics systems are identified: the system for managing the country’s Arctic space, i.e. the Arctic industry or area; holdings and other possible forms taken by multinational corporations operating in the Arctic; production associations, enterprises, individual divisions, households and associations operating in the Arctic; the Arctic territory of the country, large economic Arctic areas, economic clusters in the Arctic, administrative-territorial units (cities, districts, villages), local territorial production complexes in the Arctic; global, national and local corporate or enterprise networks operating in the Arctic region.

Arctic logistics systems emerge and exist in the Arctic space. Any Arctic logistics system can be seen as a “living” organism. As such, it is born, develops, reaches its peak of growth, and then fades, transforms on a new basis, or dies. In other words, an Arctic logistics system goes through various lifecycle stages.

The lifecycle concept is developed for many objects: the product lifecycle in marketing; the lifecycle of an organisation; the software lifecycle; the lifecycle of a socio-economic system; the lifecycle of a complex technical system; even the lifecycle of a star. In all cases, the general presentation of the lifecycle concept is presented as a finite set of common phases and stages through which an object can pass during its life history [6, 7]. For Arctic logistics systems, the formulation of the system lifecycle concept does not significantly differ from the formulation of this concept for other objects. The only significant difference consists in the last stage. If, for all objects, the last stage is the final decommissioning of the object, in the case of the lifecycle of an Arctic logistics system, this final stage comprises a conversion, understood as a change in the system’s properties due to the integration of new elements. Consequently, the lifecycle of an Arctic logistics system covers various system states, starting from the moment the need for such a system arises and ending with its conversion. At the same time, the Arctic logistics system lifecycle does not comprise a temporary period of existence, but rather a process of successive changes in the state of the system due to the type of effects produced on the system due to its unique operating conditions.

The term “Arctic logistics system lifecycle” will here mean the evolution of the system in the form of several stages, including such important stages as concept, development, creation, operation and conversion.

The main methods for analysing complex systems are the block-modular method [8], morphological analysis, functional cost analysis [9], structural analysis and design [10], Continuous Acquisition and Life-Cycle Support (CALS) technologies, Structural Analysis and Design Technique (SADT) methodology [11], lifecycle assessment, Product Data Management (PDM) technologies [12] and the Product Lifecycle Management (PLM) methodology, which includes Product Data Management (PDM), a system engineering data management approach.

Of these various approaches, the most currently advanced are the CALS and PDM methodologies.

CALS technologies comprise a modern approach to the design and production of high-tech and science-intensive products, in which computer and modern information technologies are used at all stages of the product lifecycle to provide a unified environment for managing processes and the interaction of all participants. The concept, originally developed by the US Department of Defense, is aimed at ensuring continuous support for the supply and lifecycle of all kinds of products.

PLM comprises an organisational and technical system for managing information about products and related processes across the entire lifecycle, from design and production to decommissioning. For the purposes of PLM, various complex objects can be considered in terms of products.

The PDM system uses data integration technologies to manage all data relating to a particular product. On the one hand, such systems act as a repository for all relevant product data and interact with computer systems that create or use product data. The system is used to make data available to any participant in the product lifecycle who has the appropriate access rights. On the other hand, PDM systems are aimed at improving the efficiency of individual users. In this case, PDM serves as the user's working environment, providing him or her with the right data at the right time and in the right form.

Thus, a new direction is under active development in the global technological space: high-tech computer technologies for the design and engineering analysis of complex objects of various types [13–15]. The chief feature in the analysis of various complex objects is the direct and close connection of fundamental scientific knowledge with engineering methods and approaches based on computer technologies [16–18].

At the same time, when developing design algorithms and carrying out engineering analysis of various complex objects, a number of conditions reflecting reality inevitably fail to be taken into account. Here we will briefly least the most important of these. (a) Identification and analysis of alternative solutions. The presence of alternatives in the structure of objects of a different nature. The mandatory availability of alternatives should be considered a key feature of any effective solution. The set of alternatives comprises an ensemble of possible alternative solutions, which are necessarily listed explicitly. (b) The ability to represent decision-making problems arising under risky conditions. Risk assessment is an assessment of the outcome of a particular event in terms of its adverse consequences. The main risk parameters are: the amount of possible damage resulting from the occurrence of an insured event; the indicator of the probability of an insured event; the indicator of possible costs associated with the elimination of the consequences of the insured event and restoration of the previous situation; cost of lost profits.

Lifecycle models are characterised by a set of criteria whose assessment influences the decision to recognise a particular model as optimal. The following criteria are commonly used for this purpose:

– necessary resources (time, people, money,);
– complexity of the object (number of subsystems and novelty);

– cost of the object being developed, as well as the cost of upgrading it;
– predicted lifetime of the object.

Characteristic criteria for the optimal choice of an alternative solution for a complex technical object include reliability, manufacturability, efficiency, environmental friendliness, efficiency, productivity, quality and utility.

The purpose of the present work is to present a methodology for research and management of the lifecycle of Arctic logistics systems based on graph theory models and methods in combination with the PLM and CALS technologies for managing object data [19–21].

Models and methods derived from graph theory are used to analyse structural information, i.e. objects and processes whose structure is modelled by graphs and their generalisations (graph-model). The mathematical formulation of the problem of studying the lifecycle of the Arctic logistics system is carried out using a topological model in the form of a structural graph, allowing the process of obtaining a system of model equations to be presented in a generalised ordered form. Such a representation allows the graph theory methods and corresponding algorithms for solving the formulated problems [22].

As the most complete approach for solving CALS-related problems, the PLM methodology facilitates the complex application of modern information technologies with an emphasis on managing object data. Based on the use of integrated object data models, PLM envisions new ways of working with object information to allow tight integration with underlying processes and provide simultaneous access to data for different categories of employees. As such, it fully implements the principles of parallel analysis and object management.

2 Materials and Methods

2.1 Methodology of Research and Modeling of the Life Cycle of Arctic Logistics Systems: The Dynamic Cycle of Implementation of Research and Modeling Methodology

The basis for the analysis and modelling of the lifecycle of a particular Arctic logistics system is a cyclical procedure (Fig. 1).

The dynamic cycle diagram shows all the procedures that make up the essence of the research and modelling methodology for the lifecycle of Arctic logistics systems. These are as follows: statement of the goal and objectives of the development / modernisation of the Arctic logistics system lifecycles; selecting a concept for the development of the Arctic logistics system; development / modernisation of the lifecycle of the Arctic logistics system; selection of lifecycle implementation solutions; calculation of the financial, material, labour and institutional resources required for the implementation of each solution of the Arctic Logistics System; recommendations on the management system for the implementation of the Arctic Logistics System lifecycle (system of programme-targeted activities); monitoring the functioning of the Arctic logistics system at the stages of the lifecycle; comparison and evaluation; reasons for rejection; decision made as a result of comparison and evaluation; assessment of the effectiveness of the Arctic logistics system; revision and clarification of the goal; revision and clarification of the factors

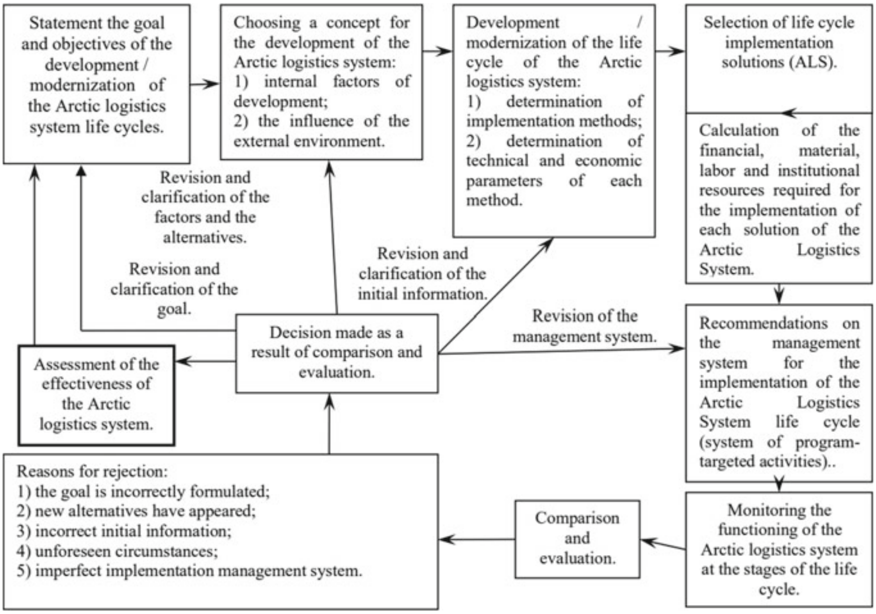

Fig. 1. Dynamic cycle diagram of the research and modelling methodology implementation of the Arctic logistics system lifecycle

and the alternatives; revision and clarification of the initial information; revision of the management system.

3 Goal-Setting Procedure

The composition and hierarchy of goals are formed on the basis of the development of the goal tree. As a rule, the goal tree has several levels of hierarchy. Each level has its own goal structure, comprised of subgoals relative to the final (general) goal corresponding to the highest, first, level. The goal tree comprises a structured goal-setting model based on a hierarchical principle. By means of this model, all the objectives of the Arctic logistics system can be represented and controlled. The goal model is displayed graphically as a hierarchical graph.

4 Procedure for Analysing and Modelling the Arctic Logistics System Lifecycle

The analysis and modelling of the Arctic logistics system lifecycle consists in a representation of the lifecycle in the form of a mathematical model.

Each stage of the lifecycle is displayed in the form of a graph. The graph G is denoted as G = (V,E), where V is a nonempty set of elements and E is a subset of the set $V^{(2)}$ of all its two-element subsets.

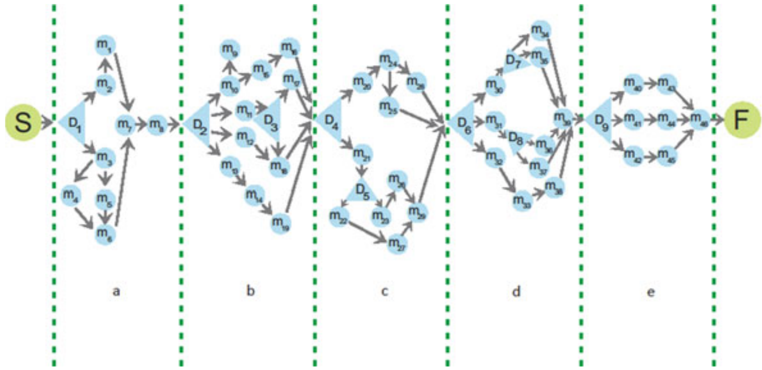

Fig. 2. Stages of the Arctic logistics system lifecycle

Figure 2 shows the structure of the lifecycle of the Arctic logistics system as a sequence of graphs.

Designation of graph elements:

Mi—i-th event of the lifecycle stage;

Di—i-th decision point.

Lifecycle stages:

a—Study of the problems of the Arctic logistics system;

b—Development (R&D) of an Arctic logistics system;

c—Creation / modernisation of the Arctic logistics system;

d—Operation of the Arctic logistics system;

e—Conversion of the Arctic logistics system.

Depending on the type of Arctic logistics system, as well as the goals of analysis and modelling, the stages of the lifecycle can be displayed in different types of graphs. Figure 3 shows an enlarged example of three types of graphs having different structures.

5 Procedure for Choosing the Best Option for Developing an Arctic Logistics System

The choice of the option is based on the ideas of dynamic programming for solving combinatorial problems when selecting a version of the Arctic logistics system that corresponds to the extreme value of the adopted objective function. The dynamic programming method applied to combinatorial problems consists in a method for finding an extreme path on a network. The combinatorial problem is solved by reducing it to a sequence of stages.

Using Bellman's principle of optimality, a system of recurrent equalities can be written in order to obtain a variant of the Arctic logistics system. For example, we may select the quality level of the Arctic logistics system as a criterion:

$$f_{i,w}(X_i) = \max_{Y_i} Q_i(X_i, Y_i),\ i = \overline{1, n} \tag{1}$$

$$Q_1(X_1, Y_1) = W_1(X_1, Y_1) \tag{2}$$

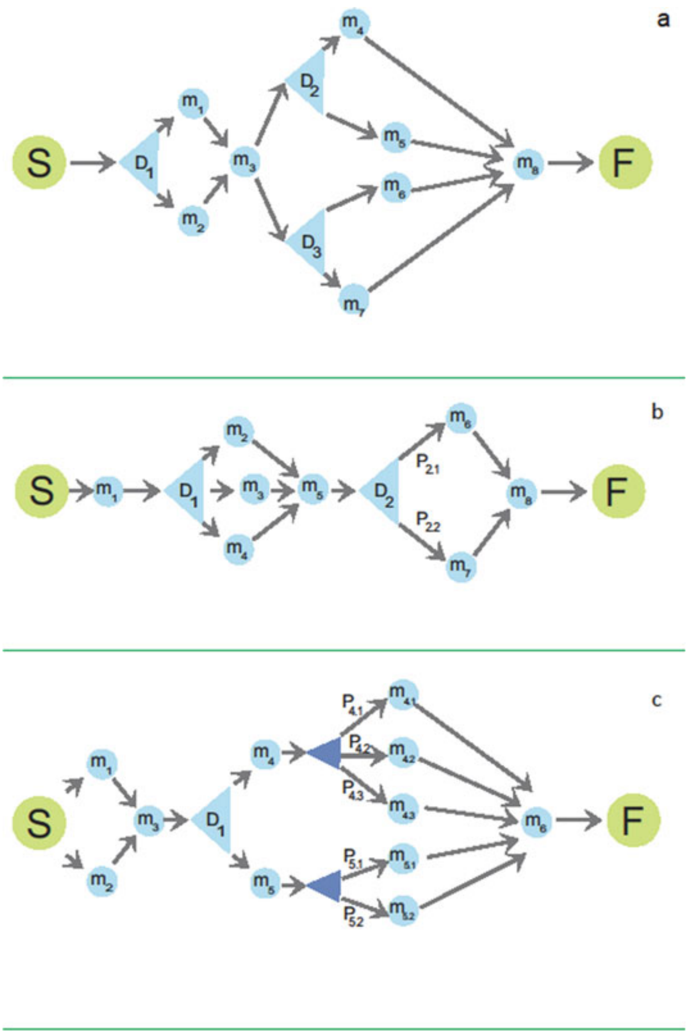

Fig. 3. 3 Types of graphs having different structures; **a** an alternative structure in the context of certainty of the implementation of the activities of the Arctic logistics system; **b** an alternative structure under the conditions of the risk of carrying out the activities of the arctic logistics system; **c** an alternative structure in the face of the risk of obtaining results when carrying out activities of the Arctic logistics system

$$Q_i(X_i, Y_i) = W_i(X_i, Y_i) + f_{i-1,w}(X_{i-1}) \tag{3}$$

where $f_{i,\mathrm{w}}(X_i)$ is the maximum quality level of the Arctic logistics system at the i-th stage as a function of the input variable (X_i); $Q_i(X_i, Y_i)$ is the results matrix for the i-th stage. The w-index shows that the problem of maximising the quality level of the system is being solved.

As a criterion for selecting an option, the minimum costs for the development of the Arctic logistics system, the minimum duration and the maximum probability of the implementation of the program for the development of the Arctic logistics system are used. The choice of the option for the implementation of the program for the development of the Arctic logistics system is carried out by solving several problems: (1) obtaining a decision-making system for the subprogrammes of the programme; (2) building matrices of decision-making stages for all schemes; (3) choosing an option for each subroutine; (4) selecting an option for the programme for the development of the Arctic logistics system as a whole.

A special procedure is used to construct the decision-making scheme for various different alternative structures.

6 Results

Selection of options for creating an Arctic logistics system according to a specific criterion.

Let us consider an example of one of the stages of the life cycle of the Arctic logistic system in order to present how the methodology for choosing options for creating an Arctic logistic system according to a certain criterion works.

Here, the goal is to develop an Arctic logistics system. We consider the stage of the lifecycle, i.e. the design of the Arctic logistics system. Let there be a design program for the lifecycle stage, depicted in the form of a graph of an alternative structure in conditions of certainty of the implementation of the activities of the Arctic logistics system (Fig. 4).

The alternative structure in the context of certainty of the implementation of the Arctic logistics system contains three decision-making peaks, ten alternatives and eighty-two programme activities. The problem of selecting a programme execution variant according to a predetermined criterion consists in selecting one alternative at each decision-making peak that meets the requirements of the criterion. For this purpose, the programme is presented as a sequence of stages. In other words, the programme for creating an Arctic logistics system can be represented as a graph of an alternative structure or as an equivalent decision-making scheme.

Bellman's principle of optimality allows the selection of programme execution options, one of which is characterised by the maximum level of system quality, while the other is characterised by having a minimal duration. All programme execution options are divided into two sets: one having many effective options, while the other has many ineffective options (Fig. 5).

As can be seen from the figure, the set of many effective options allows the maximum level of quality to be obtained.

7 Discussion

Our case study demonstrates the feasibility of our approach and allows (a) to identify work options, if known a priori, (b) quickly test a large set of alternatives, (c) effectively take into account the impact of alternatives on the outcomes of the system, (d) generate other types of impacts on the life cycle of the Arctic logistics system, such as the

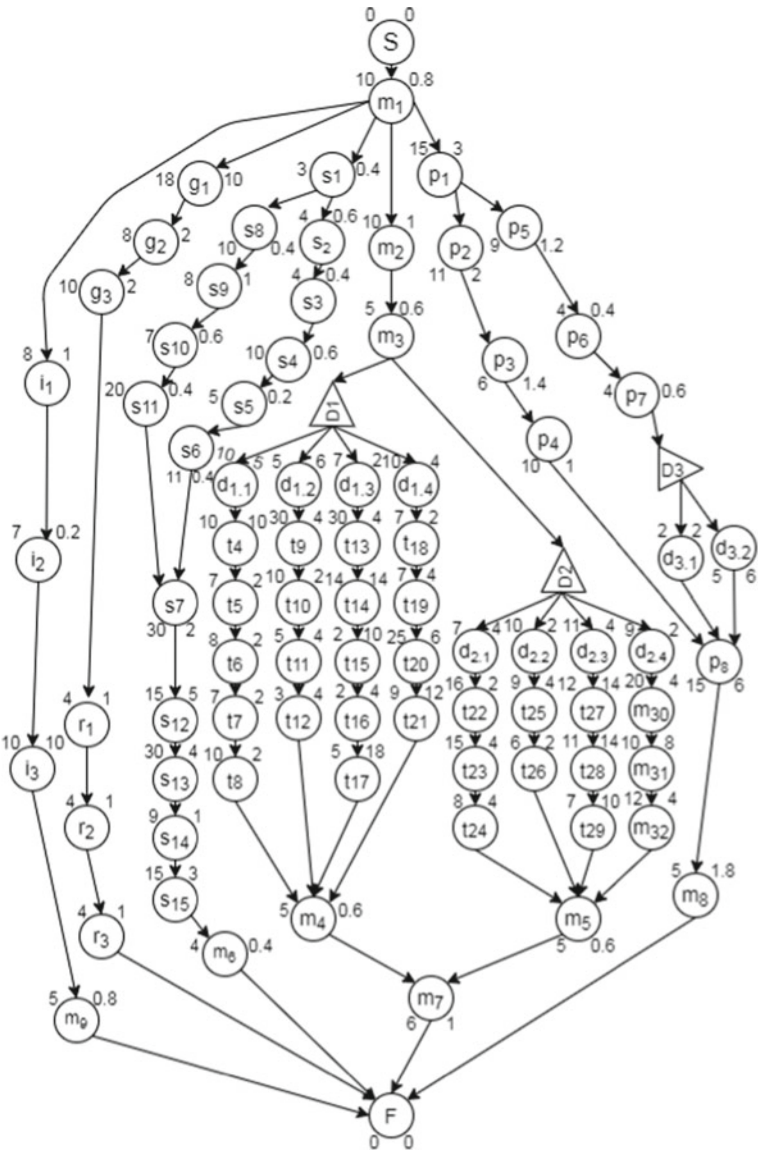

Fig. 4. Alternative structure of the graph in conditions of certainty of the implementation of the activities of the Arctic logistics system

impacts of climate change, based on the function and context of use of the system, and (e) progressively expand the scope of the assessment of the life cycle of Arctic logistics systems, where necessary, to identify appropriate trade-offs.

Our approach also has several limitations. The nature of life cycle modeling and performance estimation requires several assumptions. We have used generic or default

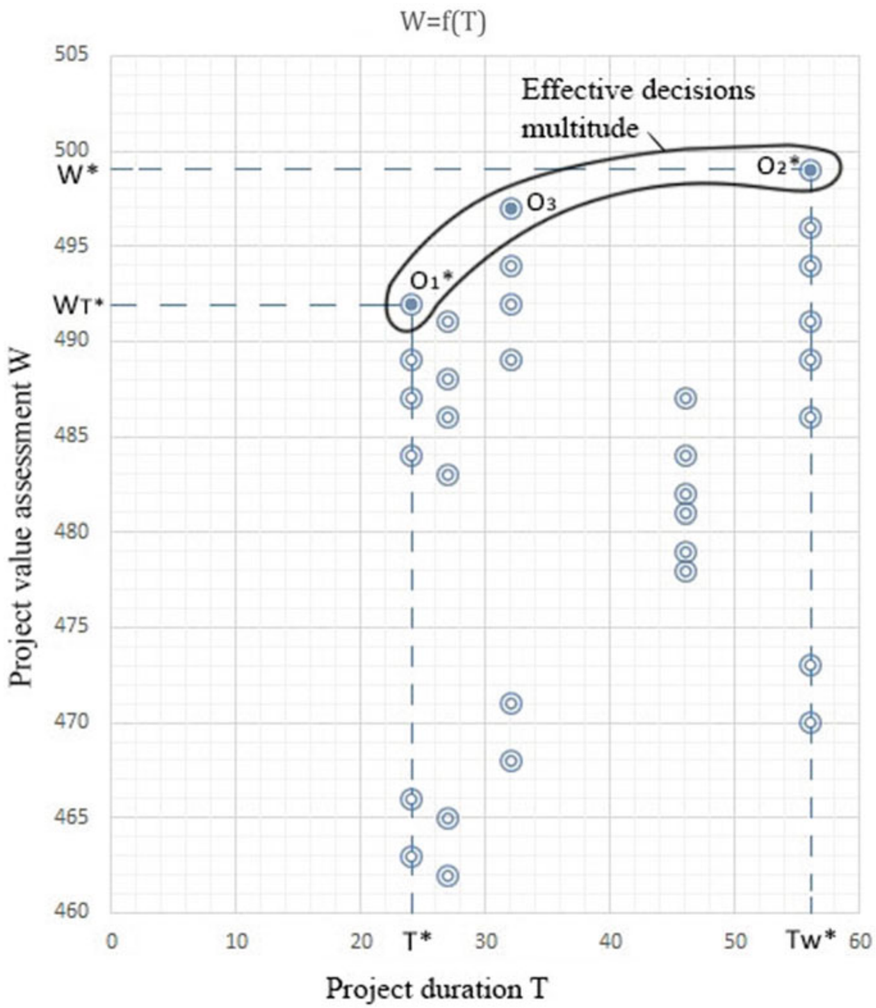

Fig. 5. Multitude solutions for creating the Arctic logistics system

values for the various inputs, which should be adapted whenever case information is available.

For some works, there is no data on their parameters. Despite its limitations, our methodology is nevertheless useful to use.

At present, the most common trends in the application of the theory of networks and graphs are: analytical model for information gathering and propagation in social networks using random graphs [23]; modeling of dynamic characteristics and technological features of high-tech equipment [24]; identification of factors that allow simulating various scenarios for the development of systems and processes [25].

Obviously, the main toolkit of graph theory allows one to formalize mathematical models of the dynamic characteristics of complex objects. Usually in scientific research

[26], the processes and stages of the life cycle of products and companies are studied with the aim of managing and minimizing the risks of ineffective management. The approach in our work also allows us to form the concept of a digital twin of the Arctic logistics system.

Future research needs and the way forward.

Lack of data on the parameters of the work. Such missing data should be thoroughly discussed in any study with current guidelines. More generally, we propose the following approach to address missing data: first, a systematic review is carried out to identify potential information. Second, both a regression approach providing a point estimate and a nonparametric analysis providing distributions are proposed. Recent advances in machine learning, such as random forest algorithms or neural networks, provide better estimates than pure regression and can be used in research to estimate job parameters.

8 Conclusions

The result of the study is a list of tasks that can be solved in the context of the methodology for using alternative graphs to study the life cycle of complex Arctic logistic systems.

1. Analysis of the initial state of the problems of the Arctic logistics systems in the context of the complex impact of environmental factors.
2 Formation of the composition and hierarchy of goals of the Arctic logistics systems.
3. Generation of scientific, technical and organisational alternatives for performing work / activities, taking into account a given goal.
4. Analysis of the deterministic structure of the Arctic logistics system.
5. Analysis of the alternative structure of the Arctic logistics system.
6. Analysis of the Arctic logistics system in the context of structural uncertainty of the programme for the creation of the system.
7. Analysis of deterministic information on the implementation of scientific, technical and organisational work / activities, taking into account the set goal of the Arctic logistics system.
8. Probability analysis of information on the implementation of scientific, technical and organisational work / activities, taking into account the set goal of the Arctic logistics system.
9. Analysis of information under conditions of uncertainty of the implementation of scientific, technical and organisational work / activities, taking into account the set goal of the Arctic logistics system.
10. Construction of the concept of a digital twin of the Arctic logistics system. The system's digital twin is a digital copy of the interrelated sub-processes that form the Arctic logistics system. The concept of a "digital twin", which has emerged from discourses around the fourth industrial revolution, is aimed at helping decision-makers more rapidly identify problems, predict their results and thus make informed decisions.

From our perspective, the digital twin of the Arctic territory presents a dynamic digital profile of this territory, containing both a priori and a posteriori data on the processes occurring in the Arctic logistics system. The digital twin is based on a huge amount of data underpinning various indicators of objects and processes existing and occurring in the Arctic logistics system. The analysis of the accumulated data allows the system to be considered from different angles in order to obtain information about the options for such a system, as well as supporting conclusions about the need to make changes to the various processes occurring in the Arctic logistics system.

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Digitalization of Geo-Information Support for Energy Logistics in Climate Change

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Abstract. The paper considers results of digitalization of geo-information support to energy logistic within Industry 4.0 period, under conditions of a COVID-19 pandemic and climate change. The research uses web technologies, methods of building databases, virtual reality tools. Also, there are used Foresight technologies, theory of decision making and risk management. As digitalization essential tools, it is proposed to use digital online platforms, which integrate heterogeneous hardware and software resources with the use of web-technologies in distributed networks and wide application of cloud services. The study uses databases and tools of geographic information digital online platforms Earth and EOS, including its Land Viewer product. As study result, there are demonstrated usage of digital geo-information support system for first Russian floating nuclear power plant Akademik Lomonosov at seaport of Pevek. The research results presented in this article has significant scientific novelty and can be useful for private investors, public environmental organizations of the civil sector and state environmental control bodies.

Keywords: Digitalization · Geo-information support · Energy logistic

1 Introduction

Recently, energy logistic (EL) is functioning in Industry 4.0 period, and when while covid-19 pandemic and climate change. In this period, many businesses are planning and implementing a wide range of information technologies [1–10]. Industry 4.0 leads to serious information technological changes in EL, including natural risks management (NRM) [11–17], which requires new tools development, including practical learning area [18].

The purpose of this article is to develop digitalization tools for geo-information support systems (GISS) to EL while climate change and Covid-19 pandemic. In paper, we describe the development results of digital tools GISS to EL within geo-information management (GIM) paradigm [19–22], in large environmental projects [23–27] within environmental economics [28–32]. We paid significant attention to GISS within climate

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change [33, 34] and Covid-19 pandemic context, including the issues of information collection and processing. Developed digital technologies, considered in this paper, take these factors into account.

2 Materials and Methods

In research, we used theory of decision making under uncertainties, risk management approach, Foresight technologies, methods of data bases constructing, web-technologies and virtual reality (VR) tools. Also, we used big data and Internet of things technologies [19, 23]. From the point of view of geo-information management, geo-space is structured to allocate the interconnected components of the solution space [28]. While study, we used data bases and tools of geo-information digital online platform (GIDOP) EOS https:www.//eoscom/., including its Land Viewer (LV) product https://www.eos com/lv/., which allows limited open access to operate space images from the Landsat-8 and Sentinel-2 satellite systems.

3 Results

As a result of performed using foresight technology research, we put forward the claim that in present conditions of Covid-19 pandemic and climate change, it would be advisable to develop EL infrastructure projects (ELIPs) with the aim of geopolitical risks management because of different sanctions and ecological restrictions of different states. NordStream-2 marine pipeline can be excellent example. Preference should be given to those ELIPs, where climate change leads to an improvement in their overall operating conditions, for example, a reduction in the timing of sea ice risks. As GISS basement, we propose to use the tools of GIDOP EOS https://eos.com/, including its Land Viewer (LV) product https://eos.com/lv/.

As an example, we consider ELIP with first Russian floating nuclear power plant Akademik Lomonosov at seaport of Pevek. From open sources, it follows that at the end of August, the floating power plant (FTPP) Akademik Lomonosov was delivered to Chukotka with the help of tugs. This event was widely covered in the media, including Reuters. Soon, on December 19, 2019, it entered service in the vicinity of Pevek. This FTPP is the first of many similar ones planned for sale in the global energy market. In Fig. 1, we present general view of FTPP Akademik Lomonosov at Pevek on computer made image while project stage, taken from open source. The commissioning of the station raised a serious question about geo-information and geo-ecological support for its operation in the Far North, as well as about similar support for next FTTPs.

Our analysis shows that there will be significant natural risks for the created natural-industrial system (FTTP itself, auxiliary structures, urbanized surrounding territories and port water areas) due to low air temperatures, strong winds, stationary and drifting ice fields, ice piles, hummocks, long waves, as well as a number of other phenomena in the atmosphere, lithosphere, hydrosphere and biosphere, including sediment movement, algae blooming, siltation, fouling of the floating hull and water intake channels. We propose to solve this problem with geo-information and geo-ecological support system

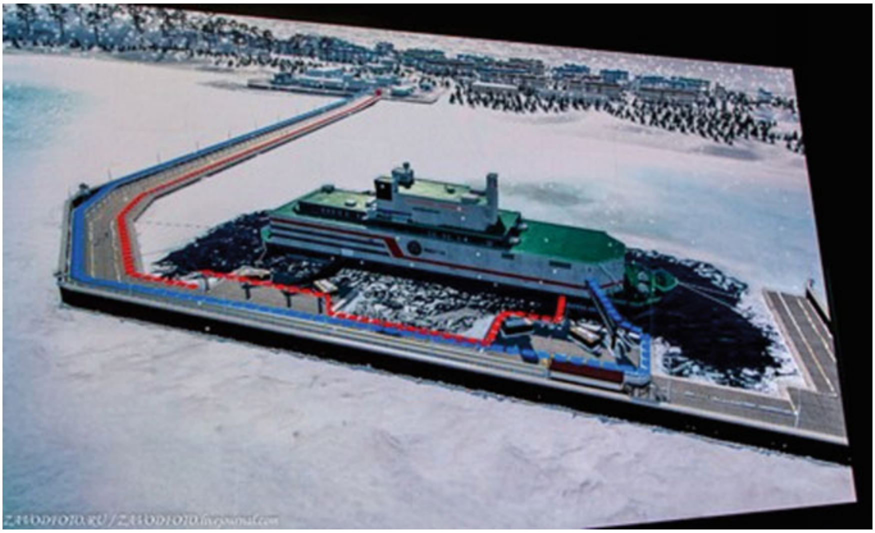

Fig. 1. General view of FTPP Akademik Lomonosov at Pevek on computer made image while project stage

(GIGESS), based on open source geo-information digital online platforms (GIDOPs) Earth https://eos.com/, including its Land Viewer (LV) product https://eos.com/lv/.

Let's move on to the example of using the proposed GIGESS for FNPP Akademik Lomonosov (here and after simply FNPP). A striking feature for its seasonal operation mode is formation and destruction of the ice cover around it. The greatest interest is in spring, when the solid ice field around the station begins to collapse and move, and drifting ice fields with a significant thickness of ice appear. Such fields can be piled on the protective hydraulic structure around the FNPP, and the force of the pile depends on the size of the ice field itself, as well as the strength and direction of the wind acting on it. In Fig. 2, we present port of Pevek space image on 12th May 2020 visualized with Atmospheric Removal Application of LV (green rectangular marks FNPP's area). You can see that the entire water area is occupied by a stationary ice field of a complex spatial structure with variable thickness and the presence of numerous cracks. It can be assumed that as this ice sheet melts, separate drift ice fields with different ice thickness will form.

In Fig. 3, we present port of Pevek space image on 5th June 2020 visualized with Atmospheric Removal Application of LV (red hexagon marks FNPP's area). As you can see, in a short period of time the stationary ice field broke up into a set of drifting ice fields with different ice thickness. The greatest danger to FNPP is represented by set of large drifting ice fields located above and to the left of the red hexagon. With a northwesterly wind, they can approach and attack the FNPP's protective hydraulic structures.

In Fig. 4, we present space image of seaport Pevek on 15th June 2020 visualized with Atmospheric Removal Application of LV (red hexagon marks FNPP's area). As you can see, inside red hexagon that marks FNPP's area there is large drifting ice field (greenish

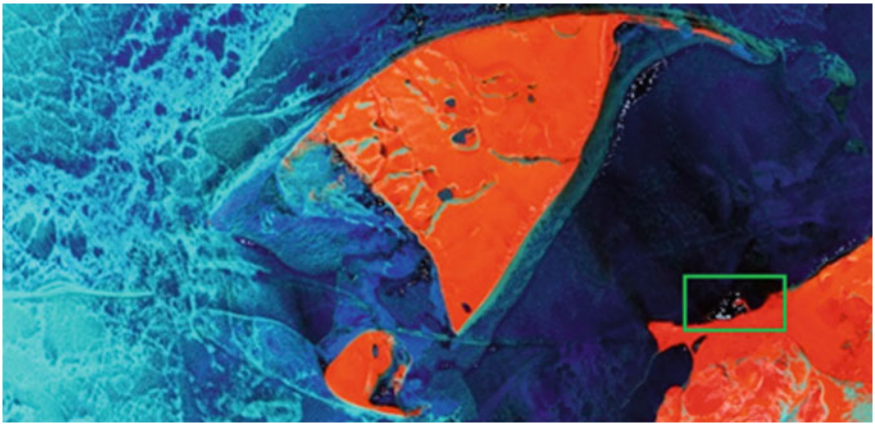

Fig. 2. Space image of Pevek seaport on 12th May 2020 visualized with Atmospheric Removal Application of LV (green rectangular marks FNPP's area)

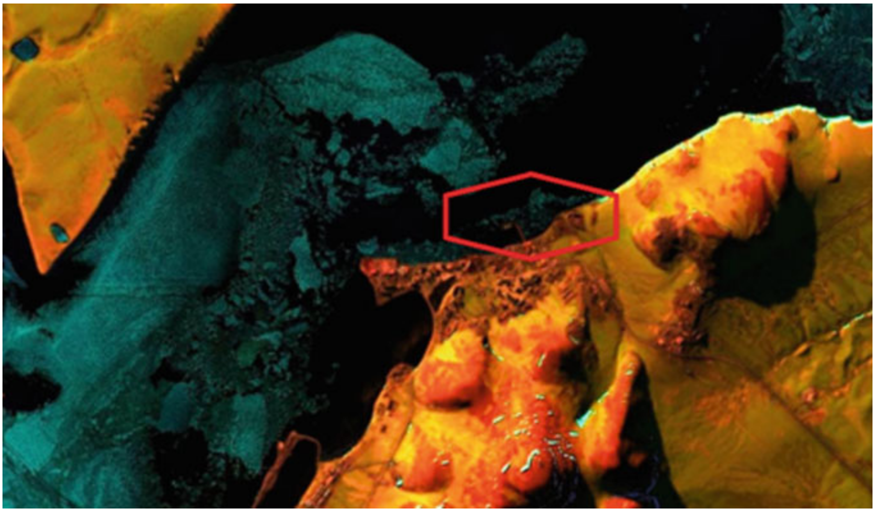

Fig. 3. Space image of seaport Pevek on 5th June 2020 visualized with Atmospheric Removal Application of LV (red hexagon marks FNPP's area)

area) which attacks the FNPP's protective hydraulic works. The maximum length and width of attacking ice field measured with LV was 1.65 km and 0.658 km.

Analysis of the wind field on 15th June 2020 in the vicinity of FNPP's area (Fig. 5) showed that the attacking ice field was affected by a northwesterly wind at a speed of about 7 km/h.

Note, above mentioned data allow us to calculate the quantitative characteristics of the impact of the attacking ice field on the FNPP's protective hydraulic structures but this is not the purpose of this article. As essential research result, we can recommend

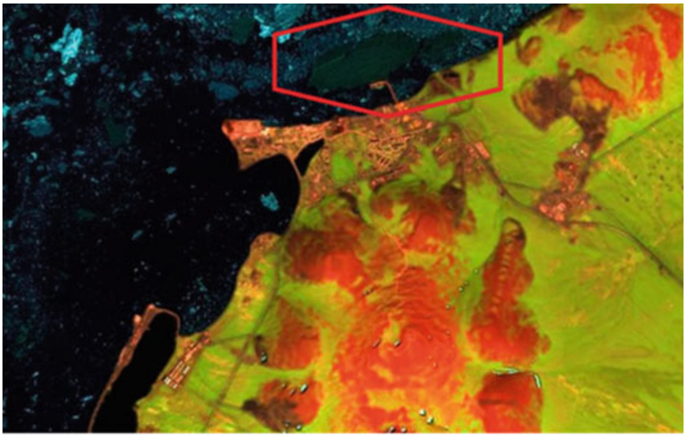

Fig. 4. Space image of seaport Pevek on 15th June 2020 visualized with Atmospheric Removal Application of LV (red hexagon marks FNPP's area)

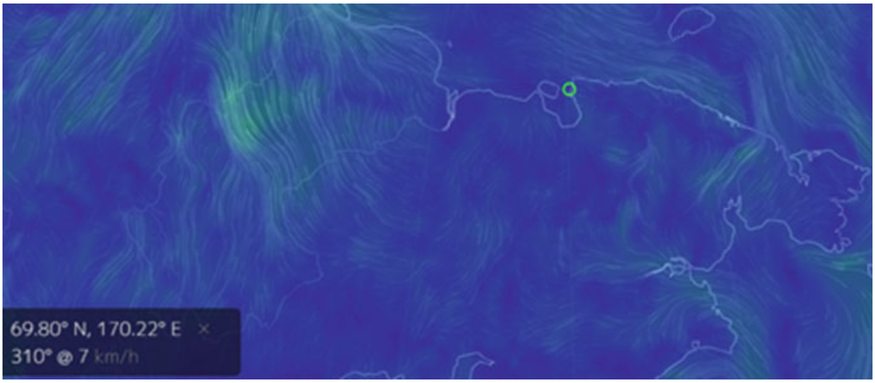

Fig. 5. Wind field at FNPP on 15th June 2020 visualized with GIDOP Earth

the developed GIGESS for FNPP Akademik Lomonosov as basement for subsequent FNPPs in the Arctic.

4 Discussion

Presented above low-cost GIGESS for FNPP *Akademik Lomonosov* can be used in training and educational tasks. The essential purpose of university practical learning (UPL) in the field of EL will be to teach students the practical aspects of work with GIGESS for FNPP *Akademik Lomonosov* tools, which requires a developed learning base within special geo-information systems (GIS) laboratory. In some cases, real practical work instead of special GIS laboratory can be undergoing with virtual reality (VR) technologies [18], that can do the learning process adapted to Covid-19 conditions and reduce its total cost.

5 Conclusions

In paper, we consider digital tools development results for geo-information and geo-ecological support system (GIGESS) to floating nuclear power plant (FNPP) in Arctic. In research, we used methods of data bases constructing, web-technologies and virtual reality tools. We suggest to use geo-information distributed online platforms (GIDOPs), as the main technological tools of digitalization in the tasks of geo-information and geo-ecological support for energy logistic infrastructure projects (ELIPs). As study result, we demonstrate usage of digital geo-information support system for first Russian floating nuclear power plant (FNPP) Akademik Lomonosov at seaport of Pevek. As essential result, we propose to use developed GIGESS as basement for subsequent FNPPs in the Arctic, including training and educational purposes. In study, we used data bases and tools of geo-information digital online platforms Earth and EOS, including its Land Viewer product. The research results presented in this article has significant scientific novelty and can be useful for private investors, public environmental organizations of the civil sector and state environmental control bodies. They can be used in training and educational purposes, including development of Master's programs in environmental economics.

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Digital Methods of Warehouse Logistics as a Tool to Accelerate Supply Chains

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Abstract. Accelerating supply chain links increasingly becomes a competitive advantage in satisfying demanding customers. A quick response to a customer's request increases the chances of success. This article discusses digital methods of warehouse logistics (including robotization of warehouses) as a tool to accelerate the link of warehouse logistics in the supply chain. The most successful cases of robotization of warehouses are considered. Based on the results of the considered cases, the barriers to the robotization of warehouses are identified. Indicators affecting the acceleration of the supply chain, as well as changes due to the introduction of digital technologies in warehouses, are determined. Conclusions are made about the existing waves of robotization, reference models of these waves are built, and conclusions are drawn about the advantages of modernizing warehouse logistics. The main indicators are considered due to which the effect of accelerating the supply chain is achieved. Possible directions for future research are considered.

Keywords: Warehouse logistics · Supply chains · Robotization · Digital methods

1 Introduction

The main principle on which modern logistics is built, is a high speed of response. In today's reality, the speed of response should be within the time of the client's patience. At the moment, the modern world has such capabilities that any product can be delivered or manufactured according to the needs of a specific client. However, such actions significantly slow down the response rate. This explains why logistics is not ready to give up stocks and storage: the client simply is not willing to wait for an order. That is why in the competition for the consumer, the winner is the one who delivers faster,

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given that all other metrics are equal. This raises a completely logical question: how to increase the speed of response to a consumer's request? First of all, a high speed of response can be achieved by accelerating supply chains, including by speeding up the work of individual links. The place of warehouse logistics in the supply chain is shown in Fig. 1.

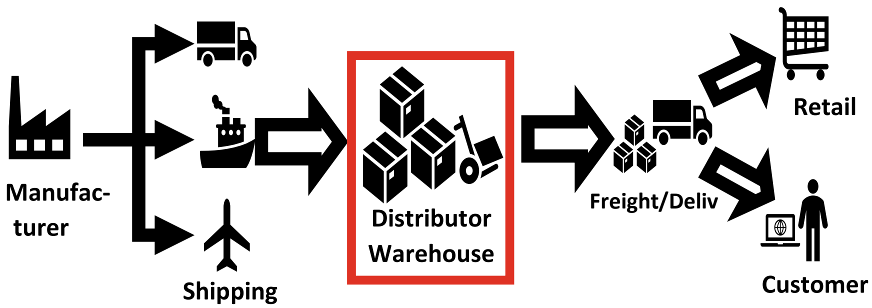

Fig. 1. Warehouse logistics place

The purpose of this article is to study the impact of the introduction of robotic warehouses on the acceleration of the warehouse logistics link in the supply chain.

2 Materials and Methods

The main research method in this article is the analysis of sources (company experience) and supply chain modeling. Materials are an analysis of existing robotic solutions for warehouses, an analysis of their implementation cases.

Let's take a look at some of the most interesting cases of the implementation of robotic warehouses.

Currently, the real giants of the warehouse robotization sphere are global companies as Ocado, Amazon and other major online stores. Thousands of robots live their lives packing groceries, moving shipping orders and accepting new goods. It seems that this is a single living organism, living according to its own laws. First of all, we will consider the mechanism of operation of robotic warehouses.

Ocado has a specificity of working with goods: it is the largest retailer in the UK that delivers food to your home. Huge warehouses are located on the outskirts of Birmingham and London. The scale is huge: these warehouses handle 1.03 million orders every day. Obviously, food is a perishable commodity in terms of storage. Any delay in the warehouse or on the way can result in losses for the company [1]. How did you manage to achieve such results?

Ocado spares no expense in the development of logistics infrastructure and warehouse robotization. However, it is not possible to completely abandon human labor. The workers sort the goods at the stage of receiving, placing the order and at the very end of the process: the rest of the work is done by robots. The new warehouse of the company is a network of conveyors with an area of about 560,000 m^2 with a total length of 25 km.

Initially, the products are sorted by the workers and placed on shelves, from where robots deliver them to the storage area. After processing a specific order, the robot collects the desired product into a container by reading the bar codes, then the container is delivered directly to the delivery van.

The performance of such a system breaks all records: for example, an order of 50 items of goods is formed on average in two to three minutes (after 10 min the container with the order is already in the van), while a person in a regular warehouse will take at least three to four hours.

"Lowest Cost—Highest Delivery Speed" is Amazon's basic rule. In total, at the moment, about 50 thousand employees are working in Amazon warehouses. Back in 2016–2017, during the peak months (Christmas, Black Friday, Cyber Monday), the company additionally hired temporary employees, the number of which was about 120 thousand, which at that time was one third of all employees of the company [2]. It is not difficult to calculate how much the staff has decreased during this time. In addition, in 2018, the organization was embroiled in a major government scandal that forced it to raise wages for workers in the US and UK [3]. All this had a significant impact on making the choice in favor of robots. For the Christmas season 2018–2019, 20 thousand fewer temporary employees were hired.

Let's take a closer look at how Amazon warehouses work. The person carries out the selection and picking of the order. Robots do the rest. Console manipulators move racks with goods, floor-mounted automatic carts are guided by QR codes located on the floor. Packaging, weighing, packing of goods is carried out only on an automatic line. The entire warehouse works on the principle of chaotic warehousing (goods are arranged in a random order, which helps to save space).

The machines for Amazon are being developed by Kiva Systems, which was acquired and later renamed Amazon Robotics. The orange conveyors, moving shelves of goods, began to appear in warehouses in late 2014, as a test.

By mid-2016, it became clear to what extent robots can actually help Amazon's online store. The little metal helpers learned to do more sorting, picking, packing, and shipping tasks in 15 min than a human employee could do in an hour. Thanks to this, the company even then reduced operating costs at 13 warehouses by 20%—$ 22 million for each warehouse (here it should be kept in mind that Amazon's warehouses are gigantic, each equivalent to twenty football fields). Moreover, the advantages of robots were not only in their speed—and the absence of requirements to increase the minimum wage. It turned out that in a room with them, you can save on heating. Machines are not as demanding on working conditions as people, and they even enjoy the cold in the warehouse. Plus, in a warehouse equipped with robots, each square meter can potentially accommodate 50% more goods—by reducing the distance between the shelves. Small robots need much less space to move than humans.

It is important to note that Amazon never mentions how many people in its warehouses it manages to replace with machines. In 2018, information was leaked to the press that there were more than 100,000 robots in warehouses. However, this is not total robotization.

Chinese companies have achieved the highest results in robotization. In Shanghai, at the warehouses of JD.com, the process is built in a completely different way than at

Amazon, where robots only greatly simplify the work of a person. In such a warehouse, a person only serves the mechanisms, while robots do all the rest of the work: from labeling barcodes to packing and loading.

For robotic control at the warehouse, a computer vision system was introduced, which checks the quality of the packaging at the exit and rejects some of the products that do not meet standards. As a result of this implementation, the company has achieved stunning results: the parcel is delivered within 24 h to anywhere in China if the order was placed before 11 am. According to representatives of the company, robots perform up to 16 thousand packages per hour, with an accuracy of forming orders of 99.99%, and to service a warehouse of 9,000 m^2, it is enough to employ only 4 qualified workers.

Speaking about the robotization of warehouses, we must not forget about the disadvantages that may arise. Already in mid-2019, Amazon announced that it was suspending the total robotization program for 10 years. What is the reason? The reason is that the robots lacked "human qualities." Experts at Amazon were faced with the fact that robotics skills are too limited to be fully automated. A corporation needs machines that can carry several items at the same time or take the desired item from the basket (not to mention the fact that each item has a different density and the robot can simply crumple it). For now, Amazon continues to use robots only to carry and distribute various categories of goods.

In addition to the shortage of skilled robots, Amazon has another problem—the safety of human employees. In most cases, robots simply do not see a person, and therefore can accidentally place a load on him or knock him down. To keep people safe from injury, Amazon began giving employees special sensor braces that scare away robots and prevent them from getting close to humans. At first, the corporation tried to prescribe for each robot a site where it was forbidden to be, but the method turned out to be costly and not so effective [4].

3 Results

In the management of modern warehouses qualitative changes, such as changes in the storage structure were identified. In order to increase the speed of response, effective management of stock in the warehouse is necessary. Efficiency in inventory management is achieved by reducing the minimum supply quantum. In fact, more assortment appears on the same warehouse areas [5].

Hence it follows that with an increase in the assortment, the storage quantum decreases. The concept of "pallet storage" disappears from warehouses. Due to the fact that the goods are stored in small batches, the number of operations associated with acceptance, storage, search, delivery of goods to the place of order assembly increases by one item. In these conditions, the capabilities of the personnel are limited. First of all, we are limited by the warehouse space. A huge number of people are needed to ensure a high speed of response. A large number of people, taking into account the amount of human error, will lead the warehouse into a state of chaos. That is why there is a need for robotization of warehouses [6].

After analyzing a large number of sources, it was possible to understand that now the world is on the verge, conditionally, of the second wave of warehouse robotization, but cannot enter it in any way. Let's take a closer look at what the wave of robotization means and why there are obstacles to development [7]. First, let's consider how the process of forming an order in a warehouse without robotic elements occurs. This process is presented in detail in the metamodel in Fig. 2:

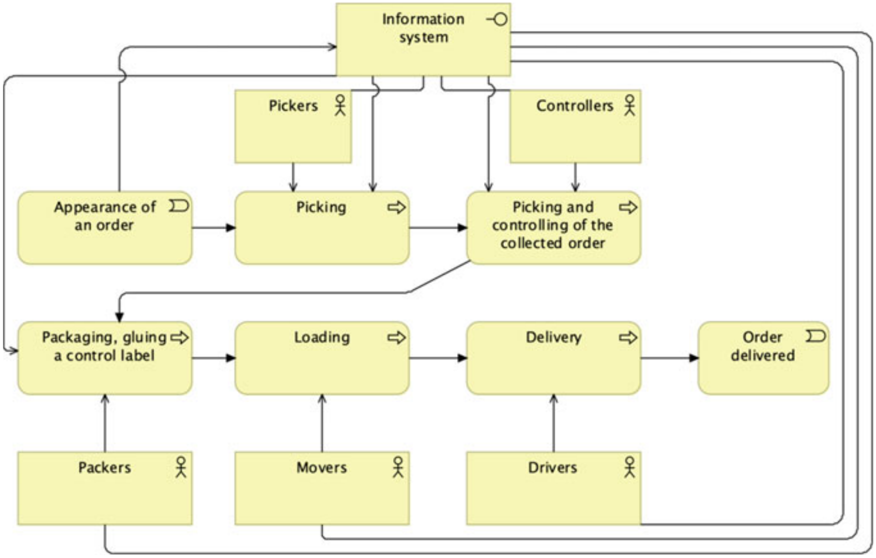

Fig. 2. "As is" metamodel of the order forming process in the warehouse without the use of robotization

The model reveals the process of forming an order in the warehouse, which ends with the delivery of the order. In this case, the process does not imply the use of robotic elements, all processes are performed only through the use of labor. Each stage uses an information system for accounting, data reconciliation, and so on.

Let's move on to the waves of robotization and look at the changes. Conventionally, "The first wave of robotization of warehouses" was to carry out the movement of goods without human intervention. Modern vehicles for moving goods are controlled by lasers, magnetic markers or wires, which act as crutches in the absence of effective AI and machine vision algorithms. Magnetic striping is the most common solution. Magnets mounted in the floor are used to move cars. An alternative technological solution is computer modeling of the warehouse topography with digitization of all movement routes, as well as the use of geolocation. But planning solutions of buildings do not always allow using these algorithms [8]. Thanks to the introduction of such systems, indicators such as: order picking speed, delivery speed and others are significantly improved. The metamodel of the process of forming an order in a warehouse that has passed the first wave of robotization is shown in Fig. 3.

This model reveals aspects of the first warehouse robotization. It is clear from it that people stop performing some processes and robots come to the rescue. First of all, robots are used in the process of collecting orders and packaging, however, people still

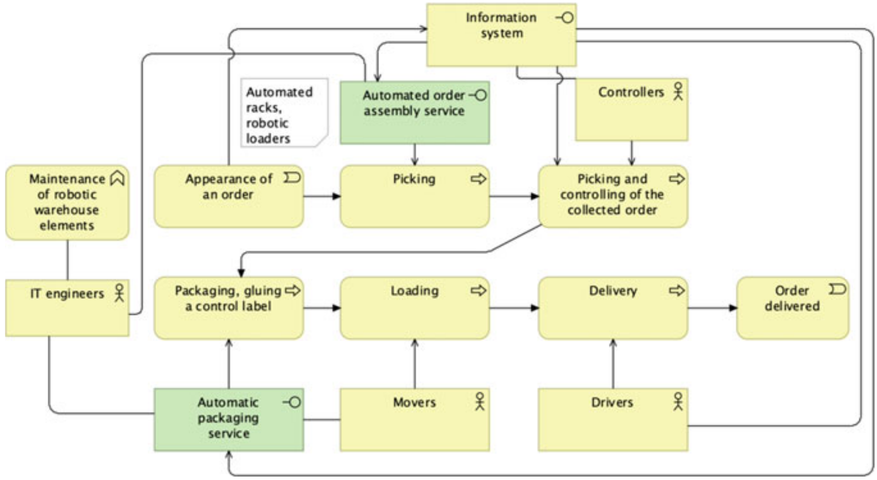

Fig. 3. The order forming process in a warehouse that has passed the first wave of robotization

continue to control robots, independently load cars with orders. All processes are linked in a single information system [9]. In addition, there is a new position of IT engineers who service the robotic elements of the warehouse.

The first wave ended successfully and companies wanted to go further and abandon the human workforce altogether. At that moment, the "Second wave of warehouse robotization" came, which, at the moment, turned out to be much more difficult than the first [10].

A metamodel was developed for the order forming process in a warehouse that went through the second wave of robotization. This model is shown in Fig. 4.

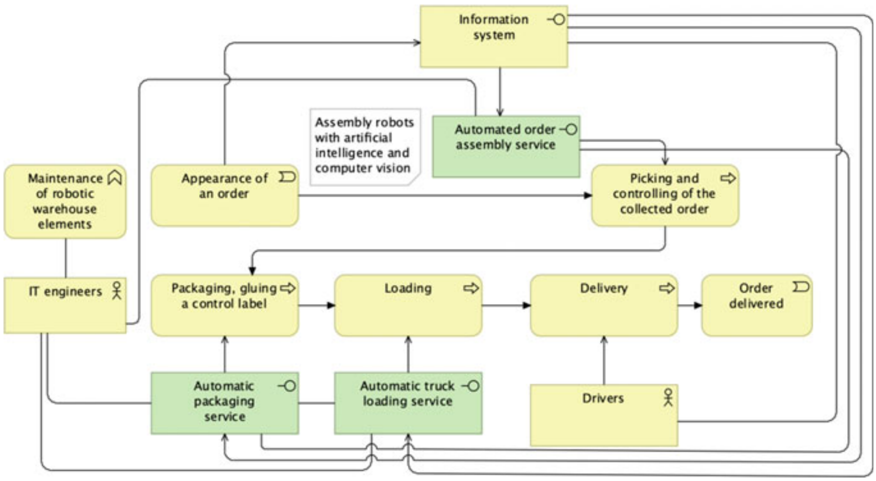

Fig. 4. The order forming process in a warehouse that has passed the second wave of robotization

In this model, human activity almost completely disappears: the processes from receiving an order to loading it into a car are fully automatic, using robots with artificial intelligence. Human influence can only be traced in supporting these robots and in delivering orders. In addition, the very duration of the process is reduced, due to the fact that the process of "control" disappears, which is now included in the assembly of the order and is carried out by the robot on site [11].

Obviously, the abandonment of labor will have a beneficial effect on the price of goods, costs, and so on. Moreover, a person is a significant source of errors: from improper packaging of goods to accidents and damage to goods [12, 13].

What are the difficulties of implementation? First of all, at the moment, it is extremely costly. In addition, the second wave of robotization requires the introduction of artificial intelligence. Now there are commercial systems that do not require marking on the floor—they are guided by machine vision mechanisms with image recognition based on built-in AI [14, 15]. This aspect is already real in our time, however, things are more complicated for AI with the recognition of warehouse units and cargo. The problem is solved using auxiliary labels or barcodes. However, these are only supportive measures, not a solution. The fact is that robots may not perceive an object if it does not exactly match the image that AI technologies have worked out [16, 17]. For example, it is enough to wrap a rectangular box with tape so that the robot stops recognizing the silhouette. Even an elementary dent on the box can throw the algorithm into a stupor. This was the reason that Amazon has suspended its campaign for total robotization of warehouses.

4 Discussion

Since the main objective of the article was to study the increase in the throughput of warehouse logistics, some side aspects of the introduction of digital technologies in warehouses were omitted. As future developments on the topic, it is necessary to consider the possibility of using other modern technologies from the near-warehouse areas, for example, the transfer of shelf control technology from the field of merchandising to the field of warehouse logistics.

Changing cost structures could also be considered as future research on the topic.

5 Conclusions

By the end of the work on this article, the authors show the following results. Despite the emerging problems with the introduction of the second wave of warehouse robotization, we can already say that it will be real in about 10 years, since there are many prerequisites for this:

- Advanced AI and computer vision systems have learned to confidently recognize a person. Any person has a unique body geometry that can be noticed by robots: the characteristic curve of the transition of the foot to the leg at the level of the ankle. This unique geometry is used in AI image libraries to prevent accidents.

- The accuracy of cargo recognition and the necessary custom orders in the warehouse can be increased by training the technical vision on "non-obvious" forms. This technology is implemented in the field of merchandising to control the shelf. The main difficulty is that the AI must train for more than one thousand hours. For comparison: only a thousand hours is a month and a half of round-the-clock training.
- Automated each picking, i.e., automated order picking at item (eaches) level may be cumbersome, especially for such diverse objects as wrenches, banknotes, coins, rubber bands, etc. You need a universal gripper applicable to all of them. Automated case picking is much easier. Here, the idea of Physical Internet (Montreuil; 2017) may come to the rescue. It is based on the concept of internet data transfer applied to physical transfer of goods. The idea is to place goods in standard boxes containing encapsulated information, usually via Internet of Things to identify the package and to route it to the right destination.

These prerequisites allow us to say that at the moment we are preparing to enter the second wave of warehouse robotization.

It is difficult to argue with the fact that the use of robotic lines significantly reduces the time of delivery and order processing, analysts around the world argue that a robot can oust a person from logistics structures. A large number of arguments support this position. Let's summarize the analyzed cases and draw conclusions:

- Thanks to robots, the storage density of goods is increased. With the same warehouse area, it can hold more space. Plus, robots need less space to move around.
- People in the warehouse are a significant source of errors. How can these errors manifest themselves? Assembly accuracy, re-grading, assembly speed and so on.
- The emergence of a competitive advantage, which is expressed in a significant acceleration of the warehouse logistics link.
- Lack of manpower reduces the cost of wages and other deductions. There is also the possibility of reducing utility costs.

The effect of robotization of warehouses is achieved primarily due to changes in the following indicators:

- Speed of response;
- Time of order assembly;
- Precision of assembly;
- Storage density;
- Throughput capacity of the warehouse;
- Cost structure.

However, all these advantages can be broken down by the huge requirements that a robotic warehouse makes during implementation. First of all, these are colossal one-time capital investments. Investments will go to the development and configuration of infrastructure, organization of address storage, adjustment of machines, implementation and configuration of a powerful information system and the like.

With the introduction of robotic warehouses that accelerate the specific link in the supply chain, at the same level of fixed costs, significantly higher indicators can be achieved, despite the fact that significant capital investments will be required. If you do not take into account capital investments, it is necessary to understand that technological progress is still imperfect. The main barrier to the introduction of robotization is the lack of development of artificial intelligence technologies. The technologies that are on the market at the moment are often imperfect and are most often a trial implementation option that cannot be scaled.

Based on the work done, it was concluded that local optimization is a good, but not sufficient move for the strategic development of the company. Isolated implementations have a limited effect compared to optimizing all links. When carrying out optimization, it is necessary to take into account other parts of the supply chain, for example, inventory management. The future belongs to integrated supply chains.

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Simulation Modeling During Operation of the Toll Collection Station on the Intercity Toll Road

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Abstract. This study is dedicated to the operation of the Toll Plaza (hereinafter TP) by the operator of the intercity toll road, where most drivers use Electronic Toll Collection Units (hereinafter ETCU). The authors note that the observed tendency for this payment type is becoming more popular and inevitably results in the necessity to control effectiveness of Toll Collection System's (hereinafter TCS) operation at the toll plaza. The solution to this operational issue is described in this article. Purpose of the study is to determine the intensity of transportation flow at which traffic jams are formed at the toll plaza with different parameters of the flow and different types of TCS operation. The study was conducted using the discrete event simulation modeling methods in the AnyLogic environment, and the statistical package R. As an example, the Western High Speed Diameter (hereinafter WHSD) Toll Plaza in St. Petersburg, Russia was studied. As a result of a study, a JavaScript programming code was written, which allows modeling a toll plaza in any configuration, with different flow parameters. Threshold definitions of incoming flow that cause traffic jams were determined; opportunities to increase the flow through a toll plaza were demonstrated, with the existing configuration of lanes. The reasons for traffic jams were identified, and limited capabilities of the existing toll plazas were depicted in the event of an increase in traffic on the toll road.

Keywords: Discrete-event simulation modeling · Toll road · Toll plaza

1 Introduction

The use of contact free electronic payments is becoming more widespread, and introduced into fields that require payment for goods and services. Transportation industry is not an exception, because modern and convenient payment systems are actively utilized for public and individual transportation services. Particular attention to the use of electronic payment drawn on the toll road projects. In Russian practice, the most popular electronic mean of payment today is ETCU—an onboard vehicle-mounted device that allows quick passage through a toll plaza.

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The issues of implementation and use of ETCU are actively discussed in the scientific community. The following authors point out the effectiveness of this payment method on toll roads of Taiwan, China, Sri Lanka and other countries [1–6]. The data on ETCU transit are used for study and analysis of transportation flows' peculiarities on toll roads, as indicated in the works of Fan et al., Weng et al., Komada et al. [7–9]. Notably, during the analysis of transportation flows based on the ETCU data, simulation modeling methods can be used, as demonstrated in the works of Hirai et al., Karsaman et al., Jehad et al. [10–12], for toll road projects in Japan, Indonesia, and Malaysia.

Most actively the ETCUs are used for intercity toll road projects. These projects are created to lessen the transportation load on the city's streets, to speed up the transit between districts, and to increase city's population mobility—for both the users of public and individual transport. The most distinctive example of such infrastructural project is the Western High Speed Diameter toll road in St. Petersburg.

The WHSD operator provides active and dynamic spreading of ETCUs for toll payments by users. By June, 2020 the quantity of users reached 91% [13]. We suppose that, in the near future, the number of ETCU users on WHSD may reach 97% at some of the toll plazas.

To evaluate the effectiveness of toll plaza operation, the operator can use simulation modeling methods. Simulation models allow to evaluate the existing capacity of the toll plaza, and to predict its operation, based on different values introduced for intensity and composition of the transportation flow.

2 Materials and Methods

Overall, a toll plaza can be viewed as a classic system for mass service with a defined number and configuration of lanes and two different parameters of the service intensity—manual and automatic methods of payment. The application of classic theory of mass service methods becomes challenging due to problems with accounting for errors in driver behavior, excess of the allowed vehicle weight, and other parameters that are difficult to estimate and predict. As an alternative, simulation modeling method was chosen to study the toll plaza traffic.

To evaluate the effectiveness of TCS during the toll plaza exploitation a discrete and event simulation model of the toll plaza, "Main road direction past the Ring Road (North) towards Primorsky prospect", was developed, located in the Northern Section of the WHSD. Unlike the methodology of toll plaza modeling used at the planning stage of the toll road, the use of simulation modeling methods during its operation stage, allows to account for and to reflect a number of additional conditions, which can only be identified after the project is completed, and have significant influence on the effectiveness of the TCS operation. These conditions can result from the specifics of toll plaza geographic location, traffic composition, regularity of user commutes, as well as from the influence of changing transportation, logistical, and social infrastructure [14]. The simulation model was developed in AnyLogic software, with the use of road traffic and process modeling libraries.

The existing configuration of the toll plaza "Main road direction past the Ring Road (North) towards Primorsky prospect" has 9 payment lanes, 5 of which accept Electronic

Toll Collection (hereinafter ETC). The remaining 4 lanes are manual and allow paying a cashier with cash or bank card by contact free or contact method.

The simulation model of the toll plaza allows accounting for the following parameters:

- The intensity of traffic on the toll plaza;
- Traffic composition;
- Distribution of vehicles by payment type;
- Time needed for service in the ETC lane;
- Time needed for service in the cash payment lane;
- Schedules of the lanes' work;
- Additional parameters (user behavior—parameter "tag failure").

The newly introduced additional parameter of user behavior called "tag failure" accounts for the possibility of ETCU being declined in ETC lanes—in case if the vehicle was not detected by the DSRC antenna when entering the lane, ETCU was not correctly installed in the vehicle, account has a negative balance, or otherwise rejected for payment. In such cases the ETC lane is blocked by the user, until the reasons for ETCU payment rejection are resolved. This parameter is never accounted for at the stage of TCS planning, however, it plays a significant role at the stage of operation, especially during peak hours at the toll plaza.

For the evaluation of existing effectiveness of "Main road direction past the Ring Road (North) towards Primorsky prospect" toll plaza, a simulation model was implemented, that took into account the current configuration of the TCS (5 ETC and 4 manual lanes), as well as the existing share of ETCU use by drivers—91% [13].

To predict the effectiveness of the toll plaza with existing configuration of TCS, three additional simulation models were created, where the projected use of ETCU by 2022 was introduced at 93%, 95% and 97%.

To solve the issue of optimization of TCS operational effectiveness simulation models were created lane configurations with 6 ETC plus 3 manual lanes, and 7 ETC plus 2 manual lanes. The abovementioned models were considered for two different types of user behavior: 10% and 5% of ETCU user errors while moving through the ETC lanes. Notably, the configuration with 7 electronic and 2 manual lanes is a maximum acceptable for this specific toll plaza. Because a toll plaza must provide opportunity for cash and bank card payment, a minimum of two manual lanes in the TCS configuration are required, taking into account needed reserve, in case if one of the lanes cannot function.

For each configuration a simulation model was implemented with both the existing and the projected data for ETCU use. Therefore, for each of the three TCS configurations, 4 simulation models of the toll plaza were implemented, which allowed to evaluate changes in the system's operation for increase in share of ETCU use to 91%, 93%, 95%, and 97% respectively, and for levels of user error set at 10% and 5%.

3 Results

3.1 Observed Traffic Intensity at Toll Plaza

The data about intensity and composition of traffic and time required to complete service were collected by visual count of the vehicles passing through the toll plaza, using the video data from online camera of the road operators' website [18] for October–November, 2019. The number of passing vehicles was calculated within 10–15 min, and then the results were totaled to a number of vehicles per hour. These calculations were done for all days of the week, and for all 24 h time periods. The results derived for the same day of the week and time of day were averaged. During the time frame studied, no significant fluctuations of traffic were observed, as pertaining to mass cultural or sporting events, which could potentially lead to significant changes in the weekly traffic cycle. The data for intensity during the 5 days of the work week are shown in Fig. 1.

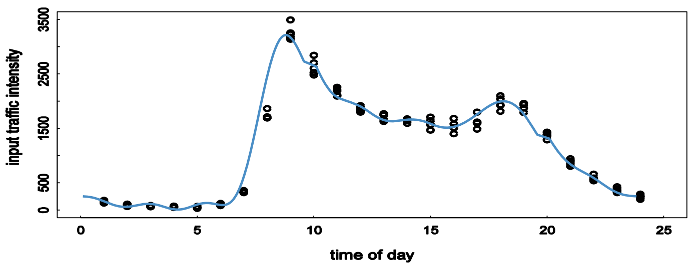

Fig. 1. Observed Intensity of work days traffic and approximated curve of fluctuating intensity at "Main road direction past the Ring Road (North) towards Primorsky prospect"

The change in intensity on working days is well approximated by a few members of the trigonometric series of the following form:

$$f(t) = a_0 + \sum_{i=1}^{\infty} A_i \cos(i\frac{2\pi}{\tau}t) + \sum_{i=1}^{\infty} B_i \sin(i\frac{2\pi}{\tau}t) \quad (1)$$

(t—time in hours, τ—period equal to 24 hours, i —ordinal number of the series member,a_0, A_i, B_i–series coefficients). Figure 1 demonstrates the approximating curve with the first nine members of the series (19 coefficients) of the form (1).

Thus, we have a fluctuating intensity of the incoming traffic flow, fairly well approximated by 9 members (19 coefficients) of the trigonometric series of the form (1). In any case, the maximum intensity of traffic during working days does not exceed 3500 vehicles per hour. Similar situation was observed during holidays and weekends, and their own approximating functions can be written. In this study we are focused on two questions:

1. At what intensity and parameters (share of ETCU users, share of user behavior errors) of the incoming flow will the traffic jams form at the toll plaza?

2. What measures can be taken by the operator to lower the risk of traffic jams within the parameters of the existing configuration of the toll plaza, consisting of 9 toll lanes?

3.2 Distribution of Time Required for Passing the Toll Plaza Zone

The toll plaza zone includes 9 toll lanes separated by safety islands and it is a part of the toll road that begins with the toll plaza entry zone where the 3 lanes of the main road widen, and ends with the exit zone of the toll plaza where 9 lanes narrow into 3 again. We separate the definitions of the time of service—spent specifically in the payment lane (which would be basic for application of the classic theory of mass service) and the time required to pass the toll plaza zone. In this case, we are interested in the time that a vehicle spends to pass all the road section from the beginning of the entry zone, to the end of the exit zone.

We believe that traffic jam happens in situations where vehicles cannot easily cross the line that divides the 3 lanes into 9 and have to form a queue prior to crossing this line.

The distribution of the service time in ETC and manual payment lanes is included in the parameters of the simulation model. When intensity is high, the distribution of time required for passage of the toll plaza zone in ETC and manual lanes forms an inseparable mixture of distributions. The situation is made more challenging by the increasing influence of user behavior errors, which lead to significant changes in the traffic flow in the toll plaza zone, and create obstacles for other participants of traffic. It turns out that the distribution of time required to pass through the toll plaza zone in such cases is well approximated by gamma distribution law (shown in Fig. 2).

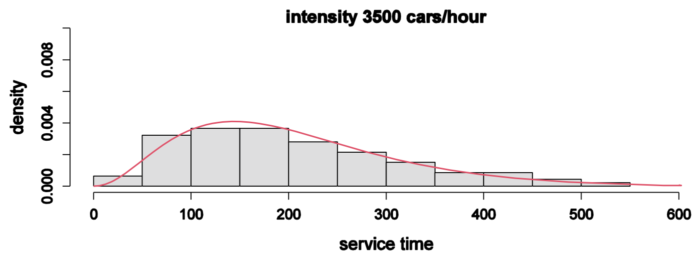

Fig. 2. Distribution of service time, with incoming traffic flow intensity of 3.500 vehicles per hour, configuration of TCS: 4 manual and 5 ETC lanes, with flow containing 91% transponders, and level of user error at 10%. Red line is density of gamma distribution law, with parameters of shape = 3.2821, rate = 0.016, p-value of Kolmogorov Smirnov test –0.99

Therefore, at high intensities, the entire toll plaza begins to work as one "mechanism", with accidental time of service, governed by the gamma distribution law. Distribution laws in this case, show clearly defined right side asymmetry. The indirect characteristic of this asymmetry is a significant difference of the average time required for passage of the toll plaza zone and its most probable value.

The mathematical expectation of a random variable distributed by gamma law $Gamma(k, \theta)$ is $k \times \theta$, and the modal (most probable) value is $(k - 1) \times \theta$, where k is—the shape parameter, and $\theta = \frac{1}{rate}$.

When traffic jam happens and intensity of the incoming traffic flow continues to increase, the parameters of the approximating gamma laws can vary (we use simulation modeling, where each simulation is the implementation of an accidental process with preset parameters in a simulation model), but evaluations of the average time required to pass through the toll plaza zone are not changing significantly when the incoming intensity increases during already existed traffic jam. Figure 3 depicts the diagrams representing changes of the average time required to pass the toll plaza zone for different parameters of the incoming flow and lane configuration (on the left—user behavior error is at 10%, on the right one—at 5%).

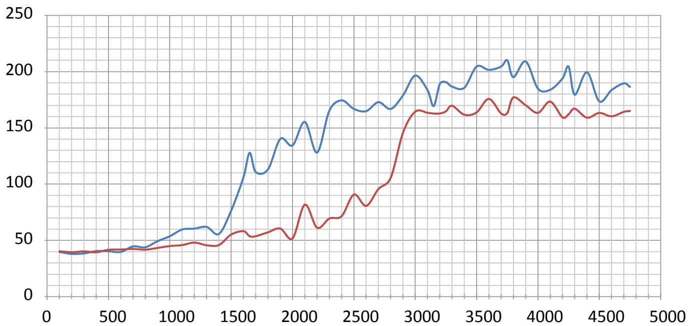

Fig. 3. Diagrams of changes in average time required to pass the toll plaza zone. Configuration of the Toll plaza lines: 4 manual and 5 ETC; 91% of the ETCU usage. Top (blue) line—for the user behavior error level—10%, bottom (red) line—for the user behavior error level—5%)

Figure 3 depicts the diagrams representing changes of the average time required to pass the toll plaza zone depending on the input flow intensity (obtained by running the simulation model for different intensities) at 91% of the ETCU usage, the configuration of the toll plaza lines as 4 manual, 5 ETC, for 10% of the user behavior error level, and for 5% of the user behavior error level.

Before the traffic jam occurred, the average time to pass the toll plaza zone was calculated as a weighted average of the average time to pass the toll plaza zone for ETC (0.91) and manual lanes (0.09). After the traffic jam occurred, the average passage time of the toll plaza zone was estimated as the mathematical expectation of the approximating density of the gamma distribution law. For the example shown in Fig. 3, a traffic jam occurs at an input flow rate of 1650 vehicles per hour, if the user error rate is assumed to be 10%, and at an intensity of 3200 vehicles per hour, if the user error rate is assumed to be 5%. In other words, reducing the user error rate by half significantly increases the throughput of the entire toll plaza zone as a whole. It is possible to see that when a traffic jam is already created, the average transit time of the toll plaza zone, having already significantly increased, stabilizes and stops growing (waiting in the queue before entering the toll plaza zone is not considered here), and the level of user errors is no longer so important.

If a traffic jam has been already formed, and intensity of the incoming flow continues to increase, it is impossible to get rid of the traffic jam until the intensity of the incoming flow decreases. Maximum intensity of the incoming flow observed at this toll plaza did not exceed 3.500 vehicles per hour. In this current circumstance a jam is formed at the toll plaza when the intensity equals 1500–1600 vehicles per hour (Fig. 1), which corresponds to peak hours.

As the transportation flow increases, the frequency of traffic jams and the length of queues for entry to the toll will only increase. Natural methods of preventing jams appear to be increase of ETCU share in transportation flow, and change in TCS configuration by increasing the number of ETC lanes.

The analysis of the constructed simulation model shows that:

- Increase in ETCU share in traffic flow with level of user behavior errors at 10% almost does not affect the threshold value of intensity, at which a traffic jam begins to form, while the time required to pass through the toll plaza zone in this case does not significantly change;
- Changes in toll plaza configuration by increasing the number of ETC lanes with simultaneous increase of ETCU users share in the flow, with level of user behavior error at 10% insignificantly affects the threshold value of intensity, at which a traffic jam begins to form and the time required to pass through the toll plaza zone;
- Relevant for the significant increase of the threshold value of intensity, at which traffic jams are formed, is the decrease in the number of user behavior errors to 5%, where the time required to pass through the toll plaza zone is also somewhat decreased, however there is a risk of short term traffic jams forming at the toll plaza zone exit. When a significant number of vehicles form a queue, but the speed of processing payments in electronic lanes is high and the number of user errors is decreased, the payment process is relative, but when the vehicles leave the lanes simultaneously, they become obstacles to each other in the toll plaza exit zone, which slows traffic and results in possible traffic jams. It is necessary to note that it is impossible for toll plaza traffic jams to be formed simultaneously in both the toll plaza entry and exit zones. If a traffic jam is formed at the entry, the lane operation effectiveness is decreased, which excludes the possibility of forming a traffic jam at the exit.

4 Discussion

To open the discussion, it is important to pay attention to the question of whether it is advisable for the operator to use the approach where the number of ETC lanes with barrier type TCS at the toll plaza would further increase, while ETCU users share also increases. Taking into consideration the simulation model of the toll plaza that we have considered, if traffic intensity increases in part of the toll road, the TCS is of a barrier type, and even when the user behavior parameter value is low, it can't decrease the time required for passing the toll plaza due to the need for the users to maneuver in the entry zone from a 3 lane highway to a 9 lane toll payment plaza, as well as in the exit zone—back to the 3 lanes after passing the zone.

In order to effectively process payments on the toll road with high intensity and large share of ETCU users it is advisable to consider possibilities of applying barrier-free or hybrid payment system.

5 Conclusions

As part of this study, an applied task was considered, focused on toll plaza operation by the toll road operator, as demonstrated in the example of WHSD. The authors note one of the peculiarities of the intercity toll road with significant share of ETCU users, which leads to the necessity for the operator to control the TCS operation effectiveness at the toll plaza. To resolve this operational issue, the authors performed the discrete event simulation modeling of the toll plaza, using the AnyLogic software.

A toll plaza in the Northern Section of the WHSD simulation models were applied, which corresponded to the different TCS configurations, and allowed to evaluate the current and planned flow capacity of the toll plaza with further increase in ETCU users.

The results received allowed to arrive to the following conclusions:

- At present time the capabilities of this toll plaza are limited for the increase of the flow capacity at peak hours. The capabilities of increasing the number of ETC lanes at the expense of decreasing the number of manual lanes are also limited (threshold level 1650, 1700, 1750, 1550), and the maximum of only 7 ETC lanes is possible;
- With further increase of the ETCU users share, above the existing value of 91%, the possibility of forming a traffic jam at the toll plaza remains likely. Traffic jams still begin to form when the input flow rate of the vehicle is in the range of 1500–1750 vehicles per hour;
- As the number of vehicle owners increases, and the transportation flows increase in their intensity, barrier type TCS may face the risk of having to function at the limits of their technical capabilities, where a breakdown of even one payment lane may lead to formation of a jam at the toll plaza (the toll plaza cannot be left in any other way than by passing through it).

As a discussion issue, the authors suggest to evaluate the principle approach to the toll collection in the conditions of high share of ETCU use. Expert community does not offer a simple answer to the issue of comparing the effectiveness of barrier type and MLFF TCS. It will always require integrated analysis for each separate project of the toll road.

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Genesis of Corporate Logistic Processes in the Course of Digital Transformation

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Abstract. The paper contains a detailed analysis of logistics development as the most important scientific direction in management from the middle of the XX century to the present day in connection with the most important stages of economic development. The material flow management methods are described in detail. These methods have been used for over half a century and in the course of their improvement, a number of concepts of corporate logistics process management that define the current state of this sector were consistently formulated. Their capabilities and shortcomings are analyzed. The reasons for the emergence of supply chain management concepts as a basic element of logistics are identified. The link between logistics and supply chain management is defined, and the research areas on which the concept is based are studied. The processes of corporate logistics digitalization, its stages and information systems that support the management processes at each stage are analyzed. Particular attention is paid to the analysis of the role of corporate logistics in the architecture of the enterprise, the specific features of management of logistics business processes architecture. The architectural approach to designing an operating model of a logistics system and integrated business architecture of logistics processes was defined, as well as tools and opportunities for its implementation in the architectural model of enterprise management. A brief overview of the tools for building logistics business models in the external and internal contours of company management is presented, as well as information systems and digital information platforms, which all participants in logistics processes rely on in their interaction.

Keywords: Logistics · Supply chain management · Digitalization · Information system · Enterprise architecture · Digital transformation · Architectural model · Business model

1 Introduction

Forming and developing digital economy is now the objective of strategic development of Russia. For quite a while all spheres of the economy actively go through a process of digital transformation based on the creation of modern information infrastructure,

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implementation of various IT solutions and technologies. Logistics and supply chain management are no exception. Today, digitalization of logistics processes is one of the key areas of the digital economy that is forming both in Russia and abroad. The basis of digital transformation is the rapid development of information and communication technologies (ICT), their widespread expansion and use in business management systems. In today's economy ICTs are becoming the drivers of economic development and the basis for digitalization [1]. The aim of the paper is to analyze the origin, formation and development of corporate logistics management system and the possibilities of their digitalization at the current stage of information economy development, as well as the availability of methodologies, tools, digital platforms and best practices to ensure their development in the process of digital transformation of the enterprise.

A special role among these factors ensuring sustainable and efficient business development is played by logistic processes, whose violation or interruption can lead to great economic and reputational losses of the enterprise. The basis of logistics processes is the supply chain (supply network)—a number of third-party organizations and services of a particular enterprise, interacting with each other in material, financial and information flows, as well as service flows, from the sources of raw materials to the end consumer of finished goods. The work of this chain is supported by logistic processes. Logistic processes management includes the processes of creating and transforming the resources in industrial, logistics and trading enterprises in terms of value chain, as well as the processes of inter-organizational interaction in the movement of these resources [2].

2 Methods and Materials

The basic general scientific research methods used were analysis, comparison, classification, architectural modeling, expert judgment, as well as scientific generalization. Well-known cases of logistics companies are used as materials for the article.

3 Results

3.1 Establishing and Developing the Logistics Process Management Concept in a Company

The processes of material and technical supply (MTS) in industrial plants have always been the focus of the control system. A huge stock, high shipping and handling costs of procurement and sales, as well as the violations of a supply plan created serious problems in the inventory management system, which either significantly increased storage costs or threatened the shipment schedule.

The emergence and rapid development of logistics as a research area is gradually becoming one of the main strategic aspects of management of any business related to the movement of material resources. In 1974, the term "logistics" was coined as a combination of material management and physical distribution, and the term SCM (Supply Chain Management) was first used by consultants in the late 1980s, and adopted by the academic community only in the 1990s.

The first mentioning of supply chain management dates back to 1982 [Oliver, Webber] and one of the first analysts to talk about SCM as an integrated supply system (e-procurement) was D.N.V. Burt [1984]. It should be noted that the idea of supply chain management emerged from an attempt to extend the horizon of logistics to a strategic level and, as a result, its activities rose beyond the limits of a single firm. Throughout the 1990s, there were debates about how logistics and supply chain management relate to each other. A team of scientists [Cooper, Lambert, Pagh, 1997] summed up these disputes, and finally separated logistics as a function of the tactical level from the strategic level of supply chain management.

The SCM concept has been developing through a number of consecutive stages, but only by the beginning of the XXI century it was assigned the functions of controlling, coordination and integration of material flows, creation of strategic partnerships and information interconnection of chain participants.

Supply chain management is the process of planning, controlling and regulating the flow of raw materials, unfinished goods, finished goods, services and related information, from design, requisitioning and purchasing through production and distribution to the end-user from the perspective of cost reduction. As a result, Supply Chain Management has evolved into a management philosophy, a set of tools and a set of processes this philosophy is based on [3].

The supply chain integrates the activities of all participants—suppliers, partners, intermediaries and consumers—through an information infrastructure that each participant in the chain has access to. It is important that the supply chain management concept overlaps the boundaries of individual firms, i.e. there is some kind of integration of key business functions. Ultimately, "supply chain management is the management of a network of organizations that are involved, through top-down and bottom-up connections, in various processes and activities that create value in the form of products and services provided to the end consumer" [4].

The growth of ICT has also played a huge role, providing tools and technical means for coordinating complex processes, treat huge amounts of data, analyze the state of the chain, as well as create information infrastructures in enterprises and organizations participating in the chain, organize joint activities and implement supply chain management processes. To solve all these tasks, SCM systems are used. These systems can be used to form and ensure the effective functioning of a supply network and channels of interaction, where the necessary materials will be delivered to the right place at the right time with the least cost.

3.2 Developing the Information Support of Logistic Processes

The system automation of material and technical supply processes (MTS) in enterprises began immediately with the advent of electronic computer technology. First of all, the tasks of calculating material resource requirements for a production program, warehouse accounting and inventory management were solved. As early as in the middle of XX century, the digitalization of supply management processes began at large enterprises. Computer-aided automated industrial control systems (AICS) were designed and introduced in the 60's and 70's and made it possible to solve a wider range of supply problems, relying already on the information system of the enterprise and the availability of data on the composition of products, material and technical standards, production plans and production technologies.

However, a comprehensive approach to the problem of supply of enterprises in solving these problems was first implemented in the methodology of MRP (Material Requirements Planning). This point can be considered a start of the real digital transformation of business. The essence of the concept of MRP is to minimize the costs associated with stocks in different areas of production. It is based on the strict dependence of demand for raw materials, components and semi-finished products on the finished product plan, its implementation and support, and links the needs for resources and the timing of their delivery to production in accordance with the technological process. It was implemented in the MRP-class IS. Further development of MRP led to the concept of Capacity Requirements Planning (CRP) and then to the methodology for planning material requirements in a closed loop (Closed Loop MRP). In addition to the functionality of MRP, it provided the ability to monitor the actual state of production and the execution of purchase or delivery orders from the materials and components warehouse at the shopfloor level. The systems implementing the MRP closed-loop technology covered all aspects of business related to product manufacturing (i.e. supply and production), but sales and financial accounting processes were not supported. Thus, the concept of Manufactory Resource Planning, called MRPII, appeared. The main essence of the MRPII concept is that the forecasting, planning and control of production is carried out throughout the entire life cycle of a product, from the purchase of raw materials to shipment of products to the consumer.

The MRPII concept has been replaced by a more advanced ERP (Enterprise Resource Planning) concept aimed at managing all enterprise resources and processes. This concept includes sales and production planning processes, demand management, material requirements planning, procurement, inventory management, sales, cost management and a whole range of production management processes, ensuring the verification and correction of shop floor plans, which is extremely important for the organization of in-plant logistics processes to reduce costs.

Further support of supply chain system led to the emergence of the CSRP (Customer Synchronized Resource Planning) concept, which facilitates the interaction of the enterprise with customers and other members of the supply chain. The CSRP methodology includes the complete product lifecycle, from customer-specific design to warranty and after-sales service [5].

The emergence of the ERP II (Enterprise Resource & Relationship Processing) concept is the result of the development of the ERP methodology and technology in the direction of closer interaction between the enterprise, its clients and counterparts [6].

Modern information and communication technologies (ICT) and digital information platforms (DIP) play an important role in the digitalization process. First of all, it is the Internet, which provides many services and have vastly expanded the information base, as well as simplified the search for and exchange of information between cooperating business entities. It has had a serious impact on the operating methods of enterprises thanks to the changes that have been introduced in all processes from procurement to production and sales. Further development of ICT will intensify the digitalization processes in the economy as a whole and in enterprises, in particular, in logistics. These are mobile devices, technologies and solutions that have changed the system of communications and open up new opportunities for business; cloud technologies, which profoundly transformed the information infrastructure of the enterprise and approaches to accessing information resources of the enterprise, which is also important for the functioning of the supply chain; Big Data technologies and tools for working with huge amounts of various types of information in different storages (which is typical for logistics processes); Blockchain technology in different versions, which creates new opportunities for searching, organizing, evaluating and transferring any objects with digital signature, making payments and concluding contracts. In other words, it is a "distributed database for transaction processing, which is formed as a continuous chain of blocks with records of all transactions and is stored by all participants in the logistics process" [7]. The "Internet of Things" is considered to be the most significant for solving the tasks of logistics process management. This is a technology that allows you to connect any physical object to the Internet using radio frequency identification (RFID) technology, and track their location. According to Cisco Systems specialists the "Internet of Things" and logistics are ideal for each other, and in the next decade a revolution in logistics is expected [8].

A special role in supporting logistics processes is played by the DIP [9]. The concept of platforms is a modern business model. It is a certain place, a platform where manufacturers and consumers can cooperate. The DIP is a platform based on ICT, which provides interfaces and services according to certain standards, and ensures the interaction of partners. The purpose of such structures is the integration of all participants in the value chain, as well as communication channels, distribution routes and the community of potential customers. The current scope of digital platforms is so wide that they can cover entire sectors of the economy. Actually, there are enough examples of such digital platforms, especially in e-commerce [10]. Digital platforms cover the entire spectrum of relationships between different actors in the transport and logistics sphere, namely, between organizations and consumers (B2C), between organizations (B2B), direct interaction between consumers and consumers (C2C), as well as the interaction between organizations and the state (B2G) [11].

3.3 Improving Logistic Processes in an Enterprise Using an Architectural Management Model

Building a business model for a logistics system in the architecture of the enterprise. All of the above system classes provided information support for certain functions and processes of logistic chain management. Due to today's rapidly changing economic situation, changes have to be introduced in the business or business processes of the enterprise using modern IT.

Such opportunities to a certain extent provide the construction of Enterprise Architecture (EA) and the transition on its basis to the architectural model of business management. The Enterprise Architecture is the most important tool for organizational changes in business, and its creation allows to ensure both the achievement of its strategic goals and operational objectives through an adequate (reflecting the current needs of the business) information infrastructure. The infrastructure allows all the participants to form a common business vision in the logistics process. The EA includes, two main domains: business architecture and IT architecture, which are closely interconnected, can be used to describe the overall structure of logistics processes for the enterprise, including its partners and participants, and to form a model for managing these processes [12].

IT architecture through its elements—the architecture of application solutions and information architecture—helps to implement (execute) the logic of business processes in the logistics system, and logical models of IT services offers a choice of specific technologies and solutions. The architecture of applied systems allows us to cope with the objective complexity of sharing the information resources and information systems of enterprises participating in logistics processes [13]. Thus, the EA can be used to build organizational, economic and information technology components, on which the management processes of all chain participants are based, as well as create an integrated information environment for management and decision-making. The management strategy based on ERP II ensures the transition of enterprises to a new way of interaction, based on B2B cooperation, especially since cooperation has always been an integral part of business.

An architectural management model is a modern concept based on the balance of needs of economic entities in information resources and the possibilities of supporting these needs by means of IT. It assumes the process approach to the construction of the management system, which has proven to be effective in the implementation of reengineering projects, in projects of building corporate systems at enterprises and in the construction of architectural models [14]. It is absolutely necessary to monitor the business model of logistics chains and information processes that support it [15]. Architectural management model supports business management processes. It is based on model-based business process management systems (BPMS) and service architectures. It should be noted that almost all logistic processes comply with international standards and can be performed in an integrated information environment by all participants of the supply chain.

All the participants in the logistic process should typify their business processes and the applications that support them. This has to be considered when contracts are made between the chain participants, in order to exclude the risks of delivery failures. Thus, the architectural approach can be used to formulate strategic requirements for the system of business processes in a supply chain and functional logistics systems. If the SCM concept is implemented in the architecture of the enterprise, integrated management of key business processes of the supply chain becomes possible in the system of cooperation between the company and its suppliers, customers and intermediaries, so in addition to information synergy we can say about the formation of architectural synergy through the use of a single business model of management and integration of logistics business processes for all participants. As a result, an architectural model of the logistics system can be built based on SCM applications in the system architecture. To support it, it is necessary to organize a logistics service "with the authority of an SC manager to ensure the integrative nature of all components of the enterprise logistics system. It should be responsible for the development of the optimal organizational structure and digital transformation of this area of activity" [16], and increase flexibility in managing multiple supply chain configurations. Digitalization of logistics and supply chain management in EA is based on a number of modern technologies, some of which have been considered earlier. Their use takes the global economy sectors to a new level of transparency and process automation in supply chains [17] and creates qualitatively new models of business, logistics, production and communications.

Modern tools and IS for corporate logistics process management. The Supply-Chain Council (SCC), an international organization, has synthesized the best achievements and best practices of the SCM concept and developed the so-called SCOR Model (Supply-Chain Operations Reference Model)—"Recommended Model for Supply Chain Operations".

The SCOR model is a reference model with its own language for describing the relationships between supply chain actors, a chain performance evaluation system, metrics and a library of standard business processes and business rules that operate in different areas. The SCOR model creates unified, comparable and applicable processes within the supply chain. This model has become an essential tool for describing and evaluating the process of material flow through the supply chain by all the participants.

In order to develop and improve SCOR standards, the SCC has developed the DCOR model (Design Chain Operations Reference), which covers the business processes of product creation, and the CCOR model (Customer Chain Operations Reference). Together they will form the IBRF model (Integrated Business Reference Framework). The IBRF is a business planning tool that will be able to link all value chains, i.e. it will make it possible to link customer requirements, product data management, product lifecycle management, chain lead time and costs [18], providing a business model for the full logistic cycle in EA.

Thus, considering the evolution of logistic processes, one can distinguish five main stages of their development (Fig. 1). It should be noted that for all the listed stages, the concept of integration of all processes is key both for logistics and for the SCM concept. Only the last stage—Architectural—relies on an integrated environment of cooperation, makes it possible to implement the concept of adaptive logistics networks and quickly respond to changes in the logistics network and market conditions in the architectural model of management of all network participants.

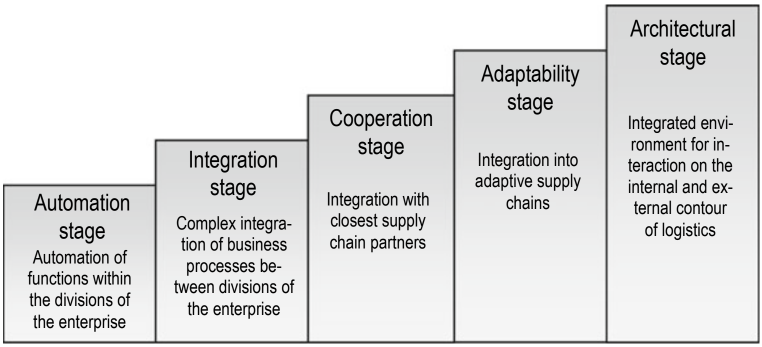

Fig. 1. Logistics management stages

It is obvious that the active digital transformation that ensures the construction of the Enterprise Architecture allows the implementation of the above supply chain management models (SCOR, DCOR, CCOR, IBRF), which combine processes, best practices, metrics, technologies, digital platforms, modern mathematical methods and tools. in the communication system of all participants in the chain with a high degree of efficiency.

As mentioned above, the SCM concept includes purchasing, production, sales and return in the logistic chain. Business process models and corresponding application solutions in SCM and CRM class ISs have been implemented for quite a long time. They are used in practice and are constantly being improved. These system solutions in AP effectively support external logistic processes.

In-house supply chain management covers the internal production process and material flows within the company, including materials, components, blanks, tools, unfinished and finished products. The management of this logistics chain is supported by MES and APS systems, which carry out production management functions from the order to the completion of production.

The International Association MESA distinguishes a number of functions, which determine the place of MES systems in the architectural model of industrial enterprise management. The main functions of MES systems that provide information support for production logistics processes in an integrated enterprise information environment are: operational detail (calendar) planning (ODS); and dispatching production units (DPU). They can be used to reflect the data on the provision of the production process with resources and work performance, order execution, give information on the place and sequence of the work with this product, including information on the work in progress, materials from suppliers and current production conditions.

An APS (Advanced Planning and Scheduling System) is a system of synchronous production planning, focused on the integration of all processes and links in the supply chain, taking into account all the features and constraints. The main goal is to provide the user with a tool that can be used to control and optimize business processes of the production logistics chain in the EA, which helps to reduce stocks to some extent and significantly improve the activities in the field of product supply [19]. To a certain extent, its use will allow to expand ERP capabilities [20].

The concept of information logistics is closely connected with logistics information systems. Information logistics organizes the flow of information accompanying the movement of resources, provides management of information resources and ISs that support the functioning of the logistics system [21].

It is necessary to point out the information support of transport logistics of the enterprise. It has certain specifics and is supported by various TSM systems of transport management. The choice of transport systems is connected with the features of the transport service in the enterprise and in the external contour. An important role in the digitalization of logistics processes is played by warehouse ISs, which appeared at the earliest stages of digitalization and are actively developing.

4 Discussion

The development of digital platforms, the emergence of modern tools and information and communication technologies, as well as the use of best practices in material flow and inventory management have become the basis for digital transformation of logistics processes. They go beyond technological transformations and lead to changes in traditional forms of enterprise management. This allows us to conclude that enterprises are fully prepared for the digitalization of corporate logistics processes based on an architectural management model, that can be the topic for the future researches.

5 Conclusions

The development of corporate logistics has gone through a number of stages of digitalization—from fragmented and integrated automation of logistics management processes to the implementation of a comprehensive and architectural approach to methodological and information support of all internal and external logistics processes at the enterprise. But the supply chain management (SCM) concept has always been the basis for all these stages. The SCM concept was a theoretical answer to the question of how to interact in the chain of suppliers, firms that used to become a factual supply chain, and its integration with CRM and ASP on the ERP platform, allows it to cover the entire value chain. As a result, supply chain management has evolved as a management philosophy, as a set of tools to implement this philosophy, and a set of processes.

This ensures a systematic approach to integrated planning and management of information, materials/goods and services flows from suppliers to end customers. The implementation of the SCM concept means doing business according to the principles of synchronization of basic business processes and planning and management models in a company using common information channels with suppliers and customers throughout the supply chain. In the architectural model of enterprise management, its implementation allows you to create a single information space for supply chain management, giving information on the current state of the logistics process for all network participants, which provides a quick response to any changes and a serious synergistic effect.

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Geo-Information Support Digitalization for Northern Sea Route Logistics in the Context of Climate Change and COVID-19

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Abstract. The article shows digital tools development results for geo-information support of Northern Sea Route within Industry 4.0 period in the context of climate change and the COVID-19 pandemic. The methods of data bases constructing, web-technologies and virtual reality tools are used in the study. Foresight technologies, theory of decision making under uncertainties and risk management are also used. As digital tools, it is proposed to use digital online platforms, which integrate heterogeneous hardware and software resources with the use of web-technologies in distributed networks and wide application of cloud services. In the research, data bases and tools of geo-information digital online platforms Earth and EOS are used, including its Land Viewer product. As a result, the usage of geo-information support system for Northern Sea Route area is demonstrated. The research results presented in this article has significant scientific novelty and can be useful for private investors, public environmental organizations of the civil sector and state environmental control bodies.

Keywords: Geo-information Support · Northern Sea Route · Climate Change · COVID-19

1 Introduction

Recently, the usage of the Arctic Ocean's space as a transport corridor between the main cargo ports of Europe and South-East Asia (SEA) is an important direction of maritime logistics development in Arctic and Subarctic. One of possible way to solve problem is to use Northern Sea Route (NSR) as such transport corridor. Now, NSR logistic is functioning in Industry 4.0 period, and when while climate change and covid-19 pandemic. In this period, a wide range of information technologies are planning and implementing by many businesses [1–7]. Industry 4.0 leads to serious information technological changes in seaports activity [8, 9], including natural risks management (NRM) [10–13], which requires the development of new tools, including practical learning area [14]. It worst to

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note, Covid-19 heavily shocks maritime activity, including NSR logistics development plans, but climate change gives excellent chance for them.

The purpose of this article is to develop digitalization tools for geo-information and geo-ecological support systems (GIGESS) to NSR logistics within geo-information management (GIM) paradigm [15], in large environmental projects [16–18] within environmental economics ([19–23]. We paid significant attention to geo-information support systems (GISS) within climate change and Covid-19 pandemic context, including the issues of information collection and processing [11, 12]. Proposed digital technologies for GISS to NSR logistics while climate change and Covid-19 pandemic, considered in this article, take these factors into account.

2 Materials and Methods

During the research, we used Foresight technologies, theory of decision making under uncertainties, risk management approach, methods of data bases constructing, web-technologies and virtual reality tools. Also, we used Internet of things and big data technologies [16, 17, 24, 25]. From the point of view of geo-information management, geo-space is structured to allocate the interconnected components of the solution space [19]. While study, we used data bases and tools of geo-information digital online platforms (GIDOP) Earth https://earth.nullschool.net/ru/ and EOS eos.com, including its Land Viewer (LV) product https://eos.com/lv/, which allows to operate with space images from the Landsat-8 and Sentinel-2 satellite systems with limited open access.

3 Results

As a result of research performed using Foresight technology, we put forward the claim from the point of view of geo-information management (GIM), that in present conditions of climate change and Covid-19 pandemic, techno-sphere security (TSS) of natural-industrial systems (NIS) in Arctic and Subarctic including NSR is to be carried out in the environmental economics paradigm as related set of large natural-industrial projects (NIPs) within common space area and time period. In Fig. 1, there is presented a block model of investment structure while NIPs, which combines the investment objectives of such NIPs (blocks 1–5) within NSR logistics development with cost of adequate geo-information and geo-ecological support (blocks 6–8), including natural risks management (NRM) within TSS of NIPs (block 7).

As study result, we propose to use geo-information distributed platform (GIDP) containing heterogeneous databases in the format of a multi-level architecture. Proposed GIDP contains three levels of data representation: “data—processing—interface”. The advantages of such representation are the independence of the system from the number of software components included in each level and its own set of protocols and application interfaces for each level, which defines its own architecture.

To avoid the difficulties of multi-user access to data, we suggest to use a mechanism for pre-processing heterogeneous data, which includes a virtual data processor (VDP) and a data preparation unit (DPU). A VDP is a software module that allows uniform access to all system data via standard interfaces (protocols), while hiding the features

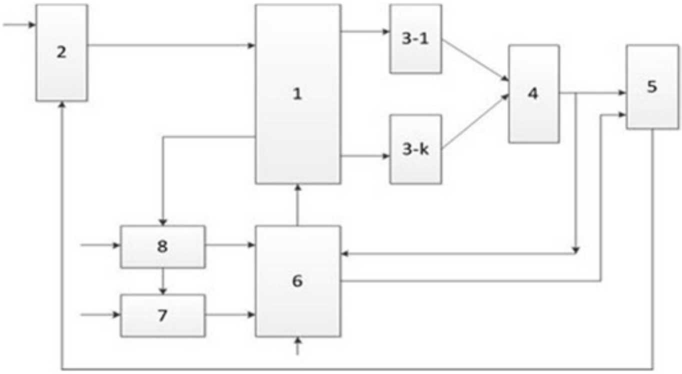

Fig. 1. Block model for investment structure within NSR: 1—block of distribution of resources; 2—block of formation of resources; 3—block of formation of private income; 4—block of formation of total income; 5—block of formation of the investment share of resources; 6—block of comparison with the permissible level of risk; 7——block of formation changing in time set of natural risks, including climate change risks and Covid-19 risks; 8—block of environmental monitoring while climate change andCovid-19 pandemic conditions

of data placement, data structures and formats. A DPU aims at collecting and first processing the data requested by the user from the system. When using this mechanism, there is no need to convert data to the format used by the system, they remain in the original view and can be used locally by their applications.

The VDP in more detail, you can say that it is a virtual data bank (VDB), which consists of a set of non-specified virtual databases, a virtual data bank (Fig. 2). Information sources of actual state databases are the actual cycle of functioning of organizational subsystems of a complex management object, when considering the geo-information system as a system for making managerial decisions. The information sources of the databases of planned States and regulatory States can be input documents, virtual results of management decision-making, as well as the results of solving regulated tasks.

On basement of above mentioned block model, we propose to develop the geo-information support system (GISS) for NSR logistics with combined structure for access, storage and analysis of information from open geo-spatial data sources, including archives and operative mode web tools.

Our analysis shows that the largest part of the cost of geo-information support is the environmental monitoring (block 8), the essence of which is determined by the content of block 7. Significant part of the cost in block 8 is the cost of hardware and software, which varies significantly for different NIPs, especially for Arctic. Reducing the cost of GISS for NSR logistics is an important direction of TSS's construction.

As a result of the research performed using foresight technologies, we suggest to use geo-information distributed online platforms (GIDOP) with cloud technologies (CT) as the main technological solutions for GISS for NSR logistics while TSS's construction. In this article, we recommend to use GIDOP Earth https://earth.nullschool.net/ru/ and GIDOP EOS eos.com, including its Land Viewer (LV) product https://eos.com/lv/, which

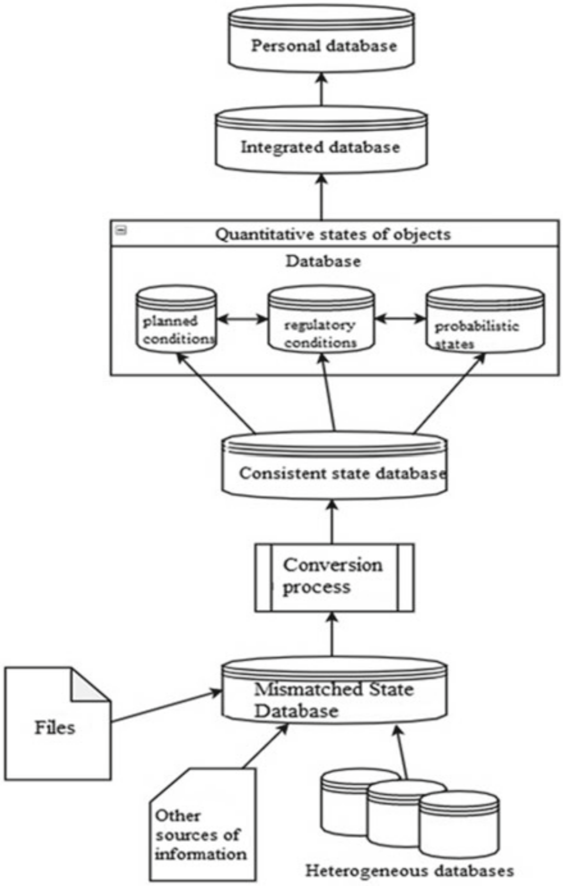

Fig. 2. General diagram of dependencies between data subsystem modules in VDP

allows to operate with space images from the Landsat-8 and Sentinel-2 satellite systems with limited open access.

Let's go to examples. Now, there is intensive maritime infrastructure development in NSR area, including port Sabetta for liquid natural gas (LNG) loading. In Fig. 3, it is presented space image of seaport Sabetta's area on 14/05/2020 from GIDOP EOS with Agriculture Color Application of LV. The characteristics of the Agriculture Color Application are given on the website eos.com. Note, reddish colors in centrum of picture correspond to the areas of artificial structures.

In Fig. 4, there is space image of Kara Strait area, another important part of NSR. Note, Kara Gate Striate is one of critically important point of NSR, which have to be monitored constantly. GIDOP EOS allows to solve this problem.

For TSS within NSR area very important to know wind field. GIDOP Earth permits to achieve this task. In Fig. 5, there is presented the image of wind field on 15th June

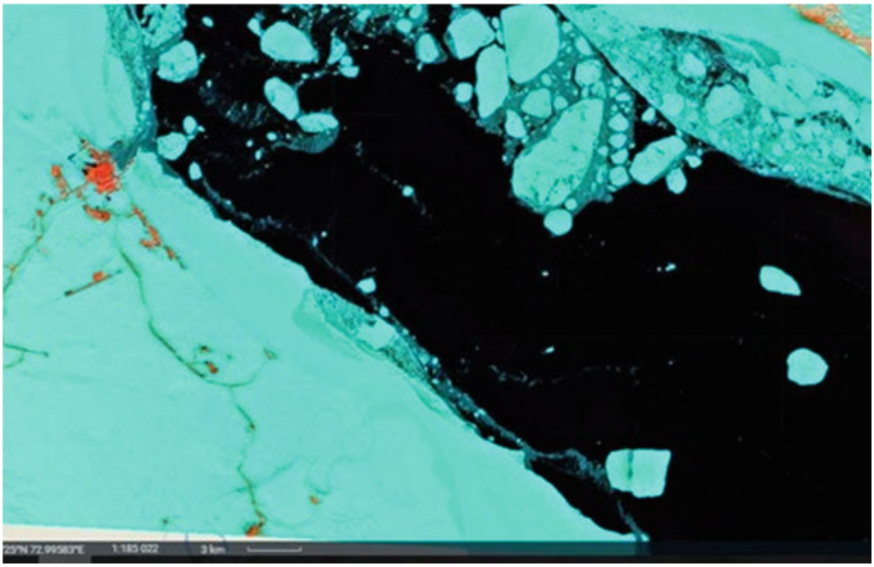

Fig. 3. Space image of port sabetta on 14/05/2020 visualized with agriculture color application of LV

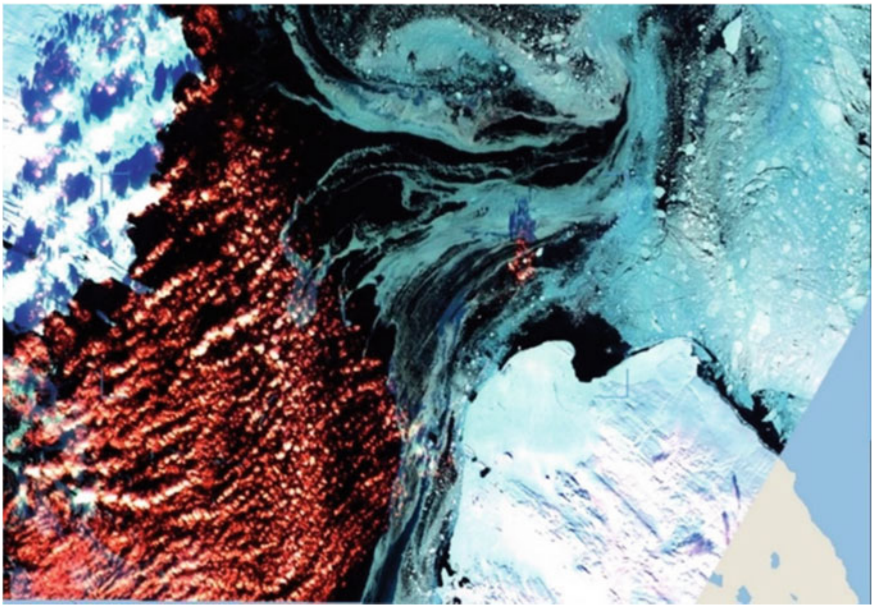

Fig. 4. Space image of kara gate strait area on 28/02/2020 visualized with agriculture color application of LV

2020 in the vicinity of seaport of Pevek, which shows that this seaport was affected by a northwesterly wind at a speed of about 7 km/h.

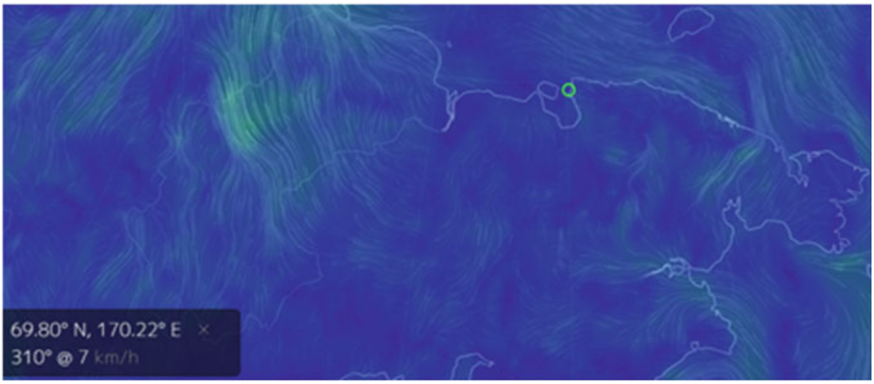

Fig. 5. Wind field image for eastern part of NSR at seaport of pevek on 15th June 2020 visualized with GIDOP earth

Then, proposed GISS for NSR logistics can be used in real practice while climate change and Covid-19 pandemic.

4 Discussion

Proposed above GISS for NSR logistics can be used in educational and training purposes. Note, tasks of training will require a developed learning base within special geo-information systems (GIS) laboratory. It can be undergoing with virtual reality (VR) technologies [18], that can reduce total cost of learning process.

5 Conclusions

In the article, we describe results of digitalization tools development for geo-information support to NSR logistics. During the research, we used Foresight technologies, theory of decision, risk management, methods of data bases constructing, web-technologies and virtual reality tools. As study result, we proposed a block model, that combines the investment objectives with cost of adequate geo-information support, adapted to climate change and Covid-19 pandemic conditions. As research result, we suggest to use GIDOP Earth and GIDOP EOS, including its LV product, as the main technological tools within GISS for NSR logistics. We demonstrate possibilities of proposed GISS for NSR logistics on some examples. As essential result, we propose to use developed GISS for educational and training purposes. The research results presented in this article has significant scientific novelty and can be useful for private investors, public environmental organizations of the civil sector and state environmental control bodies. They can be used in training and educational purposes, including development of Master's programs in environmental economics.

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Logistic Blockchain Platform Project: Railways Case Study

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Abstract. Nowadays, the problem of identifying the features of the implementation and application of blockchain technology in providing information to logistics processes is extremely urgent. The purpose of this work is to analyze the project of the Russian rail freight carrier Russian Railways to create its own blockchain platform. The object of the research is the supply chain management system. The subject of the research is the process of information support of logistics operations using information systems based on blockchain technology. This study describes the possibilities and areas of application of blockchain technology in supply chain management, analyzes world experience in the implementation of logistics information products based on blockchain technology. Moreover, the main risks were identified in the implementation of logistics information products based on blockchain technology. As a result of the work, recommendations were developed for the implementation of the Russian Railways JSC project to create its own blockchain platform, taking into account the studied world experience.

Keywords: Blockchain · Logistics · Platform · Railways · Supply chain management

1 Introduction

Nowadays, information is becoming increasingly important as a resource in social and economic processes. Transformed into knowledge, it is used to increase productivity and improve the quality of management decisions. Today, one of the most advanced technologies for transferring and storing information is the blockchain, or, in other words, a distributed ledger system. The blockchain registry technology is a fundamentally new approach to the creation of databases, the key feature of which is the absence of a single control center, where each of the subjects carries out their work, regardless of the other participants.

In such a field as logistics, the movement of information flows is an integral part of the provision of basic processes. Blockchain, as the most advanced technology, can be used

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in appropriate software products to provide logistics services with a reliable tool for the transmission and storage of information. Nevertheless, among the logistics enterprises of the Russian Federation today, this technology has not received proper distribution. However, JSC "Russian Railways", the largest Russian cargo carrier, announced the start of a project to implement its own information system based on distributed ledger technology.

Accordingly, the problem of identifying the features of the implementation and application of blockchain technology in providing information to logistics processes arises.

The object of the research is the supply chain management system. This system is understood as a set of commercial and government departments interacting with each other to ensure the movement of material and information flows between interested parties.

The subject of the research is the process of information support of logistics operations using information systems based on blockchain technology.

The purpose of this work is to analyze the project of the Russian rail freight carrier to create its own blockchain platform.

2 Materials and Methods

Blockchain is a technology that allows to exchange information securely and privately. It is based on the algorithm for forming a continuous chain of blocks, each of which has its own serial number and contains various information: for example, the amount, date and time of the transaction, as well as the data of its participants. Among other things, each block of data contains information about the fragment that precedes it. Therefore, if it becomes necessary to change the information in a particular block, the participant will also have to change the data in all subsequent fragments [1]. Moreover, copies of block chains are stored on a set of dispersed and unconnected devices, which in total makes the task of changing information practically impossible. Thus, decentralization and a distributed ledger make blockchain the most transparent method of exchanging and storing information between several organizations today.

Logistics is defined as a system for managing material and accompanying information flows. Logistic activity also involves not only the direct transportation of inventory items, but also their storage and preservation, which is also associated with abundant flows of information [2]. Due to the geographical dispersion of logistics operations, the most pressing problem is the lag of the information flow from the material one. In other words, a change in the physical state or location of inventory is not always accompanied by a timely entry into the information system, which, in turn, leads to difficulties in tracking cargo throughout the entire supply chain and complicates the development of timely response measures to unforeseen circumstances. Moreover, the recorded data for different participants in the supply chain can vary significantly, which also complicates the coordination of joint actions [3].

Due to its specificity, blockchain technology has the potential to solve this problem. The tools developed on the basis of this technology can provide a transparent information register, to which all participants in the supply chain will have access to obtain uniform information on the status of inventories. As an additional advantage, the introduction of information products based on blockchain technology into the industry will reduce the costs of ensuring the functioning of material flows: the number of information processing operations and related errors will decrease, the information network will become more secure, and the opportunities for fraud by one of the participants supply chain will be missing [4].

However, according to a 2020 study by Deloitte, more than 50% of large businesses surveyed believe that the capabilities of blockchain technology are exaggerated. Despite the persisting skepticism towards technology through the years, the number of companies that are already investing in blockchain has increased to 40%, most of which are from the financial sector. In the logistics industry, today, blockchain-based products are successfully used by a small number of enterprises. Since blockchain technology has not become widespread on the territory of the Russian Federation, an analysis of the experience of successfully implemented world projects will help determine the feasibility of using the technology, its capabilities and associated risks that should be taken into account if such projects are launched by Russian enterprises [5].

One of the most illustrative projects on the use of blockchain technology in logistics is a joint project of the Danish company Maersk, specializing in sea freight, and IT-company IBM. The platform created within the framework of the project was named "TradeLens", to which 94 partners were connected for testing [6]. Among them are both commercial enterprises and representatives of the customs authorities of several states. The main task of TradeLens is to provide users with the opportunity to implement electronic document management: product certificates and other accompanying documents are stored in an unchanged digital register, which greatly simplifies access and interaction with them. Also, participants can exchange information about ongoing transactions in real time. Moreover, the partners of the platform are integrated with the Internet of Things system, respectively, they have the ability to track various physical indicators, for example, the weight of the cargo or the temperature in the container. The main difference between the platform and a conventional electronic document management system is the ability to provide access to the register to all interested parties and the increased security of information transfer, achieved through the use of blockchain technology and a system of smart contracts [7]. It is noted that TradeLens reduces the volume of paper documents by 10 times, making it faster and easier to write invoices for the goods, issue sanitary certificates, obtain customs permits, invoices for payment and other documents [8]. Thus, the transportation time of the container is reduced by an average of 40%, since most of the time is taken not by the transportation process itself, but by the collection, preparation and processing of all related documentation, while the container itself is idle in the port.

Blockchain technology allows to record the path and state of the products with which operations are carried out. For example, when an expired product is shipped, the system sends a notification to the seller and the buyer about its inadequate condition and other errors made. In the same way, the system excludes "illegal" links in the supply chain: counterfeiting, smuggling and the use of slave labor in industries. Similar processes affect pricing: the end customer has access to information about all the stages that the product went through, which makes it possible to judge the fairness of the declared value. It was revealed that when using other services and, accordingly, when attracting intermediaries, the corresponding commissions can range from 10 to 45% of the value of the entire order. IBM notes that the use of blockchain technology within this platform reduces transportation and administration costs by an average of 80% [9].

The financial company Mastercard has developed a platform based on blockchain technology called Provenance and allows registering transactions throughout the entire supply chain of clothing from the moment of production to the acquisition of a wardrobe item by the end customer [10].

Provenance was developed with the support of major clothing manufacturers who are suffering losses due to the mass production of counterfeits. The launch of the platform was initiated after the Global Brand Counterfeiting Report was released in 2017, according to which counterfeiting losses amounted to more than $ 323 billion. Provenance was supposed to allow manufacturers to control the supply chain, while consumers increase their trust to brands. The developed platform collects an image of a product, data on its origin, position and creates a profile in which all the necessary information is displayed [11].

3 Results

On July 29, 2020, the Russian railway carrier Russian Railways JSC announced the start of a project based on blockchain technology. The project is designed to automate the execution of the terms of contracts and is to implement the concept of "smart contracts" [12].

This concept involves drawing up contracts between stakeholders using blockchain technologies. Once signed by the appropriate method, the obligations take effect. To ensure their automated execution, technology is provided with access to the provisions of the contract—the so-called objects. All objects must have a mathematical description and clear logic of execution. If there is access to the object, the smart contract monitors the achievement or violation of the corresponding clause according to the specified conditions, after which it makes independent decisions based on the parameters set in advance. So, for example, smart contracts can monitor the fulfillment of the terms of long-term loans, transferring the required amounts to specified accounts at the right time. The smart contract also updates the data in the blockchain in accordance with the initially set rules—in this example, committing a transaction from one participant to another [13].

Thus, the concept of a smart contract is designed to automate and confirm the reliability of the execution of contractual relations between counterparties. Blockchain-based contracts can provide better security than traditional law-based contracts and reduce other transaction costs associated with contracting and potential legal costs.

Thus, the task of JSC "Russian Railways" was to create a unified environment for the interaction of all participants in the transport and logistics chains. As a result of the competition, the environment should be based on "Hyperledger Fabric" and provide participants with reliable information about the state of processes, the status and execution time of operational procedures. In the specified database, it is necessary to record the entire history of changes in the relevant information, which should be available to all participants in the business process, as well as to ensure, upon the occurrence of key events, the automatic calculation of financial obligations enshrined in the smart contract. Also from the point of view of the technical components of the platform, the project task includes Apache software products, which are responsible for the implementation of the concept of the Internet of Things and its integration with the main blockchain platform [14]. The sources of primary data will be the branch information systems of Russian Railways, information systems of partners and external participants, as well as sensors for positioning and monitoring the condition of the cargo using the Internet of Things technology.

Thus, the blockchain platform that Russian Railways plans to implement is designed to perform the following tasks:

1. Integration of all subdivisions of Russian Railways into a single information base.
2. Integration of all counterparties of Russian Railways into a single information base.
3. Monitoring of all cargo operations throughout the full cycle of cargo transportation using the Internet of Things technology.
4. Registration in the distributed register of all operations with cargo during the full cycle of cargo transportation.
5. Automation of the execution of contract terms using smart contract technology.

As a result, Russian Railways expects an increase in the transparency of logistics processes, a decrease in the volume of work with documents due to its automation and a reduction in labor costs for calculating fees for additional services and fines. The already mentioned company Maersk will act as a partner in the implementation of this project. This partnership involves joint development of the potential of blockchain platforms, exchange of experience and possible integration into common information systems [15].

Representatives of Russian Railways do not disclose data on the results of the first stage of testing design solutions at the Oktyabrsky railway test site, but they note that the pilot launch went well and the company is ready to start implementing the second stage. The implementation of the first stage could be to a greater extent really successful, since we have examples of successful similar projects for the implementation of technological and software architectures, while Russian Railways has the necessary economic potential to invest in the required software products and attract the appropriate specialists. Moreover, the platform with the distributed registry technology Hyperledger Fabric, which is already used in similar software products and has successfully proven itself, was chosen as the basis for the implementation of the project. Despite this, the main risks of the project appear precisely at the second stage: in the future, interaction with many counterparties and government agencies is expected. To implement these interactions, an appropriate legislative framework is required, which is designed to regulate relations between counterparties. To date, Russian legislation does not meet the requirements of the interaction system through blockchain platforms. For example, according to the rules of maritime trade, a certain package of documents is traditionally transmitted in paper form, which contradicts the concept of electronic document management. While maintaining the current rules of electronic document management, the project will not demonstrate the expected effects from the spread of the blockchain platform throughout the entire supply chain. Moreover, with the introduction of third-party carriers and consignees into the blockchain system, the model of their communication and mutual settlements changes dramatically. In the judicial practice of the Russian Federation, there are no cases of conflict regulation when using such models. Thus, expecting a decrease in the volume of claims work, Russian Railways may achieve the opposite effect, reflecting its growth. Also, one of the obstacles may be the need for investment in the necessary security from the side of adjacent carriers and consignees [16].

4 Discussion

This project can be presented through the prism of SWOT analysis. The strengths of this project are a detailed technical task, the availability of a reliable supplier of information support, a sufficient budget for implementation, which is confirmed by the paramount importance of this project area within the company. Weaknesses are represented by the insufficiently progressive nature of the project implementation at the stage of integration of counterparties and the lack of experience in implementing such solutions on the territory of the Russian Federation. Also, the weakness of this project lies in the peculiarities of the interaction of hardware elements in the monitoring process: to implement the possibility of monitoring the cargo, an Internet connection is required. Today, the level of network coverage on the territory of the Russian Federation on some sections of the railway does not meet the requirements of the hardware part of the blockchain platform. The possibilities of this project are expressed in the cooperation of Russian Railways JSC with the Maersk company: the sea cargo carrier Maersk already has and is actively developing its own blockchain platform, accordingly, it can provide active support and, as stated, carry out joint integration within the framework of corporate blockchain platforms [17, 18]. Also, in the event of a successful launch, this platform can be extended to other types of cargo transportation, and, possibly, be transformed into a single logistics platform for interaction between shippers, carriers and consignees. Threats to the project are institutional in nature and are represented by the unavailability of the relevant legislative framework in the field of document flow, as well as the lack of approved measures to regulate relationships in the context of interaction between organizations through information systems based on distributed ledger technology [19]. Also, an external threat is the dependence of the project result on the actions of the counterparties with which Russian Railways cooperates.

Accordingly, based on the SWOT analysis carried out, a number of strategies can be developed. A breakthrough strategy is about balancing benefits and opportunities, creating an understanding of how the project's strengths will help realize the opportunities presented. Thus, close cooperation with Maersk will allow us to jointly integrate into corporate networks, creating a software and hardware base for organizing a common logistics platform for interaction of all participants in the supply chain.

Transition Strategy # 1 is shaped by balancing strengths and threats, reflecting the benefits of a project to avoid potential threats. As the largest cargo carrier in the Russian Federation, Russian Railways can create an initiative group to develop and propose appropriate amendments to the legislation regulating aspects related to the use of distributed ledgers. Also JSC "Russian Railways" can provide assistance to its partners to connect to the new information system.

Transition Strategy #2 presents the balance of weaknesses with opportunities and shows how to get away from the weaknesses of the project, turning them into strengths.

For example, close cooperation with Maersk will allow to take into account the key experience in the implementation of projects for the formation of blockchain platforms. Having formed a strong hardware and software base, Russian Railways can attract relevant organizations to improve the communications infrastructure.

In general, a prerequisite for the successful implementation of the project is the interaction of Russian Railways with Maersk and government agencies. The following are the activities that need to be carried out:

1. Development and proposal of relevant amendments to the legislation governing electronic document management.
2. Development and proposal of relevant amendments to the legislation regulating interaction with counterparties when interacting through platforms based on distributed ledger technology.
3. Sequential approbation of interaction with government agencies through the blockchain platform.
4. Development of measures to provide assistance to the main related freight carriers and consignees when connecting to the blockchain platform.
5. Integration into the corporate information system Maersk to obtain primary data.

Thus, if appropriate measures are taken to eliminate the identified risks, Russian Railways will be able to achieve the expected effects from the introduction of blockchain technology.

5 Conclusions

Thus, after analyzing the experience of successfully implemented projects, we can conclude that platforms based on blockchain technology are used to integrate several participants in information flows - government agencies, manufacturers, consumers and intermediaries. The use of blockchain technology in information systems makes it possible to promptly provide all interested parties with relevant transparent and reliable information: product features, accompanying documentation, product location and condition. Also, the use of blockchain technology makes it possible to automate document flow, reduce product losses and the number of errors in registration, reduce the number of intermediaries and reduce the duration of the logistics cycle, which leads to a significant reduction in the cost of the transportation of inventory items. A feature of this technology in relation to classical information systems is its security due to a distributed data register, which excludes the possibility of fraud attempts by any of the participants in the supply chain. The main risk is the absence in many industries of the appropriate legal framework suitable for the new model of information and document exchange. Also, connecting to an existing blockchain platform implies significant costs, while developing own is a much more expensive project.

The plans of Russian Railways to implement a platform based on blockchain technology reflect the interest of large Russian logistics companies in a distributed ledger. The share of freight turnover of rail transport in the Russian Federation is 87% of the total freight turnover, which makes JSC Russian Railways the largest freight carrier in the country. The implementation of the blockchain platform will allow the organization to significantly reduce the costs of administration and claim work, as well as achieve a significant increase in transparency throughout the entire duration of the transportation cycle. One of the significant obstacles in the implementation of solutions of this class is the significant cost of development and implementation of software and hardware, but Russian Railways has the necessary economic potential to make investments in the required volumes. Nevertheless, the institutional risks caused by the emergence of a new model of interaction between participants in logistics cycles can significantly affect the plans of Russian Railways to use blockchain technology. These risks include the lack of the necessary provisions in the legislative framework regarding electronic document management. In turn, this may lead to incomplete disclosure of the potential of the blockchain platform being implemented. Accordingly, the main priority in the implementation of the project should be close interaction with government agencies to eliminate the identified risks. In case of successful implementation and application of the blockchain platform by Russian Railways in the Russian Federation, the possibility of using this technology by other logistics enterprises will also be indicated.

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Development of Integrated Logistics Systems of Russian Large Metallurgical Companies in the Context of Digitalization

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Abstract. In the context of the digitalization of the Russian economy, the existing logistics systems of industrial companies are undergoing major changes: new technologies and tools are emerging that are actively developing under the concept of "Industry: 4.0". Large metallurgical companies, as industry leaders, are actively improving their integrated logistics systems, which can improve the economic efficiency of economic entities. The article provides an overview of "best practices" regarding the development of integrated logistics systems of large metallurgical companies in Russia in the context of digitalization over the past decade: PJSC "Novolipetsk Iron and Steel Works" (17th place in the RBC-500 rating for 2019), PJSC "Severstal" (24 place in the indicated rating) and PJSC "Magnitogorsk Iron and Steel Works" (26 place in the specified rating). It is shown that the active introduction of modern logistics systems created using the Industry 4.0 concept allowed these companies, ceteris paribus, to achieve a higher level of business efficiency. For research, the following methods were used: analytical review, comparison, statistical calculations, methods of economic and mathematical modeling. A technique for assessing the state of the integrated logistics system of an industrial company is proposed. In a further study, it is advisable to monitor the level of development of integrated logistics systems of large industrial companies in order to develop the experience of "best practices" in the domestic industry.

Keywords: Logistics system · Digitalization · Industry 4.0 · Industry · Metallurgical industry · Efficiency

1 Introduction

According to modern ideas, logistics refers to the managerial aspects associated with the acquisition, maintenance and transportation of materials, people and objects, and also corresponds to the process of planning, implementing and controlling an optimized

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flow of goods, services and information from the point of departure to the destination to satisfy consumer demand [1].

One of the directions for the formation of the competitive advantages of large metallurgical companies in the market economy is the improvement of their integrated logistics systems as complex organizationally structured and interconnected elements of the mechanism for managing material, financial and information flows [2, 3].

This work is carried out by organizations continuously for several decades, as a necessary part of management aimed at increasing business efficiency. At the end of the first decade of the twenty-first century, the authors took part in the development of methodological provisions for an integrated system of marketing and logistics controlling of industrial enterprises based on standard management and control tools, including:

- international financial reporting standards;
- models for creating corporate value;
- new approaches to planning;
- process-oriented management;
- balanced scorecard systems;
- modern information technologies;
- customer relationship management;
- change and risk management [4, 5].

At the end of the second decade of the twenty-first century, the complex logistics systems of industrial enterprises face new challenges and development prospects related, first of all, to the digitalization of the Russian economy. At the same time, the use of digital data and digital platform [6] for the organization and management of business processes can be considered as a key factor in the development of production, which allows you to create new business models and provides competitive advantages in international markets. All countries, regardless of their level of economic development, are transitioning to the digital economy [7].

Currently, there is no doubt that the logistics sector in the digital economy is one of the powerful drivers for the development of industrial production and increasing the competitiveness of individual companies and industries [8]. At the same time, experts note that for the Russian Federation, the main areas of logistics development are:

- automation and robotization of existing production processes [9];
- outsourcing of non-core activities;
- optimization of costs associated with the management of business processes;
- improvement of legislative regulation of the introduction of modern financial technologies [10].

Moreover, the development of logistics systems is considered in the framework of the concept of "sustainable development", which allows harmonizing the economic, social and environmental business [11]. Thus, in the middle of the twentieth century, foreign researchers singled out "logistic problems of the company" as an independent direction [12], and now they argue that measuring the sustainability of the logistics activities of industrial enterprises can significantly contribute to achieving the goals proposed by the UN in the field of sustainable development [13].

According to the ideas of modern scientific thought [9], the logistics system consists of several components that can be divided into key types of activity: managing the main business processes in order to fully satisfy the needs of consumers of the final product (order processing, delivery of finished products to consumers, inventory and flow management information) and supporting activities (storage, processing of materials, procurement management, packaging design and information management). Improving logistics activities is an integral part of an industrial organization's strategy and is critical to business success. Given that logistics planning is an integral part of business competitiveness management, it is necessary to integrate all areas of business activity, thereby ensuring the quality of logistics services [14]. Companies should also consider the impact of logistics activities on the sustainability of their development [15] and business security [16].

The purpose of this study is to analyze "best practices" in the formation of logistics systems of the largest metallurgical companies in Russia in order to identify key trends and development drivers in this area of business process organization.

2 Materials and Methods

For research, the following methods were used: analytical review, comparison, statistical calculations, methods of economic and mathematical modeling. The authors relied on data obtained from an analysis of sources presented in the public domain on the official websites of the analyzed companies.

The object of the study was the largest metallurgical holdings of the Russian Federation: PJSC "Novolipetsk Iron and Steel Works" (hereinafter referred to as PJSC "NLMK", 17th place in the RBC-500 rating [17] for 2019), PJSC "Severstal" (24th place in the rating) and PJSC "Magnitogorsk Iron and Steel Works" (hereinafter referred to as PJSC "MMK", 26th place in this rating).

3 Results

Analysis of the main economic results of the largest metallurgical companies in Russia made it possible to formulate the main trends in their economic development. It should be emphasized that the negative aspects of the development of the metallurgical business of large Russian companies were primarily associated with significant environmental factors: a decline in economic activity in industries that are key consumers of metal products, geopolitical sanctions, increased activity of Chinese metallurgists, etc. However, starting in 2015, there has been a fairly steady increase in the economic indicators of the organizations under study, which is due, inter alia, to a closer attention of company management to existing logistics problems, and is confirmed by information presented on official websites and in annual reports.

In particular, according to public annual reports, in 2015 PJSC "NLMK" actively introduced innovations in its business processes, including logistics [18], achieving "optimal logistics" due to the organization of metal production in regions with developed infrastructure and close to sources of raw materials, which, without a doubt, reduces logistics risks and costs. In addition, the Strategic Planning Committee of PJSC "NLMK" since 2017 actively worked on the consolidated "Strategy 2022", including logistics, as a functional area of business, which led to an increase in the operational efficiency of all key production processes.

At the same time, suppliers and contractors are ensured transparency of competitive procedures for the procurement of goods and services, timely fulfillment of contractual obligations, the presence of an effective feedback system and work with complaints, the effectiveness of a risk management and anti-corruption system. And for consumers of metal products relevant: compliance with contractual obligations, the provision of high quality products, development of assortment policy, competitive pricing, timeliness and reliability of supplies [18]. In order to more effectively introduce these values into business practices, PJSC "NLMK" in 2017 together with SAP created the first innovation laboratory in Russian metallurgy, which creates digital prototypes of innovative ideas in order to test their applicability in practice. For example, now artificial intelligence, trained by machine methods, helps to solve the problem of using ferroalloys at various stages of steel production [18].

PJSC "Severstal" also demonstrates significant achievements in the field of digitalization in implementing the logistics approach to managing business processes, highlighting key development areas in which elements of an integrated logistics system occupy an important place: "customer focus", "quality of service", "product quality" and "discipline of supplies." At the same time, the company's short-term investment program is aimed at reducing costs and increasing customer focus, and in the near future, the active use of Big Data technologies, the Internet of Things and diagnostic services, which, according to the company's specialists, will further optimize logistics costs [19].

In developing the general trend of improving the logistics approach to managing metallurgical companies, PJSC "MMK" not only improves its integrated logistics system, increasing operational and functional efficiency, but also actively participates in various competitions: for example, in 2018, the company became the 24th winner Of the International Industrial Exhibition "Metal-Expo 2018" and received a gold medal for the development and implementation of the information system for production logistics of a metallurgical enterprise [20].

An automated system for operational and calendar planning of production (hereinafter referred to as AS OCPP) is a key element in the implementation of the Just in Time logistic concept at PJSC "MMK", which allows for the production and delivery of metal products to customers on schedule, as well as to reduce variable storage costs thanks to the fully coordinated work of different departments of the organization. Development of AS OCPP allows increasing the productivity of units and reducing the "delivery window"—the period during which the order must be executed.

The main goal of the ongoing project was the significant development of customer service. The implementation of AS OCPP allows PJSC "MMK" to provide completely new services for an enterprise of this scale:

- calculation of the date of shipment at the time of receiving orders with accuracy that suits both sides of the process;

- the formation of a schedule for the production and shipment of the order for both the client and the production staff;
- creation of a customer portal with the provision for him of all the information he is interested in, including the ability to track the progress of his order in the factory's redistribution [21].

In addition, in 2019, at a Russian inter-industry summit "Industry 4.0: Digital Plant", organized by the Ministry of Industry and Trade of the Russian Federation, PJSC "MMK" introduced a unique electronic document management system that allowed significant savings in working time when making logistics transactions. A commercial version of the system was offered for sale to all interested parties [20].

Given that the introduction of innovations in logistics is a labor-intensive and expensive process, the authors propose a methodology for assessing the state of the integrated logistics system of an industrial company, which will allow management of organizations to assess the degree of change in the quality parameters of the existing logistics system of the organization (group of companies) and outline directions for its development and further improvement (Table 1).

For analysis purposes, it is advisable to consider ten elements (subsystems) of an integrated logistics system (ILS) of an organization (table), the functional dependence of which can be represented by the formula:

$$ILS = f\,(Pur;\ Wh;\ St;\ Prod;\ Distr;\ S;\ F;\ Inf;\ Pers) \tag{1}$$

Using expert opinion, you can evaluate the work of each area on a 10-point scale: from "0"—"complete lack of work" to "10"—"maximum work efficiency". The authors propose the following general rating scale:

- from 86 to 100 points—excellent work of an integrated logistics system of the organization;
- from 71 to 85 points—good work;
- from 51 to 70 points—satisfactory work;
- up to 50 points—unsatisfactory work.

The scale for an individual assessment of the performance of individual subsystems of an integrated logistics system of an organization is also advisable to vary:

- from 8.6 to 10 points—excellent work of the subsystem;
- from 7.1 to 8.5 points—good work;
- from 5.1 to 7 points—satisfactory performance;
- up to 5 points—unsatisfactory work.

Fractional points are obtained due to the involvement of several experts in assessing the state of the integrated logistics system of an industrial company, who can set different quantitative estimates.

It should be noted that for the most expensive logistics subsystems, such as "Stocks", it is advisable to use mathematical modeling methods, with which you can achieve the optimal cost option, which provides significant savings on logistics costs.

Table 1. Ten elements (subsystems) of the integrated logistics system of the organization

Name and content of the subsystem	Goal	Tasks
1. Purchase (Pur) (Material flows directly from the supplier)	Minimization of costs for the purchase of raw materials, materials, etc.	Organization and Procurement Managemen
2. Warehouses (Wh) (Warehouse areas (buildings, structures, etc.), technical means for moving and processing material flow in the "storage space")	Minimizing the cost of storing stocks and their associated cargo handling in the warehouse	Organization of warehouse facilities and management of the movement of goods within the "warehouse space"
3. Stocks (St) (The presence of material stock guarantees high adaptability to a changing market situation, but involves justification of the optimal value of stocks)	Inventory optimization	Inventory Management
4. Transport (Tr) (The process of ensuring the uninterrupted and timely functioning of the elements of the logistics system as a whole)	Minimization of material transportation costs	Organization and management of transport processes
5. Production (Prod) (Transformation (processing) of the incoming material flow into products demanded by the market with minimal costs and specified quality)	Cost optimization for the production of products, goods, works and services	Organization and effective management of production processes
6. Distribution (Distr) (The disposal of material flow from the production subsystem and its entry through logistics channels and chains with minimal costs to places of potential consumption)	Minimization of distribution costs for products, goods, works and services	Organization and effective management of the distribution of material flows

(*continued*)

Table 1. (*continued*)

Name and content of the subsystem	Goal	Tasks
7. Sales (S) (Timely implementation of finished products, goods, works and services to consumers with related logistics services in the right place and at the appointed time)	Minimization of costs for the sale of products, goods, works and services and related logistics services	Organization and Sales Management
8. Finance (F) (Financial services for all elements of the logistics system)	Timely provision of all elements of the logistics system with financial resources to achieve a given level of efficiency	Timely provision of the organization's activities with financial resources at a given level of efficiency
9. Information (Inf) (Providing information communication between all elements of the logistics system with a simultaneous management and control function)	Minimizing the cost of storing, transmitting and processing information in a digital enterprise	Organization and management of information flows
10. Personnel (Pers) (Provision of personnel for all elements of the logistics system)	Optimization of the degree of influence of the human factor in the performance of the logistic functions of the system	Management of the process of performing logistics operations in the context of a "knowledge economy"

4 Discussion

Starting in 2015, there has been a fairly steady increase in the economic indicators of the organizations under study, which is due, inter alia, to a closer attention of company management to existing logistics problems, and is confirmed by information presented on official websites and in annual reports.

In order to more effectively introduce these values into business practices, PJSC "NLMK" in 2017 together with SAP created the first innovation laboratory in Russian metallurgy, which creates digital prototypes of innovative ideas in order to test their applicability in practice. For example, now artificial intelligence, trained by machine methods, helps to solve the problem of using ferroalloys at various stages of steel production.

PJSC "Severstal" also demonstrates significant achievements in the field of digitalization in implementing the logistics approach to managing business processes.

At the same time, the company's short-term investment program is aimed at reducing costs and increasing customer focus, and in the near future, the active use of Big Data technologies, the Internet of Things and diagnostic services, which, according to the company's specialists, will further optimize logistics costs.

An automated system for operational and calendar planning of production (hereinafter referred to as AS OCPP) is a key element in the implementation of the Just in Time logistic concept at PJSC "MMK", which allows for the production and delivery of metal products to customers on schedule, as well as to reduce variable storage costs thanks to the fully coordinated work of different departments of the organization.

Given that the introduction of innovations in logistics is a labor-intensive and expensive process, the authors propose a methodology for assessing the state of the integrated logistics system of an industrial company, which will allow management of organizations to assess the degree of change in the quality parameters of the existing logistics system of the organization (group of companies) and outline directions for its development and further improvement.

5 Conclusions

One of the directions that allowed large metallurgical companies in Russia to overcome the crisis was the introduction of integrated logistics systems, the development of which at the end of the second decade of XXI occurs within the framework of the "Industry: 4.0" and the concept of sustainable development.

The dynamics of indicators of PJSC "NLMK", PJSC "Severstal" and PJSC "MMK" indicate that the steady growth of the business over the past 3 years coincided with the emergence of new, "digital" trends in logistics development.

The authors propose a methodology for assessing the state of the integrated logistics system of an organization (industrial company), allowing its management to evaluate the effectiveness of the implemented logistics systems and identify the most promising directions for its development.

Further research in this area can be aimed at identifying the features of the impact of the logistics systems of metallurgical companies on the environment and society as a whole in accordance with the principles of the concept of sustainable development, as well as modeling the effectiveness of all logistics processes working into innovative "digital" technologies.

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Forecasting of Supplies in Liquidation of Emergency Situations

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Abstract. In the article, the management of transport and logistics services and forecasting of cargo deliveries in emergency situations is considered. Emergencies cause significant damage to the economy and society. Effective response to the consequences of emergencies is determined by many factors. One of them is the adequacy of the decisions taken to organize the delivery of special cargo to emergency zones. This problem does not yet have a satisfactory solution. The authors present an approach that implements forecasting options for the supply of goods to the special forces engaged in emergency situations based on the mathematical apparatus of fuzzy set theory. A mathematical model has been developed that allows finding the optimal supply option in the conditions of representing the needs for cargo in the form of fuzzy numbers. An effective algorithm for implementing the developed model is proposed. Recommendations for its practical use are given.

Keywords: Optimal cargo delivery plan · Mathematical models · Fuzzy set · Fuzzy number · Membership function · Cargo delivery forecasting

1 Introduction

The stability of socio-economic development at the national level in recent years due to the development of the fourth technological revolution is subject to challenges and threats [1–4]. The success of this development depends not only on the policies implemented by the authorities, the actions of civil society institutions and the processes of market self-regulation, but also on accidents. For this reason, Michael Porter's "competitive rhombus" scheme includes, along with key factors, random events [5]. Key factors that

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determine competitiveness include: parameters of factors, demand parameters, related and supporting industries, strategy of firms, their structure and competition. In addition, the competitiveness is influenced by random events.

In the analysis of processes and results of socio-economic development, as a rule, not enough attention is paid to random events. This is largely due to the inability to influence them. Meanwhile, random events, the development of which leads to emergencies, can play a dramatic role in the socio-economic development of countries and regions. They can significantly slow down the development process and lead to regression.

The scale of emergencies caused by various accidents is very large in the world. According to the United Nations Office for Disaster Risk Reduction (UNDRR), cited in the report "The Human Cost of Disasters 2000–2019", the cumulative material damage caused to the global economy by emergency situations over the past twenty years amounted to about US $ 3 trillion, negative consequences emergencies have changed the lives of over 4 billion people worldwide. Equally important is the impact of emergencies on the socio-economic systems of individual countries. According to official data, 266 emergency situations occurred on the territory of the Russian Federation in 2019 (Table 1) [6].

Table 1. Indicators of emergency situations in Russia, 2019.

Emergency type	Share in total, %	Number of deaths, people	Number of injured people	Damage, million rubles
Technogenic	75.94	498	2532	4751.47
Biological-social	5.64	0	5	736.45
Natural	18.42	34	118,374	15,019.96
Total	100	532	120,911	20,507.88

Thus, forecasting of emergency situations, countering their occurrence and prompt elimination of the consequences caused by them are an important task. This task should be solved at the official level—national and regional authorities, as well as international organizations. A significant number of studies are devoted to its solution [7–12]. They consider actions to prevent and eliminate the consequences of various types of emergencies, taking into account their peculiarities, as well as assessing risks and damage.

A key feature of almost any emergency situation, regardless of its scale and cause of occurrence, is a clear spatial localization. The area where the emergency occurred is called the "emergency zone". Special measures are taken to effectively and promptly eliminate the consequences of an emergency and restore the normal life of the population and business in the emergency zone. At the same time, the transport connectivity of the emergency zone and the rest of the region plays a key role in achieving their success [13–15]. The presence of a stable transport connection allows to evacuate the population and quickly transfer emergency and other special crews to the emergency zone, as well as carry out the transportation of a significant volume of cargo in a short time.

Based on the experience of EMERCOM of Russia, it can be noted that when managing emergency response processes, as a rule, it is impossible to clearly determine the transport situation on the road network. This is due to both damage (destruction, flooding) of transport facilities (bridges, tunnels, defiles, etc.), and the uncertainty of special crews and the population needs at the emergency zone due to the insufficient quality of information support systems [16–20]. Therefore, the planning and organization of efficient cargo transportation is an urgent task. The author's research is aimed at solving this problem.

2 Material and Methods

In emergency situations, in the mathematical models of transport and logistics services in the interests of EMERCOM of Russia formations, not all initial data can be specified accurately. Therefore, we propose to use the theory of fuzzy sets for modeling [16, 18]. In order to predict effective cargo deliveries to EMERCOM of Russia crews in emergency situations, the study used a multi-stage transport model (task) of linear programming [17, 18, 20], in which the needs of special crews in cargo are fuzzy and are specified using fuzzy numbers.

Further, we define the variables to be used. In order to provide transport and logistics services to the EMERCOM of Russia crews participating in the elimination of the consequences of emergencies, m bases (warehouses) of cargo are used. The demand for goods of the j-th consumer ($j = 1, 2, ..., n$) in the—τ-th day of the emergency ($\tau = 1, 2, ..., T$) is $P_{j\tau}$ (tons). The possibilities of cargo receiving in the i-th ($i = 1, 2, ..., m$) supplier of goods on the τ-th day of the emergency are equal $V_{i\tau}$ (tons). The costs of purchasing a unit of cargo in the i-th supplier of goods and delivering it to the j-th consumer of goods on the τ-th day of the emergency are $C_{ij\tau}$ (rubles).

The solution to the problem is a cargo delivery plan—X, i.e. volumes of cargo planned for delivery in every τ-th day of an emergency from each i-th supplier to each j-th cargo consumer:

$$X = \left(x_{1,1,1}, x_{1,1,2}, ..., x_{1,1,T}, ..., x_{m,n,T}\right).$$

It is necessary to determine a plan for the supply of goods, which would ensure the timeliness and completeness of their delivery to the EMERCOM of Russia crews participating in the elimination of the consequences of the emergency. At the same time, the financial costs associated with the implementation of the cargo delivery plan should be minimal.

The mathematical formulation of the multistage transport model (problem) is as follows:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{\tau=1}^{T} C_{ij\tau} \cdot x_{ij\tau} \to min, \tag{1}$$

Model constraints:

$$\sum_{j=1}^{n} x_{ij\tau} \le V_{i\tau}, \ \ i = 1, 2, ..., m, \ \ \tau = 1, 2, ..., T, \tag{2}$$

$$\sum_{i=1}^{m} x_{ij\tau} \geq P_{j\tau},\ j = 1, 2, ..., n,\ \tau = 1, 2, ..., T, \tag{3}$$

$$x_{ij\tau} \geq 0,\ i = 1, 2, ..., m,\ j = 1, 2, ..., n,\ \tau = 1, 2, ..., T. \tag{4}$$

Suppose that to meet the needs for cargo of the EMERCOM of Russia crews in full, there may not be enough stocks, so their needs $P_{j\tau}$ $(j = 1, 2, ..., n,\ \tau = 1, 2, ..., T)$ are considered as fuzzy.

Clarifying the mathematical setting of the problem (1)–(4), suppose that the consumer with the number j is ready on the τ-th day of the emergency to agree to a certain decrease in his needs compared to the value $P_{j\tau}$, and $\beta_{j\tau}$—the maximum amount of underdelivery that this consumer can agree to on these days. We define the need for cargo of the j-th consumer in the τ-th day of the emergency as a fuzzy number:

$$\hat{P}_{j\tau} = \langle P_{j\tau} - \beta_{i\tau};\ P_{j\tau};\ +\infty \rangle,\ j = 1, 2, ..., n,\ \tau = 1, 2, ..., T.$$

We assume that there may not be enough stocks $V_{i\tau}$ $(i = 1, 2, ..., m,\ \tau = 1, 2, ..., T)$ to meet the needs in volumes $P_{j\tau}(j = 1, 2, ..., n,\ \tau = 1, 2, ..., T)$ with the values of the membership functions equal to one, but they are enough to meet the minimum requirements.

$$P_{j\tau} - \beta_{i\tau}\ \ (j = 1, 2, ..., n,\ \tau = 1, 2, ..., T)$$

.

We emphasize that the greater the deficit, the lower the value of the membership function, which we will interpret as the degree of confidence that the consumer is satisfied. We will designate the membership function $\mu_{\hat{P}_{j\tau}}$ of a fuzzy number $\hat{P}_{j\tau}$.

Define $P_{j\tau\,\min} = P_{j\tau} - \beta_{j\tau}$, then

$$\mu_{\hat{P}_{j\tau}}(u) = \begin{cases} \frac{u - P_{j\tau\,\min}}{P_{j\tau} - P_{j\tau\,\min}}, & if\ u \in \left[P_{j\tau\,\min},\ P_{j\tau}\right], \\ 1, & if\ u > P_{j\tau}, \\ 0, & if\ u < P_{j\tau\,\min}. \end{cases}$$

Let us consider the task in which it is required to find a variant of the cargo delivery plan, in which the degree of confidence that it is efficient in terms of costs and the level of consumer provision is maximum. Let us denote by $S_{\min}$—the minimum total costs for the delivery of goods for the case when the daily needs of consumers are minimal, i.e. are equal $P_{j\tau\,\min} = P_{j\tau} - \beta_{j\tau}$ $(j = 1, 2, ..., n,\ \tau = 1, 2, ..., T)$.

The degree of confidence that the proposed option for organizing the cargo delivery is effective will be characterized by the value of the membership function of the received costs, determined by a fuzzy number— S_u"costs are almost minimal", which describes our goal. We emphasize that the greater the difference between costs:

$$S(X) = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{\tau=1}^{T} C_{ij\tau} \cdot x_{ij\tau}$$

,

associated with the variant of the cargo delivery plan X, and the value $S_{\min}$, i.e. the difference $S(X) - S_{\min}$, the less we are confident that the plan X is effective.

Define $S_{ц}$ as a fuzzy number $\langle -\infty;\ S_{\min};\ S_{\max}\rangle$ with a goal membership function $\mu_{ц}$, where $S_{\max}$—are the minimum costs that are a solution to problem (1)–(4):

$$\mu_{ц}(X) = \begin{cases} 0, & if\ X - invalid\ plan, \\ \dfrac{S_{\max} - S(X)}{S_{\max} - S_{\min}}, & if\ X - acceptable\ plan. \end{cases}$$

We give the constraints (3), assuming that their right-hand sides are fuzzy numbers $\hat{P}_{j\tau}$: $\sum_{i=1}^{m} x_{ij\tau} \geq \hat{P}_{j\tau},\ j = 1, 2, \ldots, n,\ \tau = 1, 2, \ldots, T.$

Given that $\hat{P}_{j\tau}$ are fuzzy numbers, these constraints specify fuzzy sets with membership functions $\mu_{j\tau}$:

$$\mu_{j\tau}(X) = \begin{cases} 1,\ if\ \sum_{i=1}^{m} x_{ij\tau} \geq P_{j\tau}, \\ \mu_{\hat{P}_{j\tau}}\left(\sum_{i=1}^{m} x_{ij\tau}\right),\ if\ \sum_{i=1}^{m} x_{ij\tau} < P_{j\tau}. \end{cases}$$

According to [18], the optimal variant must belong to all fuzzy sets with membership functions $\mu_{j\tau}$ ($j = 1, 2, \ldots, n,\ \tau = 1, 2, \ldots, T$) and, in addition, it must belong to a fuzzy set of goals with a membership function $\mu_{ц}$, that is, it must belong to the intersection of the indicated fuzzy sets. The membership function of this intersection is:

$$\mu_{\cap}(X) = \min\left\{\mu_{ц}(X), \mu_{j\tau}(X)\ npu\ j = 1,2,\ldots,n, \tau = 1,2,\ldots,T\right\}.$$

The function $\mu_{\cap}(X)$ characterizes the degree of our confidence that the cargo delivery plan X is effective in terms of total costs and the level of customer provision. The degree of this confidence needs to be maximized.

3 Results

Using the above initial assumptions and notations, we obtain the following formulation of a fuzzy mathematical model of a multistage transport problem:

$$\mu_{\cap}(X) \to \max, \tag{5}$$

$$\sum_{j=1}^{n} x_{ij\tau} \leq V_{i\tau},\ \ i = 1, 2, \ldots, m,\ \ \tau = 1, 2, \ldots, T, \tag{6}$$

$$\sum_{i=1}^{m} x_{ij\tau} \geq \hat{P}_{j\tau},\ j = 1, 2, \ldots, n,\ \tau = 1, 2, \ldots, T, \tag{7}$$

$$x_{ij\tau} \geq 0,\ i = 1, 2, ..., m,\ j = 1, 2, ..., n,\ \tau = 1, 2, ..., T. \quad (8)$$

It should be emphasized that in contrast to the model (1)–(4), the right-hand sides of the constraints from (7) are fuzzy numbers.

Suppose that:

$$X^* = \left(x^*_{1,1,1},\ x^*_{1,1,2}, ...,\ x^*_{1,1,T}, ...,\ x^*_{m,n,T}\right)$$

—optimal task plan (5–8),

It is clear that X^* is a solution to the following problem with precise constraints:

$$\mu_{\cap}(X) \to \max, \quad (9)$$

$$\sum_{j=1}^{n} x_{ij\tau} \leq V_{i\tau},\ \ i = 1, 2, ..., m,\ \ \tau = 1, 2, ..., T, \quad (10)$$

$$\sum_{i=1}^{m} x_{ij\tau} \geq b_{j\tau},\ \ j = 1, 2, ..., n,\ \ \tau = 1, 2, ..., T, \quad (11)$$

$$x_{ij\tau} \geq 0,\ \ i = 1, 2, ..., m,\ j = 1, 2, ..., n,\ \ \tau = 1, 2, ..., T. \quad (12)$$

Statement. The plan X^* is a solution to problem (9)–(12) as well in the case when the right-hand sides $b_{j\tau}$ of all constraints from (11) are such that $\mu_{\overleftarrow{P}_{j\tau}}\left(b_{j\tau}\right) = Q$.

Evidence. Since smaller values of the membership functions correspond to smaller values of the right-hand sides of the constraints from (7) and

$$Q \leq \mu_{\hat{P}_{j\tau}}\left(b_{j\tau}\right),\ j = 1, 2, ..., n,\ \tau = 1, 2, ..., T,$$

then, when replacing numbers $b_{j\tau}$ in (11) with numbers $\tilde{b}_{j\tau}$ such that $\mu_{\hat{P}_{j\tau}}\left(\tilde{b}_{j\tau}\right) = Q$, the set of feasible plans of the resulting problem will contain all feasible plans of a task (9)–(12). Hence, with such a replacement, the value of the objective function of problems (9)–(12) cannot worsen, i.e. become smaller Q. This completes the proof of the statement.

We propose for the approximate solution of the problem (5)—(8) the following algorithm.

Step 1. Calculation of the values for the minimum daily requirements of consumers $S_{\min}$, and for the daily needs of consumers in problem (1)–(4)—$S_{\max}$ and the values of the function $\mu_{\eta}$for them.

Step 2. Modification for the k-th $(0 \leq k \leq N - 1)$ step of the values of the membership functions of fuzzy numbers $\hat{P}_{j\tau}$ (starting from 0) by the value $\varepsilon = \frac{1}{N}$, where N is the number of steps of the algorithm.

Step 3. Calculation at the k-th step for each j-th consumer of the values $b^k_{j\tau} = \frac{k}{N}\left(P_{j\tau} - P_{j\tau\,\min}\right) + P_{j\tau\,\min}$, and on their basis the values of the functions $S_k(X)$ (the optimal value of the objective function of the constructed problem), $\mu_{ij}$and the values of the objective function of the problem (9)–(12) with the right-hand sides in (11) equal $b_{j\tau}^{k}$, equal $F_k(X) = min\left\{\frac{S_{\max} - S_k(X)}{S_{\max} - S_{\min}},\ k\varepsilon, k\varepsilon, ..., k\varepsilon\right\}$. Note that we consider only those k for which the constructed problem has feasible plans.

Step 4. If $k < N - 1$, then modify the step ($k = k + 1$) and go to step 2, otherwise go to step 5.

Step 5. Find $\max\limits_{k} F_k(X)$, and according to it, the optimal values of $x_{ij\tau}$ and the objective function (1).

4 Discussion

The given theoretical provisions will be illustrated on the basis of the initial data, given in [18] for the fourth day of emergency ($\tau = 4$). Figure 1 shows a graph of the degree of confidence that the plan is cost effective and efficient in terms of customer supply. In this case, x is the level of needs, y is the degree of confidence in the effectiveness of the plan.

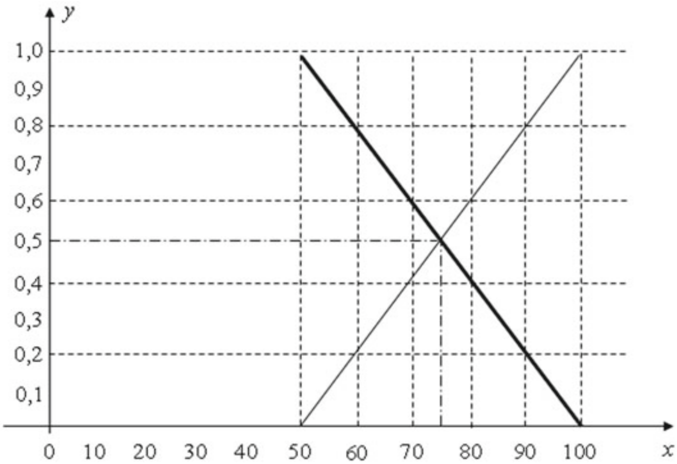

Fig. 1. Graph of the confidence degree in plan's cost and the level of customer support effectiveness.

It should be emphasized that the values of the cargo requirements of EMERCOM of Russia crews during the calculations changed with a step of 10%, which corresponds to a change in the values of the corresponding reliability functions by 0.2.

The analysis of the obtained graphs showed that the maximum value of confidence that the plan is effective in terms of total costs and the level of customer support is approximately 0.5. This value is achieved at approximately 75 percent (of the maximum) level of support for EMERCOM of Russia formations, i.e. the fourth special formation should plan to deliver cargo in the amount of 0.3 tons, the sixth—0.375 tons, and the seventh—0.3 tons. The optimal plan for the delivery of goods in this case is: $x_{9,4} = 0,3$, $x_{11,6} = 0,375$, $x_{11,7} = 0,3$.

Thus, the analysis shows that optimal management, in terms of transport and logistics services, in emergency zones is impossible without the use of the proposed mathematical model, and this model should be based on the scientific and methodological apparatus of the theory of fuzzy sets. The use of this model will increase the efficiency of the management of transport and logistics services. The result will be an increase in the efficiency of emergency response management.

5 Conclusions

The developed methodology, based on the provisions of the fuzzy sets theory, allows, in quantitative form, using strict analytical forms, to predict options for cargo delivering to EMERCOM of Russia crews in emergency situations. This significantly increases the rigor and reliability of the specified forecast, compared with the approaches used for these purposes, which, as a rule, use the theory of probability. The proposed model (9)–(12) forms the basis of the methodological approach to making optimal management decisions for the transportation of goods in emergency zones.

The developed approach can be used in the practice of EMERCOM of Russia, as well as other similar organizations, including regional, national and international. The direction of further research is the development of software models based on the author's mathematical model and their integration into digital control systems in emergency situations.

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Decision Support Digitalization for Large Environmental Logistic Projects

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Abstract. The paper considers decision aids digitalization for large environmental logistic projects within Industry 4.0 in the context of modern global economic crisis in last years. In the study, Foresight technologies, theory of decision making under uncertainties and risk management are used. The methods of data bases constructing, web-technologies and virtual reality tools are also used. For the main method of digitalization, it is proposed to use digital online platforms that integrate heterogeneous hardware and software resources using web technologies in distributed networks and a wide use of cloud services. As a result, a structural model that combines the investment objectives with cost of adequate decision support adapted to COVID-19 pandemic and climate change conditions is proposed. The paper demonstrates decision-making support for a large environmental logistic project to expand the cargo turnover of Russian seaports in the Gulf of Finland eastern part. The research results have significant scientific novelty and can be useful for private investors, public environmental organizations and environmental control bodies.

Keywords: Digitalization · Decision support · Logistics · Environmental project

1 Introduction

Nowadays, environmental logistics [1] is functioning in Industry 4.0 period, and when while climate change and covid-19 pandemic. In this period, a wide range of information technologies are planning and implementing by many businesses [2–9], including transportation sector [10, 11]. Industry 4.0 leads to serious information technological changes, including natural risks management (NRM) in environmental logistics within natural-industrial systems (NIS) [10–16], which requires the development of new tools, including practical learning area [17–19]. The purpose of this article is to develop digitalization tools for geo-information support systems (GISS) to large environmental logistic projects (LELPs) within Industry 4.0 while modern global economic crisis. In

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the paper, we describe the development results of digital tools for GISS to LELPs within geo-information management (GIM) paradigm [20] within environmental economics [21–23]. We paid significant attention to the issues of information collection [24] and processing, including modern digitalization approaches [25–28]. Proposed digital tools for GISS to LELPs while climate change and covid-19 pandemic, considered in this article, take these factors into account.

2 Materials and Methods

During the study, we used Foresight technologies, theory of decision making under uncertainties, risk management approach, methods of data bases constructing, web-technologies and virtual reality tools. Also, we used Internet of things and big data technologies [24–27]. From the point of view of geo-information management, geo-space is structured to allocate the interconnected components of the solution space [20]. While study, we used data bases and tools of geo-information digital online platform (GIDOP) EOS, including its Land Viewer (LV) product, https://eos.com/lv/, which allows limited open access to operate space images from the Landsat-8 and Sentinel-2 satellite systems.

3 Results

From the point of view of geo-information management (GIM), we made statement that logistic development of natural-industrial systems (NIS) while climate change and Covid-19 is to be carried out in the environmental economics paradigm as related set of LELPs within common space area and time period. As a result of performed using foresight technology research, we put forward the claim that in present conditions of climate change and Covid-19 pandemic, it would be advisable to develop, first of all seaports logistic infrastructure with the aim of geopolitical risks management because of different sanctions and ecological restrictions in territorial waters of different states. Preference should be given to those seaports, where climate change leads to an improvement in their overall operating conditions, for example, a reduction in the timing of ice risks in their waters.

In Fig. 1, there is presented a block model of investment structure while set of LELPs, which combines the investment objectives of such LELPs (blocks 1–5) with cost of adequate geo-information and geo-ecological support (blocks 6–8), including natural risks management (NRM) within of LELPs (block 7). Our analysis shows that the largest part of the cost of geo-information and geo-ecological support is the environmental monitoring (block 8), the essence of which is determined by the content of block 7. Significant part of the cost in block 8 is the cost of hardware and software, which varies significantly for different NIPs, especially for Arctic. As GISS basement, we propose to use the tools of geo-information digital online planform (GIDOP) EOS https://eos.com/, including its Land Viewer (LV) product https://eos.com/lv/.

Let's go to example for in Gulf of Finland, where ice risks are very important within NRM. In Fig. 2, there is the Enlarged image of East Gulf of Finland around Kronstadt on 04/04/2018 visualized with False Color (Urban) Application of LV with character

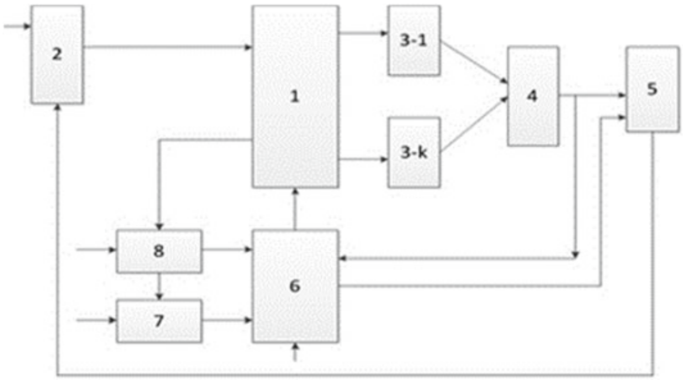

Fig. 1. Block model for investment structure while set of LELPs: 1—block of distribution of resources; 2—block of formation of resources; 3—block of formation of private income; 4—block of formation of total income; 5—block of formation of the investment share of resources; 6—block of comparison with the permissible level of risk; 7—block of formation changing in time set of natural risks, including climate risks; 8—block of environmental monitoring

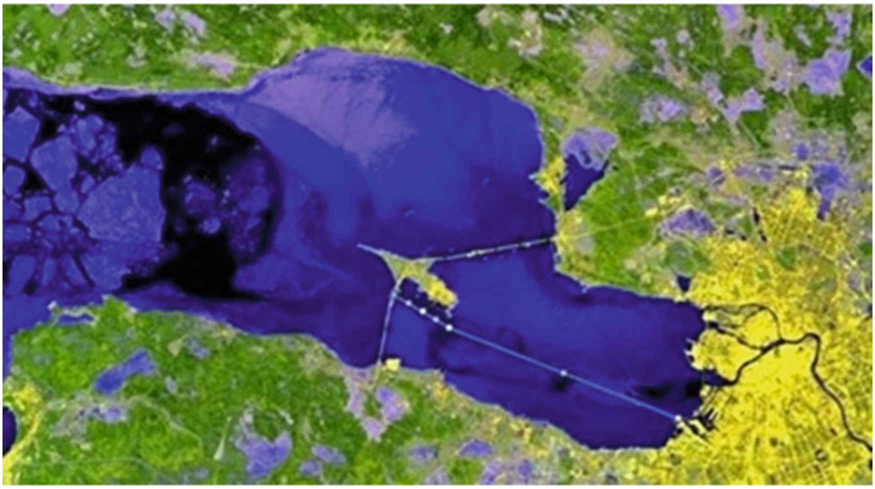

Fig. 2. Enlarged image of East Gulf of Finland around Kronstadt on 04/04/2018 visualized with False Color (Urban) Application of LV with character space scale 5 km

space scale 5 km. We recommend to use this application for sea ice visualization near city's shores.

In Fig. 3, we present enlarged image of East Gulf of Finland near Neva Dumb on 21/02/2019 visualized with Atmospheric Removal Application of LV, space scales 1 km.

As other example, we consider LELPs for Russian seaport Sabetta in Arctic, which is new point of liquid natural gas (LNG) global logistics. In Figs. 4 and 5, we present enlarged space images of Sabetta seaport with ice fields details.

Note, full decoding of above-mentioned pictures was not purpose of this articles.

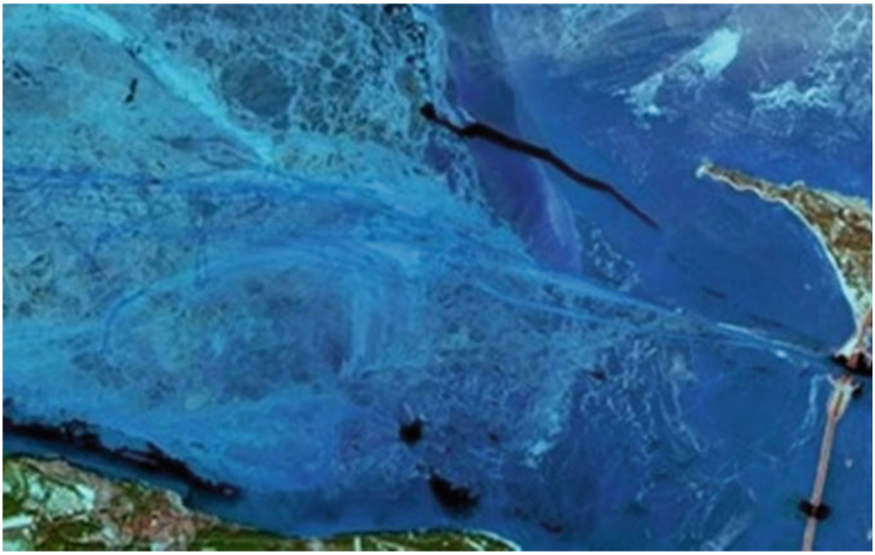

Fig. 3. Enlarged image of East Gulf of Finland near Neva Dumb on 21/02/2019 visualized with Atmospheric Removal Application of LV with character space scale 1 km

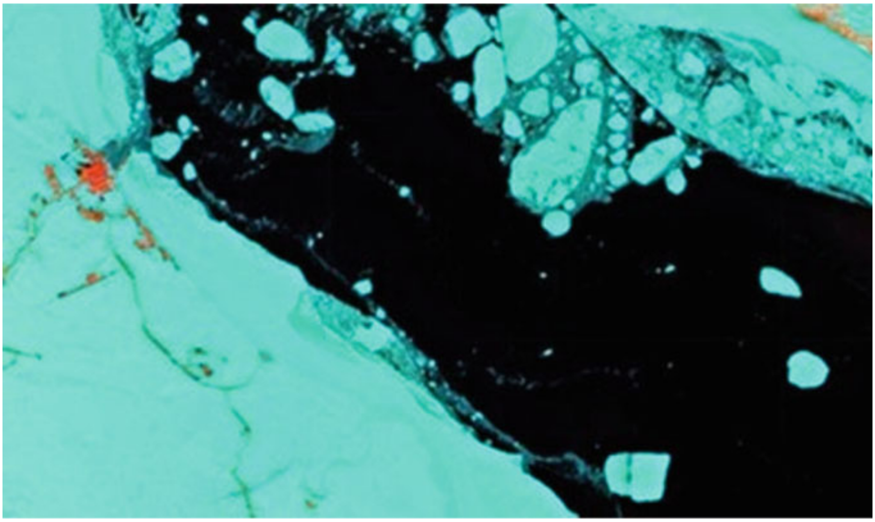

Fig. 4. Enlarged image of Sabetta seaport space image on 14/05/2020 visualized with Agriculture Application of LV at with character space scale 3 km

4 Discussion

Presented in paper results are important for the digitalization of decision support to LELPs. Proposed in article block model of investment structure combines the investment objectives of LELPs with cost of adequate GISS for LELPs. As GISS basement, we

Fig. 5. Enlarged image of Sabetta seaport space image on 13/06/2020 visualized with Agriculture Application of LV at with character space scale 500 m

propose to use the tools of geo-information digital online planform (GIDOP) EOS https://eos.com/, including its Land Viewer (LV) product https://eos.com/lv/ that gives easy and cost effective way to huge volumes of open space data and sophisticated application for its visualization and analysis. Especially effective this GISS can be used for ice risks management for seaports infrastructure, including Arctic and Subarctic. Results can be useful for investors and operational bodies.

Proposed here GISS for LELPs can be used in educational and training purposes. Note, tasks of training will require a developed learning base within special geo-information systems (GIS) laboratory. It can be undergoing with virtual reality (VR) technologies [17]), that can reduce total cost of learning process.

5 Conclusions

In article, we describe results of digitalization for decision support to LELPs. While research, we used Foresight technologies, theory of decision, risk management, methods of data bases constructing, web-technologies and virtual reality tools. As study result, we suggest to use GIDOP EOS, including its LV product, as the main technological tools within GISS for LELPs. We demonstrate possibilities of GISS on example for Russian seaports in the East Gulf of Finland and new arctic port of Sabetta. As essential result, we propose to use developed GISS as basement for arctic and subarctic seaports with ice risks, including educational and training purposes. The research results presented in this article has significant scientific novelty and can be useful for private investors, public environmental organizations of the civil sector and state environmental control bodies. They can be used in training and educational purposes, including development of Master's programs in environmental economics. In paper, all graphical materials are original and produced by authors from open sources with DOP EOS tools.

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Agricultural Systems Management and Digitalisation in Agriculture

Digital Technologies in Modern Logistics and Supply Chain Management: Key Opportunities, Prospects

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Abstract. The article analyzes and clarifies aspects of using various digital technologies in logistics and supply chain management now and in the near future. The main directions of using digital technologies in logistics and supply chain management are schematically shown. The ten main areas of use of digital technologies in logistics and supply chain management are summarized and analyzed in detail, in particular, such as the Internet of Things, big data, cloud computing, blockchain, 3D printer, robotization, artificial intelligence, machine learning, augmented reality and virtual (digital, artificial) space. A table of the prevalence of digital technologies in logistics for various functional areas has been built. The main advantages and prospects of using "Big Data" in the functional areas of logistics are outlined, a generalized scheme of the blockchain technology is drawn up. A more active introduction of the indicated areas of using digital technologies in the logistics of Russian enterprises is proposed in order to increase the efficiency of operating activities and achieve additional competitive advantages. The legal, technological, organizational and economic problems of Russia's integration into the international digital infrastructure in the field of logistics have been identified. Barriers, issues related to the development of digital logistics in the country are identified, which are conditionally divided into three groups: implementation of ICT standardization, assistance in a complete transition to electronic documents and payments, and personnel training. In the conclusion of the article, a number of methods for minimizing the risks of digital logistics are proposed.

Keywords: Logistics · Digital technology · Digital transformation · Supply chain · Digital economy

1 Introduction

In the current context, a digital economy crowds out the traditional one, changing everyday life and business, providing substantial benefits to economic sectors where the use of digital technologies is well-thought and quickly introduced. Each year, new digital technologies emerge and the existing ones are improved, due to which enterprises

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using traditional approaches and technologies in logistics management can't be competitive with no innovation introduced, most of which are related to digital transformation. Research shows that companies actively introducing modern digital technologies see growth in profit, and, on average, are 26% more profitable than enterprises that show subdued activity in this same area [1].

In this regard, the purpose of this article is to study the main possibilities and prospects of using digital technologies of modern logistics and supply chain management in the Russian economy.

2 Materials and Methods

When writing the article, the methods of analysis and synthesis, induction and deduction, methods of comparative analysis, methods of logical generalization and abstraction were used.

The theoretical and methodological basis of the study was the scientific articles of Russian and foreign authors.

3 Results

Studies highlight 10 key areas of digital technology application in logistics and supply chain management. At the same time, the digital technologies can be used in all forms of logistics having function areas (see Table 1).

Production, warehouse, transport logistics represent functional areas of logistics where the largest proportion of digital technologies is used or can be used. The mark "+ " implies that digital technology is already used in the corresponding logistics form or will be used in the near future. However, the results of the studies shown in Table 1 are not final and are controversy. This is, in particular, due to permanent changes in the area of digital technologies, their explosive development and the complexity of adapting modern business processes to such rapid changes when it is difficult to immediately identify those (technologies) that are indeed important and can significantly affect the functioning of logistics processes, and those that are temporary and insignificant.

Let's consider some of these aspects.

3.1 Internet of Things

The Internet (including the Internet of Things) can be considered the basis of the digital economy. Due to the Internet of Things, physical devices (objects) are linked and communicate with each other (exchange data) with no human intervention [4].

For example, in warehouse logistics pallets to accumulate and move products are used. To the pallets, some innovative devices (sensors, controllers) can be attached, which can communicate among themselves via the Internet of Things to increase efficient functioning of the structure in general.

In warehouse logistics, in case appropriate innovative tools and technologies are applied, the Internet of Things can be used in many ways [5, 6].

Table 1. Prevalence of digital technology according to logistics forms

No	Digital technologies	Logistics forms								
		Procurement	Production	Distribution	Marketing	Warehousing	Transport	Information	Financial	Reverse
1	Internet of things	+	+	+	+	+	+	+	+	+
2	Big data	+	+	+	+	+	+	+	+	+
3	Cloud computing	+	+	+	+	+	+	+	+	+
4	Blockchain	+	+	+	+	+	+	+	+	+
5	3D-printing		+			+	+			
6	Robots		+			+	+			
7	Artificial intelligence	+	+	+	+	+	+	+	+	+
8	Augmented reality and virtual (Digital) space		+	+	+	+	+	+		
9	Sensors	+	+	+	+	+	+	+		+

Source compiled by the authors based on [2, 3]

Within transport logistics, the Internet of Things can clearly identify material asset location and condition monitoring their delivery path, which allows to accurately determine the timeliness of their delivery to the right place and in required quality, ensure transportation reliability and safety, prevent theft and product substitution, damage to original packaging, violation of storage conditions [7].

In distribution and marketing logistics, management decisions on product distribution to markets, impacting consumer preferences and product demand, ordering products from the manufacturer and the like can be more justified and prompt due to the Internet of Things. After-sales service (which is part of marketing logistics) may include continuous monitoring of the product condition by using various sensors, which in case of some damaged products and worn-out state of its components will be able to transmit the information from the manufacturer or service center via the Internet of Things in order to provide a specialist and/or required components to the consumer.

3.2 Big Data

Logistics is one of the areas of business with a large volume of various structured and unstructured data, well-organized work with which can provide companies with competitive advantages in data storing, processing and analyzing. Big data is an aggregation of tools to search, analyze and process large volumes of structured and unstructured data in order to obtain fundamentally new knowledge [8].

Decisions on the use of automated logistics process management systems, which not only optimize operations, arrange communication, control and reduce costs, but also save time—the most important resource today, are still made by business entities. However, these systems, in addition to the benefits in everyday work, allow logistics companies planning and making decisions based on reliable and valid data analysis.

3.3 Cloud Computing

Big data requires huge and powerful storage and processing space. This problem can be solved by cloud computing technologies that provide remote data processing and storage with no specific location [9]. Cloud computing is software and hardware for a consumer self-service on demand via the Internet or local network using corresponding data processing and storage services; a model for online access to multiple hardware (hosts, databases, networks) and software (web versions of offline programs, various application software programs requiring significant computing resources) resources, which can be quickly used by consumers of these resource to solve problems with minimal interaction with a resource provider.

3.4 Blockchain

Along with the increase in digital data volume and its availability, there is a need for their fidelity and storage reliability. Specifically, this can be provided by Blockchain, which is an innovative distributed database technology that does not store data in a single location (single web-site) but in a certain way distributes data among network computers (web-sites), though the user has an illusion of database integrity. Inability to modify or destroy database representation leaving no trace, encryption and decentralized data storage with Blockchain technology should ensure transparency and controllability of logistics operations throughout the chain of supply from the manufacturer to the end user. One of the key Blockchain aspects is the instant simultaneous updating of information for all supply chain members [10].

Thus, for example, the Blockchain platform developed by IBM enables tracking truck location and status, and all authorized chain members can see the required information during the transport cycle. Traditionally, supply chain transactions are drawn out manually which results in delays and increased risks to duplicate data or falsify information. The use of RFID identifications, showing data on the vehicle, driver and cargo, enables IoT sensors to monitor truck movement and transfer these data to Blockchain. In such deliveries, the use of IoT can be enhanced, for example, by installing humidity and temperature sensors on the goods. In the event of a sharp change in these indicators, an insurance company involved in the smart contract will report that the goods may have been damaged [7].

Blockchain has grown into a technological basis for solving current issues in different sectors, so many companies introduce it to gain a competitive advantage due to transparency in their operation. But introducing the system can cause significant difficulties, since it is quite difficult to change and adapt supply chains. Companies spend years to restructure supply chains, so integration of new technology should not be underestimated.

Due to Big Data, Cloud Computing, and Blockchain technologies, information analysis can be carried out quickly anytime and at any step of the supply chain in order to make prompt and informed decisions on the supply chain operation.

3.5 Crowdsourcing

Crowdsourcing is receiving information, work or expert commentary from a large number of users via the Internet, social networks, hosting platforms or smartphone applications that jointly solve certain problems. Crowdsourcing today is widely used in logistics. A canonical example is Amazon which guarantees two-day delivery of goods purchased through this platform using crowdsourcing, involving almost any potential carrier in logistics, even taxi companies [11].

Crowdsourcing in logistics is an opportunity for medium-sized logistics enterprises to become competitive in this environment. Another example of crowdsourcing in logistics is Cargomatic's operations. It is a logistics enterprise that designed an online platform connecting local cargo shippers with carrier companies having additional truck space [12].

With regard to this, Cargomatic helps long-haul truck drivers develop their business through web and mobile applications, and helps shippers track their freight in real time [13].

3.6 3D Printer

The widespread use of 3D printers for manufacturing a variety of products can destroy the existing system of production and delivery of finished products to the end user due to the fact that virtually every consumer will be able to have their own "production" at home. In this context, production will be highly customized, and the existing supply chain system will be radically changed. In such supply chains, the material flow will generally involve printer consumables, and the logistics warehousing and stock management operations will relate to printer consumables, components and spare parts. Datastream will necessarily contain all information required for product 3D manufacturing (digital imaging of a physical object). However, 3D printers have not yet become so endemic as to indicate fundamental changes in production and supply in the near future [14].

3.7 Robotization

High and growing staff taxes paid by companies, as well as the risks posed by employees, force companies to automate any process that is subject to mathematical algorithmization. Thus, according to the Global Customer Report 2019, the number of warehouse robotics tests increased by 18% compared to 2018 [15].

Logistics companies actively apply the following types of robotic devices: sensors for warehouse equipment, vehicles; industrial robots (pods) for goods selection and packing at the warehouse; robotic cars; drones; automated parcel terminals; mini printers for label printing; interactive interfaces [16].

3.8 Artificial Intelligence

Artificial intelligence is a powerful support for logistics decision-making and supply chain management, as it improves the quality, validity and speed of the decisions made. Artificial intelligence is feasible in processing a large array of data, providing cloud computing services. Artificial intelligence can be applied almost everywhere when there is a need for data analysis and subsequent decision-making, that is, anywhere in the supply chain and in any logistics form.

3.9 Machine Learning

Introducing machine learning platforms enables companies to achieve an extensive analysis and supply chain control and to improve logistics management in such functional logistics areas as procurement logistics, warehouse inventory management, distribution logistics, and sales logistics. The following benefits of Machine Learning to improve management in functional logistics areas can be highlighted: improving procurement logistics, inventory management, warehouse logistics, sales logistics, distribution logistics [2].

3.10 Augmented Reality and Virtual Reality, VR

Currently, augmented and virtual reality are widely used in the entertainment industry, video games, and medicine. However, in the business sector, augmented and virtual reality application is sporadic, being introduced in production, retail and logistics by leading world companies only. Augmented reality has already been applied and has good opportunities to be applied in logistics operations at warehouses and logistics centers for cargo handling works, product placement planning, product transportation both within warehouses and when being delivered to consumers, etc. [9].

3.11 Sensors

Sensors can be considered as stand-alone digital technologies, but they are closely related to other technologies, the Internet of Things, Big Data in particular. Sensors decrease in size and become cheaper every year, but their capability to store and process information increases, leading to their greater use in logistics and supply chain management.

4 Discussion

Having described the key capabilities of digital technologies in modern logistics and supply chain management, let us proceed to analyzing the prospects for their use in the Russian economy. First of all, it should be noted that Russia is a world logistics outsider today [17]. Thus, the World Bank's Logistics Performance Index (LPI) 2018, which is compiled on the basis of public data and survey with more than 1000 people engaged in international transport and logistics processes, the Russian Federation is ranked 75th only. According to the World Bank's estimates, Russia fails to keep pace with Kazakhstan, Ukraine and the Baltic States in terms of transport and logistics industry efficiency [18].

Such a low ranking was influenced primarily by low ratings for customs operation (ranked 97th), cargo tracking (ranked 97th) and international transportation (ranked 96th).

In the initial stages, to understand what logistics trends have real potential to be changed, DHL, an acknowledged global leader, created Trend Research program which enables management to adopt an open and customer-focused approach to identify trends.

Over the past seven years, DHL has been conducting the research called Logistics Trend Radar [19, 20].

This is a specific rating of trends in logistics that have already come to existence or will become relevant and will change logistics over the next five years. Logistics Trend Radar, released by DHL in 2018, confirms some known trends and provides valuable information on the forthcoming social, technological and business trends that could affect logistics in future. In particular, it refers to the key trends, such as the Internet of Things and artificial intelligence. One of the trends that could boost the industry growth is the proliferation of next-generation wireless networks, which can significantly increase economic benefits and value of supply chain connecting to the Internet. Another publication trend is the Blockchain technology, which is actively discussed in the information space and has great potential for its development, but the application of which can be highly challenging for the industry [21–23].

Regulatory, technological, institutional and economic problems of Russia's integration into international digital infrastructure are also explicitly peculiar to logistics projects.

5 Conclusions

Given the fact that today's domestic economy substantially depends on the state of the logistics complex, the introduction of digital logistics technologies will increase the competitiveness of the entire Russian economy.

Thus, the article analyzes the global trends in digital technology development, based on which the competitive advantages of traditional and digital business forms are determined. Ten main trends in digital technologies applied in logistics and supply chain management are summarized. Introduction of the specified trends will provide Russian business entities with the following competitive advantages: improved logistics processes (cooperation with carriers, logistics costs management, warehouse operations, time management); creation of flexible integrated management structures; improved information accessibility; improved reliability of logistic operations and logistical product quality; improved responsiveness by timely data updating and reducing order processing time; reduced logistical risks; and increased efficiency by logistics costs reduction.

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Big Data as a Tool for Risk Management of Transport and Logistic Support of Arctic Fields

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Abstract. Today, in the age of Industry 4.0—The Fourth Industrial Revolution—the issues of digitalization of processes at all stages of oil production are becoming increasingly important. It has been established that the gradual digitization of enterprises is one of the priority tasks for Russian oil companies and oil and gas companies of the world. The introduction of technology such as Big Data allows solving every day small problems and preventing possible major accidents at offshore fields, saving large amounts of money on eliminating the consequences. In this article, the system of transport and logistics support of the Pobeda field was analyzed, the possibility of implementing the project in Arctic conditions without using digital technologies was assessed, and it is concluded that it is necessary to introduce Big Data technology into the system of transport and logistics support of deposits, mainly offshore and shelf, including at the Pobeda field.

Keywords: Big data · Logistic support · Oil industry

1 Introduction

Today, hydrocarbon production in the Arctic is one of the most promising areas of the oil and gas industry. In the Arctic environment, the production, storage and transportation of oil is associated with many risks, including those associated with possible oil spills in the water areas. Organization of safe, environmentally friendly oil production at offshore fields is becoming an urgent task today. This, according to the authors, can be facilitated by the introduction of modern digital technologies. To minimize the risk of an oil spill accident and ensure the safest possible operation on the Arctic shelf, technology such as Big Data can be used at all stages of oil production, which has many advantages. The purpose of this work is to consider the possibility of organizing work on oil production at the field without the use of digital technologies and to justify the need to use Big Data technology at the Pobeda field.

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2 Materials and Methods

2.1 Offshore Field Pobeda. Organization of the Oil Production System in the Field

In 2014, the Pobeda field was discovered in the Kara Sea, when Rosneft, together with ExxonMobil, drilled an exploration well in the Vostochno-Prinovozemelsky-1 license area. But US sanctions against Russia forced ExxonMobil to freeze its participation in the project and made it difficult for Rosneft to find equipment and funding for further exploration. After the discovery of the field, Rosneft did not specify a time frame for its possible commissioning.

The Pobeda field's reserves are estimated at 130 million tonnes of oil and 499.2 billion m^3 of gas in C1 + C2 categories. It will take 2 days to get to the field by sea from Murmansk, which indicates the distance to the shoreline. The operator performs from 50 to 300 operations per day to deliver the necessary equipment and personnel to the drilling site. This shows the need for appropriate equipment capable of operating in harsh Arctic conditions [1].

In addition to the undoubtedly difficult natural and climatic conditions—difficult ice conditions, the presence of a squally wind, sea disturbance—there are a number of risks that experts put on the agenda. These include economic, technological and, finally, environmental risks. Avoiding any accidents that could harm the environment, flora and fauna of the Arctic basin is the main condition for working in the Arctic shelf area of oil companies. All oil production and transportation work must be carried out without spills, accidents or incidents [2].

2.2 Environmental Risks. Oil Spills

There are certain risks associated with offshore and offshore projects, which are due to the specifics of working in harsh Arctic conditions. The main risks are presented in Table 1.

An oil spill is a serious environmental disaster with several consequences. First of all, it is a significant damage to the fragile Arctic ecosystem, and secondly, it is a direct damage to the economy—the cost of eliminating the consequences of the accident and paying penalties [4]. The danger of an oil spill is that oil breaks up in natural conditions over a long period of time, and when the seas are contaminated with oil it covers the surface with a dense layer of oil in a short period of time and prevents access to light and air. The danger is that the consequences of such an accident cannot be eliminated in a short period of time: the greatest negative impact of a spill is in the medium and long term, especially in the coastal zone [5, 6].

To ensure safe and efficient operation in such conditions, major leading companies are introducing various digital technologies into their industrial processes, including Big Data technologies [7].

Table 1. Main risks in developing offshore fields

Types of risks	Source of risk	Risks
Geological	Weak study of the shelf, lack of knowledge and experience in developing offshore fields	• Risk of mismatch between predicted and actual resource levels • The risk of prematurely reducing the well flow rate • High/low impurity content • Risks related to depth of occurrence • Risk of inability to develop the field
Economic	Significant capital intensity, long project implementation period	• Risk of non-recoverability of the field development • Risk of exceeding the budget due to liquidation costs
Transport and technological risks	Difficult ice conditions, difficult transportation, lack of technology, high risk of equipment failure in Arctic conditions	• Risk of equipment failure • Risk of equipment damage • The risk of inability to maintain the equipment on a regular basis • The risk of complicated logistics availability
Ecological	Vulnerable ecosystem, long distance from shoreline	• Risk of irreparable damage to the ecosystem • Risk of climate change due to extraction • Risk of extinction of animals due to mining operations [3]

2.3 Liquidation of Oil Spills

Under normal conditions, oil has been decomposing for decades. Under Arctic conditions, these processes are slower because evaporation is slower and oil may also be trapped from the ice or under the ice.

Under normal conditions, the following oil spill response methods are highlighted:

- mechanical cleaning. Spilled oil is held in place by booms and then collected for storage and disposal.
- on-site combustion. Ignition is carried out by releasing fuel from a helicopter or ship.
- dispergators are used. Dispersants are chemical reagents that accelerate the dispersal of oil, thus accelerating the decomposition process [8, 9].

2.4 Big Data. Opportunities and Prospects

Big data technologies are a whole complex of various tools, approaches and methods of work with information, which allow to solve several global tasks: storage and management of giant information arrays; organisation and systematisation of this unstructured or partially structured information, recorded in various formats; processing and analysis of the received information, including for the formation of highly accurate forecasts [10].

Many oil companies are increasingly using systems to automate their logistics processes in order to optimise them, reduce costs, reduce errors from manual labour and overall transparency. Big data technologies have found wide application at all stages of the oil production process. They are capable of obtaining various types of information about the operation of equipment, as well as analyzing data, forecasting production processes and evaluating the quality of equipment operation. This enables managers and operators to resolve issues on a daily basis and make accurate decisions about future work. These technologies make it possible to prevent possible accidents at production facilities, update the information to be relevant in real time and optimise the production process as a whole [11].

3 Results

The reasons for such an accident as an oil spill may include environmental risks—severe Arctic climatic conditions, including squally wind, sea disturbance, difficult ice conditions, minimal visibility, critical temperatures, etc.; imperfection of the technologies used; and the lack of modern digital technologies in production to prevent accidents, accurately forecast events and monitor the condition of equipment [12, 13].

An important factor affecting the safety of operations is the availability of the necessary qualification of personnel. In its absence, a personnel training system should be organized to work in Arctic conditions [14, 15]. Due to the harsh climatic conditions, work in the fields is carried out seasonally, which leads to equipment downtime that can cause additional damage. The penetration of a proper safety control system is a must when working on the Arctic shelf. In the event of an accident, the consequences are inevitable, such as the high cost of accident management, depending, among other things, on the volume of oil spilled [6].

In order to prove or deny the need to introduce Big Data technology in the development of the Victory field, a comprehensive analysis must be carried out based on a set of indicators that assess the technical characteristics and conditions of the field. The conclusion as to the extent to which it is necessary to introduce technology to reduce the risk of an oil spill will be influenced by a combination of production, economic, social and technological factors in the region [16–18].

Therefore, the authors propose the following indicators for evaluation (Table 2).

These indicators are heterogeneous factors, some of which can be quantified, while most can only be assessed qualitatively. In this case, it is necessary to use criteria for which ratings can only be obtained using specially designed verbal number scales. The Harrington scale has been used quite extensively. This study will use three scores from Table 3 to justify the conversion of qualitative characteristics into quantitative indicators.

Table 2. Evaluation indicators

X_1	Developed service infrastructure
X_2	Availability of technologies for safe operations during field development
X_3	Logistic availability
X_4	Remoteness from shoreline
X_5	Ice conditions
X_6	Availability of technologies for oil spill response
X_7	The ability to accurately and continuously monitor the condition of equipment during field development
X_8	Qualification of personnel for work in the Arctic environment
X_9	The possibility of regular work

Table 4 presents the assessments of the factors considered and the final score. The factors are ranked according to the level of significance.

The authors calculated an estimate, upon receipt of which it was decided to conditionally consider that there is no need to introduce digital technologies into production at this field to minimize the risks of an oil spill accident. This estimate corresponds to the sum of the lowest values of the highest grading for all factors, taking into account the weighting factor. This estimate is accepted at 0.694.

The analysis calculation gave the following results: the assessment, which takes into account the various factors affecting the implementation of the project, was 0.468. In view of the above, it can be concluded that the risks of an oil spill exist and may hinder the implementation of the Pobeda field development project. This demonstrates the need for additional measures to minimize risks.

4 Discussion

The introduction of Big Data and artificial intelligence may be additional measures to minimize risks. This technology, despite the high cost of implementation, has several advantages:

- the ability to track the required indicators in real time using a sensor system;
- rapid response to emergency situations;
- the ability to forecast equipment breakdowns;
- the ability to predict situations leading to oil spills based on already available data.

In this example, the probability of human error is quite high due to severe climatic conditions and lack of necessary staff skills. Big Data technology will help to reduce the risks associated with the human factor, and this technology will make it possible to create a system of predictive repair of equipment, which under such operating conditions will significantly reduce the risk of accidents [19].

Table 3. Conversion of qualitative characteristics into quantitative indicators

Index	Quantitative value	Qualitative assessment
X_1—developed service infrastructure	0.71–1	Exists
	0.46–0.70	Poorly developed
	0–0.45	Not available
X_2—availability of technologies for safe operations during field development	0.71–1	Exists
	0.46–0.70	Poorly developed
	0–0.45	Not available
X_3—logistic availability	0.71–1	Light
	0.46–0.70	Complex
	0–0.45	Extreme
X_4—remoteness from shoreline	0.51–1	Insignificant
	0–0.50	Significant
X_5—ice conditions	0.71–1	Light
	0.46–0.70	Average
	0–0.45	Severe
X_6—availability of technologies for oil spill response	0.71–1	Exists
	0.46–0.70	Poorly developed
	0–0.45	Not available
X_7—the ability to accurately and continuously monitor the condition of equipment during field development	0.71–1	Exists
	0.46–0.70	Poorly developed
	0–0.45	Not available
X_8—qualification of personnel for work in the Arctic environment	0.71–1	There are personnel of the necessary qualifications and a training system
	0.46–0.70	There is a training system
	0–0.45	No training system
X_9—the possibility of regular work	0.71–1	All year round
	0.46–0.70	Less than 6 months a year
	0–0.45	Less than 3 months a year

5 Conclusions

Thus, according to the results of the study, the following conclusions can be drawn:

1. Environmental safety in oil production is the main condition that should be a priority for all oil producing companies in the implementation of their projects in any field, especially in the unique fields of the Arctic shelf [6, 20].

Table 4. Factor assessment

Index	Weighting ratio	Evaluation	Score
X_2—availability of technologies for safe operations during field development	0.18	0.71	0.128
X_1—developed service infrastructure	0.15	0.4	0.060
X_7—the ability to accurately and continuously monitor the condition of equipment during field development	0.14	0.3	0.042
X_6—availability of technologies for oil spill response	0.13	0.46	0.060
X_3—logistic availability	0.1	0.4	0.040
X_5—ice conditions	0.1	0.3	0.030
X_8—qualification of personnel for work in the Arctic environment	0.1	0.7	0.070
X_4—remoteness from shoreline	0.05	0.3	0.015
X_9—the possibility of regular work	0.05	0.46	0.023
Final score			0.468

2. An oil spill is a serious accident that must be prevented, and even now such a disaster is not uncommon.
3. Big data technology is used for timely detection of inaccuracies in equipment, for constant monitoring of process parameters and analysis of unstructured information from various sources, which can significantly reduce the risk of oil spills and improve the economic performance of companies operating in the Arctic. shelf zone [21, 22].
4. Development of deposits, especially offshore ones, is impossible without the use of modern digital technologies.

The fragile Arctic ecosystem should not be exposed to the slightest danger in the implementation of projects of oil and gas companies [23]. Neither economic benefits nor other priorities of the company should conflict with environmental safety. In addition, the costs of oil spill response can significantly exceed all costs associated with the implementation of big data technology in the field.

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Assessment of the Effectiveness of Sustainable Management in Supply Chains

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Abstract. The instability of economic, political, social and environmental conditions of companies' activities, reinforced by modern crisis phenomena and increased competition, determine the relevance of developing and implementing complex measures to ensure the stability of the supply chain management systems that these companies participate in. One of the most important tasks of the development and implementation of these complexes is to assess the effectiveness of the relevant measures. The article offers a methodological approach to solving this problem. At the same time, the effectiveness of measures to ensure the stability of the supply chain management system is understood as the degree to which the system's ability to perform its functions is preserved in the face of destructive impacts on its elements. The efficiency indicator is proposed to be mathematically formalized in the form of a function, the argument of which is the change in the duration of the control cycle associated with the need to restore the operability of the elements of the control system. The proposed approach constitutes a theoretical basis for constructing mathematical decision support models when planning measures to counter destructive influences on control systems of a wide class of supply chains.

Keywords: Supply chain · Control system · Operation · Sustainability measures · Efficiency · Evaluation

1 Introduction

A promising direction of business development at present and in the foreseeable future is the formation of supply chains and their management in the process of production and delivery to end users of goods and services [1–4]. Their formation and rational management allow obtaining a positive synergetic effect both for producers and consumers of goods and services and increasing on this basis the competitiveness of participants in

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the chain. As a rule, supply chain management systems are created in the form of appropriate software or software-hardware complexes. At the same time, the achievement of the required level of quality of supply chain management in modern conditions is inextricably connected with the increase in the volume of processed information, introduction of new information technologies and is accompanied by complication of these complexes [5–11]. The accompanying effect of complication is an increase in the vulnerability of supply chain management systems to intentional and unintentional destructive influences. In this connection in the conditions of aggravation of competitive struggle, characteristic for a modern state of the economy, along with traditional methods of economic competition, unscrupulous competitors more often make attempts to decrease competitiveness of the organizations united in a chain of deliveries by breaking stability of functioning of a chain control system at the expense of various destructive influences on its elements [12–14]. Therefore, counteraction to the specified destructive influences becomes one of the important tasks of development of supply chain management. Rationale for decisions when planning measures to counteract destructive influences in the interests of ensuring the sustainability of the supply chain management system is based on an assessment of their effectiveness.

The purpose of this article is to develop a methodological approach to assess the effectiveness of measures to ensure the sustainability of the supply chain management system under conditions of destructive influences on its elements.

2 Materials and Methods

The theory of supply chain management has passed the way of evolutionary development from the solution of fragmentary management tasks in the areas of procurement, warehousing and distribution within a single company to the formation of global management systems of a set of logistic processes of companies involved in the implementation of all stages of the life cycle of relevant goods (services). At the same time, most attention was paid to the development of methods for the formation of rational (optimal) options of appropriate management decisions in order to form competitive advantages of the companies involved in the supply chain by reducing the time to bring goods and services to the end consumer and reduce their cost. [15–23]. The achievement of this goal essentially depends on the timely development and implementation of a set of measures to ensure the sustainability of the functioning of supply chain management systems in the conditions of destructive influences on their elements. One of the important tasks of creating models and methodologies to support decision-making on the development and implementation of the above complexes is the formation of an indicator of the effectiveness of relevant measures [24–27]. This indicator should in the generalized form take into account a variety of destructive influences and a casual character of their consequences [28–30].

3 Results

Supply chain management can be represented as a cyclic process, in each cycle of which the formation and subsequent implementation of control actions is carried out. In this case management is stable, if time t of a control cycle does not exceed some threshold value T. Influence of destructive influences on supply chain management process manifests itself in increase of duration of control cycle. Moreover, the more the time t of management cycle exceeds the value of T, the lower the efficiency of management is [25]. The typical nature of this relationship is illustrated by the graph in Fig. 1.

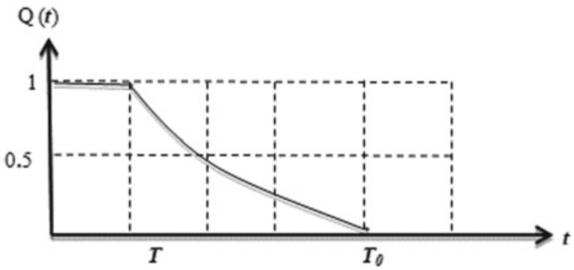

Fig. 1. Dependence of the management efficiency on the cycle duration.

In formalized form these circumstances are represented by dependence

$$Q(t) = \begin{cases} 1, att \leq T \\ e^{-\lambda(t-T)}, att > T \end{cases} \tag{1}$$

where $Q(t)$—the degree to which the supply chain capabilities are realized, assuming that the duration of the control cycle is t;

λ—the rate at which the supply chain capability is reduced if the duration of the control cycle exceeds the value of T.

Measures to ensure the sustainability of the supply chain management system under disruptive influences are aimed at ensuring the possibility of timely formation and implementation of control actions. Consequently, their efficiency can be estimated by time τ to eliminate the consequences of destructive impacts.

We can assume that in the absence of destructive influences the duration t of the control cycle is equal to T, and in their presence the value of t exceeds by time T for τ, of elimination of consequences of destructive influences. Therefore,

$$t = T + \tau \tag{2}$$

Then the degree of realization of supply chain capabilities under disruptive influences can be represented by the ratio:

$$Q(\tau) = e^{-\lambda(\tau)\tau} \tag{3}$$

Let's assume that elimination of consequences begins immediately after each destructive action. And the time spent on elimination is random and significantly less than the time interval between successive impacts. Then the random value can be represented as:

$$\tau = \sum_{n=1}^{N} \tau_n \tag{4}$$

where N is the number of disruptive influences on the supply chain management system during the time T of the management cycle;

τ_n—remediation time of n ($n = 1, 2, \ldots, N$) destructive impact.

Since the moments of time at which destructive actions are carried out are not known in advance, we will assume that these actions are a random flow of events. Then N in relation (4) is also a random variable.

It is natural to assume that random variables τ_n ($n = 1, 2, \ldots, N$) of the duration of destructive consequences elimination are equally distributed among themselves and do not depend on N. Then to construct the distribution function of random variable τ we can use the apparatus of characteristic functions.

Let us denote by $r(x)$ the distribution density function of random variables τ_n ($n = 1, 2, \ldots, N$). Then the corresponding characteristic function takes the form:

$$\varphi(z) = \int_{-\infty}^{\infty} e^{izx} r(x)dx \tag{5}$$

where $i = \sqrt{-1}$—imaginary unit;

z—real number.

If we denote by p_N the probability that N destructive influences occur during one control cycle, then the characteristic function $\xi(z)$ of the random time τ of counteraction to these influences is defined by the relation:

$$\xi(z) = \sum_{N=0}^{\infty} p_N [\varphi(z)]^N \tag{6}$$

Given (6), the density g(x) of the distribution of a random variable can be represented by the relation:

$$g(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-izx} \sum_{N=0}^{\infty} p_N [\varphi(z)]^N dz \tag{7}$$

Given the limited values of $\sum_{N=0}^{\infty} p_N [\varphi(z)]^N \le \sum_{N=0}^{\infty} p_N [\varphi(0)]^N < \infty$, in relation (7) we can replace the order of integration and summation. Consequently, (7) takes the form:

$$g(x) = \sum_{N=0}^{\infty} p_N \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-izx} [\varphi(z)]^N dz \tag{8}$$

Taking into account relation (8), the mathematical expectation τ^* of time to eliminate the consequences of disruptive influences on the supply chain management system is equal to:

$$\tau^* = \int_0^\infty x\left[\sum_{N=0}^{\infty} p_N \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-izx}[\varphi(z)]^N dz\right]dx = \\ \sum_{N=0}^{\infty} p_N \int_0^\infty x\,[1/2 \int_{-\infty}^{\infty} e^{-izx}[\varphi(z)]^N dz]dx \tag{9}$$

Substituting (9) into (3), we obtain the ratio for determining the average degree of realization of supply chain capabilities under disruptive influences on its management system:

$$Q(\tau^*) = exp\left\{-\lambda \sum_{N=0}^{\infty} p_N \int_0^\infty x\left[\frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-izx}[\varphi(z)]^N dz\right]dx\right\} \tag{10}$$

For constructive representation of the relation (10) it is necessary to define: intensity $\lambda(\tau)$ of reduction of a degree of realization of potential possibilities of managing system of concrete supply chain at $t > T$; function p_N of distribution of a stream of destructive influences; density r(x) of distribution of time of elimination of consequences of each of destructive influences. The specified parameters of the relation (10) are defined on the basis of the statistical information on functioning of control system of a supply chain for the previous period of time.

4 Discussion

As a whole experience of functioning of supply chains in various branches of economy testifies that the most vulnerable to destructive influences of objects in their structure are control systems. Therefore maintenance of stability of functioning of these systems in the conditions of destructive influences becomes one of important problems. Complexity of the decision of this problem and considerable material and reputation losses from miscalculations at decision-making on introduction of corresponding means and ways of maintenance of stability at all stages of life cycle of a chain of deliveries causes necessity of all-round substantiation of the specified decisions. A tool for such justification is performance assessment. The methodological approach to the mathematical formalization of the problem of assessing the effectiveness of measures to ensure the sustainability of supply chain management systems, proposed in the article, is based on sufficiently general characteristics of the systems and processes under study. In this regard, it can serve as a theoretical basis for the construction of models and decision support techniques for the implementation of tools and methods to ensure the sustainability of such systems, taking into account the specific features of various supply chains.

5 Conclusions

The article develops a methodological approach to solve the actual problem of assessing the effectiveness of measures to ensure the sustainability of the supply chain management system.

At the same time, the effectiveness of these activities is interpreted as the degree of preservation of the ability of the supply chain management system to perform its functions in the face of destructive influences on its elements.

For a quantitative estimation of efficiency of maintenance of stability of management in supply chains the variant of mathematical formalization of indicator.

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Impact of Logistics on Urbanization in the Digital Economy

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Abstract. In the conditions of fast urbanization development, the issues of ensuring the comfort of the human life environment are becoming increasingly important. Along with the growth of cities and the influx of population into territories limited in terms of their area and infrastructure capacity, there is a widespread penetration of digital technologies into all spheres of human life. To date, the development of the human environment is associated with the implementation of a smart city concept, with the meaning of safe and comfortable environment based on the use of digital technologies. Logistics acts as an element that brings together various economic actors and ensures the continuity of the movement of material resources within the framework of goods production. The article discusses the main prerequisites for the necessity to develop logistics in order to create comfortable environment for human life, characterizes global trends in improving the logistics sector. The key areas of logistics inherent in the various stages of the formation of a comfortable living environment are identified, especially in urban areas. As a result of accomplished study, recommendations are given on the intensification of the logistics development in the context of increasing demands for quality of the human life environment.

Keywords: Logistics · Comfortable living environment · Smart city · Digital technologies

1 Introduction

Currently, urbanization of territories is taking place at an ever faster pace. So, back in 2008, the number of urban population on a global scale for the first time exceeded the number of rural residents and it is predicted that this trend will intensify [1]. According to experts' opinion, by 2030 more than 60% of the world population will live in cities, and by 2050—over 66% [2]. Moreover, the expansion of urban agglomerations is happening twice as fast as the growth of the urban population, which in general will lead to the fact that the growth of cities in the first three decades of the twenty-first century will be equal to that for the entire period of human history [1].

Such an increase in the urban population determines the task of improving the comfort of the living environment, since the existing infrastructure will face a huge influx

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of residents, which is supposed to be solved on the basis of the smart city concept development. According to experts' opinion, smart cities are characterized by a safe and efficient environment based on the use of digital technologies in order to improve the quality of life of the population and ensure the sustainability of city development [3, 4]. Different stages of smart cities formation are highlighted [5], however, in general, the living environment always develops in such areas as economy, governance, mobility, living, environment and people. In our opinion, logistics is a connecting element that unites all these areas of development of the human life environment, since it provides comfortable interaction between residents and organizations, as well as acts as the basis for an uninterrupted production process, which affects the quality of life in the particular territory from both directions. The purpose of this work is to determine the main direction for the development of logistics in the context of the digital transformation of the economy, as well as to develop recommendations for intensifying the development of this area in order to create a comfortable environment for human life.

2 Materials and Methods

In the most general sense, logistics in a smart city is the management of the flow of goods, people and information, which requires solving a multilateral problem of simultaneous optimization of heterogeneous elements [6]. Logistics is often understood as part of a larger area which is a smart mobility. In a narrower sense, logistics is considered from the point of view of individual organizations and the flows between suppliers, consumers and intermediate links, united by common management [7].

Let us consider the world practice of logistics development in order to improve the comfort of the human life environment. According to European experts, in cities the logistics sector is related with [8]:

- 10–15% of traffic flows (expressed in km);
- 6% of carbon dioxide emissions associated with vehicles operation;
- 300–400 transport routes per 100 people daily;
- 2–5% of urban employment;
- on average 0.1 delivery per person per day;
- on average 1 delivery per organization per week.

As you can see, logistics services are in demand both among the population and among organizations, which is associated with a load on infrastructure and the environment. The solution of this problem became the matter of serious concern in Barcelona. So, in the city, large companies (DHL, Amazon, TNT) transferred part of their orders to local suppliers (through a micro-distribution center), which, in turn, regulate the warehouse and deliver orders by electric vehicles [8].

In general, many Western countries are following the way of creating urban distribution centers that coordinate the loading of vehicles (bringing it to the level of 70–80%), facilitate cooperation between logistics organizations and also optimize the use of trucks by transferring services within the city for light-duty vehicles [9].

Along with reducing the environmental burden, logistics in a smart city should ensure a decrease in transportation costs. In France, the largest grocery chain Monoprix has implemented the following supply system: from various warehouses, goods are transported by rail to a logistics platform in Bercy and then goods are delivered to stores in vehicles powered by natural gas or electricity and equipped with a noise absorption system [10]. Franprix Company delivers goods to shops in Paris along the Seine River without overloading the road network [10]. Of course, logistics centers change the appearance of cities, so it is important to initially plan the development of territories, taking into account the optimal location of such facilities in order to achieve a harmonious combination of residential and commercial construction development with these centers.

Speaking about Russia, it should be noted that due to its geographical position, the Russian Federation is crossed by three international transport corridors (parts of the systems originating in Crete, in Helsinki, as well as pan-European corridors), the Northern Sea Route and the North–South Transport Corridor. According to scientists' estimates, for the period 2007–2030 the total scope of freight traffic in Russia will increase by 48% to 17.858 million tons, cargo turnover will increase by 55.6% to 3.86 trillion ton-kilometers [11]. The share of road transport will increase 6.7 times, rail—5.6 times, sea—5 times, inland waterways—17.5 times [11].

In Russia, the transition to a comfortable living environment in cities is based on the program "Digital Economy of the Russian Federation" within the framework of which it is also planned to develop a departmental project "Digital Transport and Logistics", the goals of which are:

- growth of the transport and transit potential of the Russian Federation;
- development of a system of mixed (multimodal) transportation;
- increasing the quality level of freight traffic;
- ensuring the availability of logistics services for the population;
- increasing the efficiency of the transport and logistics infrastructure;
- creation of a digital platform in the transport and logistics sector.

Consequently, logistics is a generally recognized element of the formation of a comfortable environment for human life in the development of the smart city concept. On the one hand, it is necessary to reduce the negative impact of this area on the environment, the level of city noise, etc. On the other hand, logistics should keep up with the pace of development of the digital economy, since in the future, the comfort of life will largely be ensured through the use of information and communication technologies.

3 Results

Let's consider the directions of development of the logistics sector under the influence of the necessity to improve the comfort of the living environment. At the end of the twentieth century, network strategies for organizing logistics processes in the area of route planning became widespread; specialized facilities for parking and loading and unloading were built; the issues of spatial concentration of activities actively using logistics services began to be taken into account; the legislative regulation of freight traffic was strengthened (restrictions on entry into certain areas, restrictions on the time of unloading, etc.); the practice of toll roads was spread in order to make up for damage caused by freight transport to the road network; the emergence of logistics terminals on the territory bordering the city to optimize flows and reduce the movement of large-sized vehicles in urban areas [12].

Along with the spreading of digital technologies, tasks similar in essence began to be solved by modern methods. Digital systems for collecting traffic information, intelligent transport systems for managing traffic flows, systems for collecting tolls on toll highways, specialized logistics information systems for exchanging data between various participants in the logistics sector in order to organize optimal work in the market have appeared; introduction of vehicles with reduced emissions into the atmosphere [13].

Now there are three main directions of logistics development [14]. Firstly, the personalization of services is distinguished, which is expressed in the maximum compliance with the requirements of customers. Goods can be delivered to the address or to the point of delivery of parcels, the time of receipt is flexible and you can clarify a specific interval, etc. Secondly, robotization of order collection is carried out in order to speed up logistics processes. The ultimate goal is to achieve such a level of robotization that from the moment the order is received until it is handed over to the addressee, everything will be implemented automatically, without involving manual sorting, packaging and checking. In addition, distribution centers must ensure such a speed of work that no more than half an hour should pass from the moment of ordering to sending it along the delivery route [14].

The third direction of logistics development is to improve the distribution system of logistics flows in order to reduce air emissions and reduce the load on transport networks. It is already customary to form logistics centers on the outskirts of cities, from where smaller vehicles deliver goods to consumers, and it is assumed that various logistics companies will cooperate to optimize the loading of vehicles.

The implementation of the above directions for the development of logistics is supposed to be based on the use of modern digital technologies, which can be considered from the point of view of the stages of digital transformation of the logistics sector (see Fig. 1).

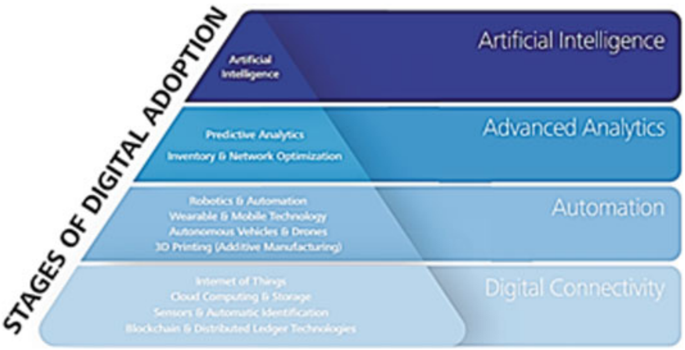

Fig. 1. Logistics digital transformation technologies [15]

The goal of the first stage of digital transformation is to optimize the collection and organization of information that comes to the logistics company from many sources. MHI surveys showed that in 2019 already 70% of organizations began using certain technologies inherent in this stage [15].

At the second stage of digitalization, automation is carried out to perform repetitive resource-intensive tasks in order to accelerate them, increase reliability and safety. 53% of organizations are using some of the automation technologies and their share has been growing over the past six years, albeit at a slow pace due to the high costs of introducing such innovations and the lack of competencies among employees to work with them [15].

The third stage of digital transformation of logistics is based on a deep analysis of the data collected at the first stage. Only 30% of surveyed organizations have a developed predictive analytics system, but 87% of organizations are planning to implement it within 5 years [15].

The most digitally advanced logistics organizations are adopting artificial intelligence technology, which means making decisions based on machine learning. Few organizations are at this stage so far, but it is recognized that over the next three years, artificial intelligence will play a leading role in risk management decisions.

Another equally important direction in the development of logistics is the spreading of blockchain technology, which means a distributed database of all events in a digital format, which is shared by all participants in the supply chain [16]. Decentralization of data increases the security of storage and exchange of information due to the impossibility of making changes to previously added records [17, 18].

Thus, the logistics sector is constantly evolving in order to adapt to rapidly changing demands for a comfortable living environment. As part of the spreading of digital technologies in all spheres of human life, logistics is becoming an essential element that ensures a comfortable life in a smart city.

4 Discussion

The development of logistics is aimed at the following goals, leading to an increase in the level of comfort of the living environment [19]:

- reducing the cost of using transport and logistics services,
- reduction of noise and air pollution for a safer living on the territory,
- reducing the number of traffic jams and, as a result, accelerating the speed of movement across the territory.

Achievement of the above goals is associated with the need for interaction between many participants in the logistics market, among which, in a broader sense, one can single out power structures, logistics companies, sellers of goods and IT companies providing services in the logistics sphere. A promising option for the development of logistics in the context of widespread digitalization is the formation of digital platforms, which are represented by a single neutral information environment that forms digital services for services consumers of transport and logistics organizations based on the technological integration of various resources and infrastructures [20].

In this work, we will dwell in more detail on the recommendations for the development of logistics in order to improve the comfort of the human life environment. Regional and local authorities need to set goals in the process of solving problems at the last stage of the provision of logistics services (delivery from the warehouse to the consumer) and agree on their delivery between different city structures. Also, regional authorities can, together with logistics companies, develop and approve a logistics development strategy that would take into account the characteristics of a particular territory (city size, population, infrastructure, needs for logistics services, etc.). Moreover, it is necessary to develop regulatory legal acts at the regional and local level in order to reduce the time of loading and unloading operations and comply with environmental standards.

It is also recommended to develop financial incentive schemes in order to intensify cooperation between logistics companies within the framework of urban distribution centers. The joint use of the warehouse, distribution centers and road transport will allow logistics organizations to reduce non-productive costs associated with underutilization of transport and the need to maintain incompletely exploited warehouse space.

It should be noted that in recent years, the scientific community has been paying more and more attention to the development of logistics within the framework of not only a smart city, but also such concepts as a green economy, sustainable development of territories, a digital city, a programmable city [21–23]. Consideration of these issues is a promising task for further research, since the above mentioned concepts, although they have a common goal—to increase the comfort of the living environment, still presuppose its achievement in various ways.

5 Conclusions

The spreading of digital technologies is becoming the main trend inherent in all spheres of human life. Such penetration of technologies into people's lives is usually associated with the concept of a smart city, designed to improve the safety and quality of life of the population. One of the key elements of the formation of a comfortable environment for human life in the context of an increasing global urban population is the development of logistics.

The issues of managing transport and logistics flows have always been in the attention of the scientific and professional community, however, at present, it is becoming urgent to develop qualitatively new directions for the development of logistics based on the use of modern technologies. As a result of the study, the author identified the key directions for the development of logistics inherent in various stages of the formation of a comfortable environment for a person's life, taking into account the four levels of digital transformation of this area—digital connectivity, automation, advanced analytics, artificial intelligence. In addition, the author proposed recommendations for intensifying the development of logistics in the face of increasing requirements for the quality of the human life environment, including increasing the consistency of various areas of improving logistics within the framework of strategic plans for the development of territories, updating regulatory legal acts in the field of logistics, as well as the development and implementation financial incentives to intensify cooperation between logistics companies within urban distribution centers.

In conclusion, it should be noted that the improvement of logistics, which permeates all spheres of the city's life, is associated with increased interaction of various market participants—from authorities to end consumers of services. It is important already now to increase the degree of cooperation between all participants in the process of providing logistics services in order to implement timely solutions to improve the comfort of the living environment of the population.

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Decision Aid Digitalization in Geopolitical Risks Management for Maritime Logistics

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Abstract. The article presents digitalization results for decision aids in geo-political risks management for maritime logistics within Industry 4.0 period, in the context of climate change and the COVID-19 pandemic. During the study, the methods of data bases constructing, web-technologies and virtual reality tools are used. Also, there are used Foresight technologies, theory of decision making under uncertainties and risk management. As digitalization tools, online platforms, which integrate heterogeneous hardware and software resources in distributed networks, are proposed to use. The study proposes a structural model that combines investment objectives with the cost of adequate management support adapted to the COVID-19 pandemic and climate change conditions. The use of the developed decision-making tools for managing the geopolitical risks of maritime logistics in the Russian Arctic and Subarctic is demonstrated. The research results presented in this article has significant scientific novelty and can be useful for private investors, public environmental organizations of the civil sector and state environmental control bodies.

Keywords: Digitalization · Decision aids · Geo-political risks · COVID-19

1 Introduction

Recently, maritime logistics (ML) is functioning in Industry 4.0 period, and when while climate change and covid-19 pandemic. In this period, a wide range of information technologies are planning and implementing by many businesses [1–7]. Industry 4.0 leads to serious information technological changes in ML [8, 9], including natural risks management (NRM) [10–15], which requires the development of new tools, including practical learning area [16].

The purpose of this article is to develop digital tools for geo-information support system (GISS) to ML within geo-information management (GIM) paradigm [17–20], in large environmental projects [21–24] within environmental economics [25–29]. We paid significant attention to geo-information support systems (GISS) within climate

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change [30, 31] and Covid-19 pandemic context, including the issues of information collection and processing [32]. Developed digital technologies for GISS to ML while climate change and Covid-19 pandemic, considered in this article, take these factors into account.

2 Materials and Methods

In the research, we used Foresight technologies, theory of decision making under uncertainties, risk management approach, methods of data bases constructing, web-technologies and virtual reality tools. Also, we used Internet of things and big data technologies [17, 20]. From the point of view of geo-information management, geo-space is structured to allocate the interconnected components of the solution space [25]. While study, we used data bases and tools of geo-information digital online platform (GIDOP) EOS, including its Land Viewer (LV) product.

3 Results

Currently, maritime logistics (ML) is a hot place in global environmental economy, including Arctic resources involvement problem. We made statement, that the best way to involve the Arctic into global economy is sustainable development paradigm with adequate decision aids tools developed on geo-information management (GIM) basement. From GIM point of view, ML in Arctic and Subarctic (MLAS) while climate change and Covid-19 pandemic is to be carried out as related set of large natural-industrial projects (NIPs) within common space area and time period. In Fig. 1, we present a block model of investment structure for such NIPs, which combines the investment objectives (blocks 1–5) with cost of adequate geo-information and geo-ecological support (blocks 6–8), including GPRM and natural risk management (NRM) within NIPs in ML in Arctic and Subarctic while climate change and Covid-19 pandemic (block 7).

Currently, there are greats GPRMs, for MLAS because of different sanctions and ecological restrictions in territorial waters of different states. Situation with NordStream-2 marine pipeline can be excellent example.

Our analysis shows that the largest part of the cost of managerial support is the environmental monitoring (block 8), the essence of which is determined by the content of block 7. Significant part of the cost in block 8 is hardware and software, the cost of which varies significantly. Now, in Covid-19 pandemic conditions, cost of GPMR and NRM for MLAS can arise greatly because of general economic situation, when every country have to implement limitations for boards crossing and suffer from economic slowdown.

While research, we hypothesized that the main factor of geopolitical risks for MLAS during the Covid-19 pandemic is the restrictions imposed by various states at the level of national legislation aimed at combating the Covid-19 pandemic. In this article, the main focus of the fight against this group of geopolitical risks proposed the use of international cooperation within the framework of the Arctic Council, initially focused on the development of the Arctic within the framework of the sustainable development paradigm. It should be noted that in 2021–2023, Russia will the Chairman in the Arctic Council and

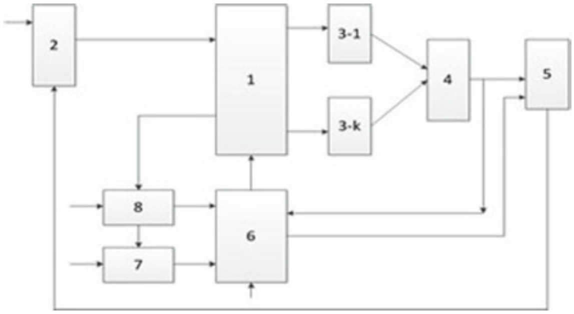

Fig. 1. Block model for investment structure while territory development: 1—block of distribution of resources; 2—block of formation of resources; 3—block of formation of private income; 4—block of formation of total income; 5—block of formation of the investment share of resources; 6—block of comparison with the permissible level of risk; 7—block of formation changing in time set of GPRM and NRM, including Covid-19 pandemic and climate change; 8—block of environmental monitoring corresponding to block 7

is currently developing a program for such a chairmanship. The main working mechanism could be the creation of a working group on Covid-19 within the Arctic Council, following the example of a similar working group on climate change in the Arctic. As tools for preparing and supporting decision-making in the framework of such a working group, it is advisable to use innovative digital technologies and tools, the structure of which is discussed below.

In research, we proposed a structural model of a geo-information distributed platform (GIDP), which contains heterogeneous databases under multi-level architecture. Proposing GIDP contains three levels of data representation DATA—PROCESSING—INTERFACE. Such representation guaranties system independence from the number of software components. We propose flow model (Fig. 2).

On basement of above mentioned model (Fig. 1) and GIDP conception (Figs. 2), we propose to develop the geo-information and geo-ecological support system (GIGESS) with combined structure for access, storage and analysis of information from open geospatial data sources, including archives and operative mode web tools.

As a result of the research, performed using foresight technologies, the authors suggest to use geo-information distributed online platforms (GIDOP) with cloud technologies (CT) as the main technological solutions for geo-information support system (GISS). In this article, we recommend to use GIDOP EOS eos.com, including its product LandViewer (LV) https://eos.com/lv/.

Let's go to examples. In Figs. 3 and 4, we show the results of sequential operations with proposed GISS performed online with LV for the Svalbard.

In Fig. 4, there is the same as in Fig. 3 space image but visualized with Agriculture Application of LV.

Obviously, that Fig. 4 is more informative for space decoding. Note, space decoding of Fig. 3 and Fig. 4 was not task of this paper. As essential research result, authors propose to use GIDOP EOS eos.com, including its product LV https://eos.com/lv/, as basement of

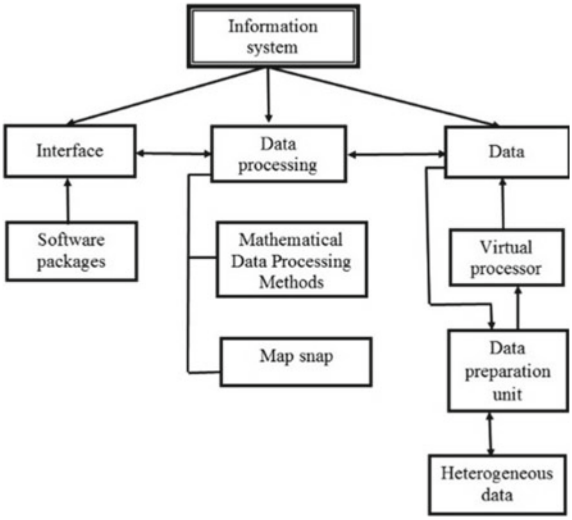

Fig. 2. Flow model of a GIDP with heterogeneous databases

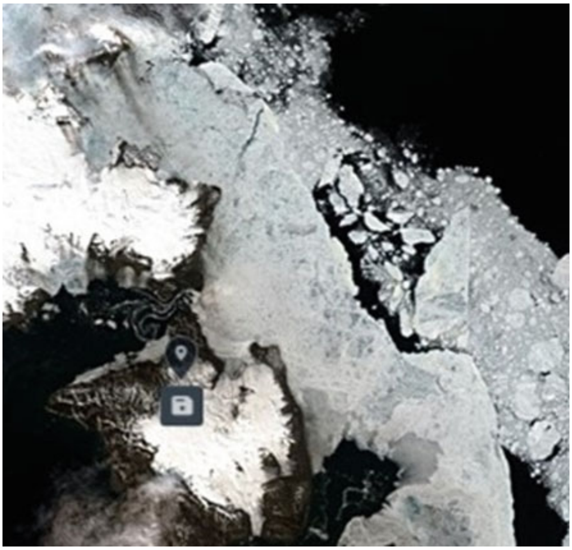

Fig. 3. Svalbard image on 21/06/20 visualized with natural colors application of LV

low-cost GISS for GPRM and NRM to ML including MLAS while Covid-19 pandemic and climate change.

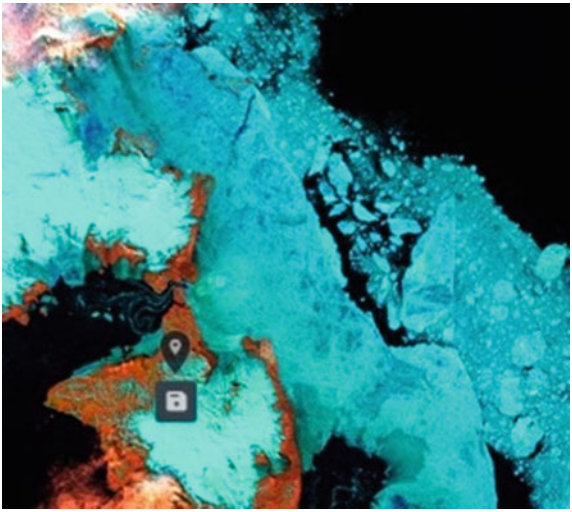

Fig. 4. Svalbard image on 21/06/20visualized with agriculture application of LV

4 Discussion

Proposed above GISS for ML including MLAS can be used in educational and training purposes. Note, tasks of training will require a developed learning base within special geo-information systems (GIS) laboratory. It can be undergoing with virtual reality (VR) technologies [18], that can reduce total cost of learning process.

5 Conclusions

We describe results of digital technologies development for GPRM and NRM within ML including MLAS, adapted to Covid-19 pandemic. In studies, we used methods of data bases constructing within digital educational platforms, web-technologies and virtual reality tools. Also, we used Foresight technologies, theory of decision making under uncertainties, risk management approach. From the point of view of geo-information management, we structured geo-space to allocate the interconnected components of the solution space. As digital tools, we propose to use digital online platforms, which integrate heterogeneous hardware and software resources with the use of web-technologies in distributed networks and wide application of cloud services. As study result, we proposed a structural model, that combines the investment objectives with cost of adequate managerial support, adapted to Covid-19 pandemic conditions. As essential result, we propose to use GIDOP EOS eos.com, including its product LV https://eos.com/lv/, as basement for low-cost GISS for GPRM and NRM within ML including MLAS while Covid-19 pandemic and climate change. The presented in the article results of the research have a significant scientific novelty and can be useful for private investors, public environmental organizations of the civil sector and state environmental control bodies. They can be used in training and educational purposes, including development of Master's programs in environmental economics.

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Natural Risks Management Digitalization for Arctic Seaports While Climate Change

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Abstract. The article describes digitalization results in natural risks management for arctic seaports within Industry 4.0 period, in the context of climate change and the COVID-19 pandemic. During the study, methods of data bases constructing, web-technologies and virtual reality tools are used. Foresight technologies, theory of decision making under uncertainties and risk management are also used. As digitalization tools, there is proposed to use online platforms, which integrate heterogeneous hardware and software resources in distributed networks. As a result, a block model is proposed, which combines the investment objectives with cost of adequate natural risks management for arctic seaports adapted to the COVID-19 pandemic and climate change conditions. The use of the developed digital tools within natural risks management for seaports in Russian Arctic and Subarctic is demonstrated. The research results presented in this article has significant scientific novelty and can be useful for private investors, public environmental organizations of the civil sector and state environmental control bodies.

Keywords: Natural risks management · Arctic seaports · Climate change · Covid-19

1 Introduction

Recently, arctic seaports are functioning in Industry 4.0 period, and when while climate change and covid-19 pandemic. Now, a wide range of information technologies are planning and implementing by many businesses [1–7]. Era of Industry 4.0 leads to serious information technological changes in seaports activity [8, 9], including natural risks management (NRM) [10–15], which requires the development of new tools, including practical learning area [16].

The purpose of this article is to develop digitalization tools for geo-information support systems (GISS) to activity of arctic seaports. In this paper, we describe the development results of digital tools for such GISS within geo-information management

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(GIM) paradigm [17–20], in large environmental projects [21–24] within environmental economics [25–29]. We paid significant attention to GISS within climate change [30, 31] and Covid-19 pandemic context, including the issues of information collection and processing [32, 33]. Developed digital technologies for GISS to activity of arctic seaports while climate change and Covid-19 pandemic, considered in this article, take these factors into account.

2 Materials and Methods

During the study, we used theory of decision making under uncertainties, risk management approach, Foresight technologies, methods of data bases constructing, web-technologies and virtual reality (VR) tools. Also, we used big data and Internet of things technologies [17, 20, 34, 35]. From the point of view of geo-information management, geo-space is structured to allocate the interconnected components of the solution space [25]. In research, we used data bases and tools of geo-information digital online platforms (GIDOP) Earth https://earth.nullschool.net/ru/ and EOS eos.com, including its Land Viewer (LV) product https://eos.com/lv/, which allows limited open access to operate space images from the Landsat-8 and Sentinel-2 satellite systems.

3 Results

Using research results with Foresight technologies, we claim from the point of view of GIM, that in present conditions of climate change and Covid-19 pandemic, activity of arctic seaports (AASP) is to be carried out within the environmental economics as related set of large natural-industrial projects (LNIPs) within common space area and time period. In Fig. 1, we present a block model of investment structure while LNIPs in AASP, which combines the investment objectives of such LNIPs (blocks 1–5) with cost of adequate geo-information support to AASP (blocks 6–8), including NRM within AASP (block 7).

As study result, we propose to use geo-information distributed platforms (GIDPs) containing heterogeneous databases in the format of a multi-level architecture. We propose to use GIDP with three levels of data representation: "data—processing—interface". The advantages of such representation are the independence of the system from the number of software components included in each level and its own set of protocols and application interfaces for each level, which defines its own architecture.

To avoid the difficulties of multi-user access to data, we suggest to use a mechanism for pre-processing heterogeneous data, which includes a virtual data processor (VDP) and a data preparation unit (DPU). A VDP is a software module that allows uniform access to all system data via standard interfaces (protocols), while hiding the features of data placement, data structures and formats. A DPU aims at collecting and first processing the data requested by the user from the system. When using this mechanism, there is no need to convert data to the format used by the system, they remain in the original view and can be used locally by their applications.

On basement of above mentioned block model, we propose to develop the geo-information support system (GISS) for AASP with combined structure for access, storage

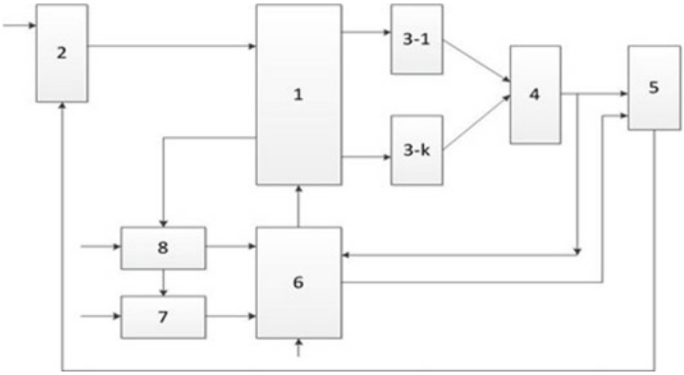

Fig. 1. Block model for investment structure within AASP: 1—block of distribution of resources; 2—block of formation of resources; 3—block of formation of private income; 4—block of formation of total income; 5—block of formation of the investment share of resources; 6—block of comparison with the permissible level of risk; 7—block of formation changing in time set of natural risks for AASP, including climate change risks and Covid-19 risks; 8—block of environmental monitoring within AASP while climate change andCovid-19 pandemic conditions

and analysis of information from open geo-spatial data sources, including archives and operative mode web tools.

Our analysis shows that the largest part of the cost of geo-information support is the environmental monitoring (block 8), the essence of which is determined by the content of block 7. Significant part of the cost in block 8 is the cost of hardware and software, which varies significantly for different NIPs, especially for Arctic. Reducing the cost of GISS for AASP is an important direction of GISS construction.

As a result of the research, performed using foresight technologies, we suggest to use geo-information distributed online platforms (GIDOPs) with cloud technologies (CT) as the main technological solutions for GISS construction. In this article, we recommend to use GIDOP Earth https://earth.nullschool.net/ru/ and GIDOP EOS eos.com, including its Land Viewer (LV) product https://eos.com/lv/, which allows to operate with space images from the Landsat-8 and Sentinel-2 satellite systems with limited open access.

Let's go to examples. For arctic and subarctic ports, the main natural risk is ice phenomena, primarily in the form of ice fields. As a result of performed researches, we proposed that ice fields state in the waters of Arctic ports should be monitored using GIDOP EOS including LV product. In Fig. 2, we present enlarged space image with view of ice field in subarctic seaport Ust-Luga on 01/03/2019 visualized with Atmospheric Removal Application of LV. Note, decoding of this space image was not purpose of this paper.

Also important natural risk is strong wind over waters adjacent to the port. As research result, we recommend to use GIDOP Earth for wind field visualization. In Fig. 3, we present wind field over east part of Russian Arctic coast including seaport of Pevek (green circle) on 09/10/2020 visualized with GIDOP Earth. In left low corner of Fig. 3 there are coordinates of mark with green circle point, and also values of wind direction and speed in this point. Note, decoding of Fig. 3 was not purpose of this paper.

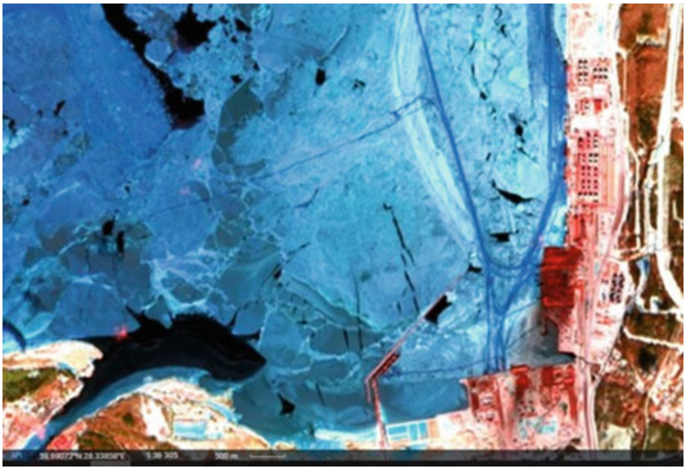

Fig. 2. Enlarged space image of ice field in Luga Bay at Ust-Luga seaport on 01/03/2019 visualized with atmospheric removal application of LV

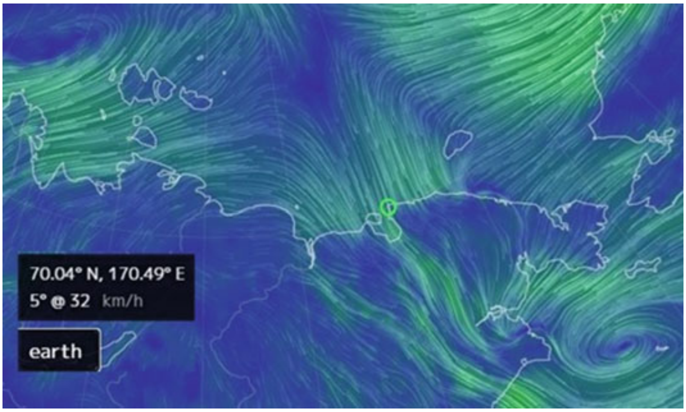

Fig. 3. Wind field over east part of Russian Arctic coast including seaport of Pevek (green circle) on 09/10/2020 visualized with GIDOP earth

Another important natural risk is high wind waves in adjacent to the port waters. As research result, we recommend to use GIDOP Earth for wind waves field visualization. In Fig. 4, we present wind waves field in east part of Russian Arctic including seaport of Pevek area (green circle) on 09/10/2020 visualized with GIDOP Earth. In left low corner of Fig. 4 there are coordinates of mark with green circle point, and also values of wind waves direction of propagation, period of wave spectrum peak and mean height of wave in marked point. Note, decoding of Fig. 4 was not purpose of this paper.

Then, proposed GISS for NRM can be used in real practice while climate change and Covid-19 pandemic.

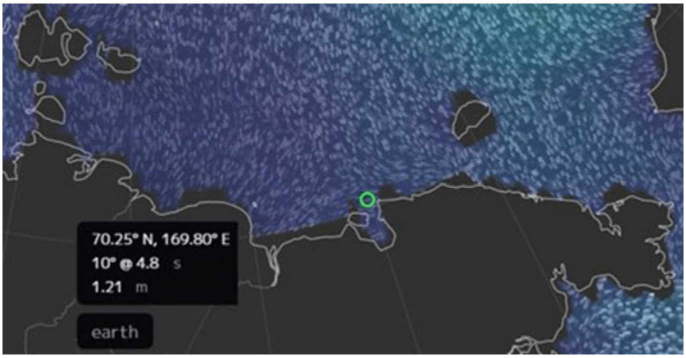

Fig. 4. Wind waves field in east part of Russian Arctic t including seaport of Pevek (green circle) on 09/10/2020 visualized with GIDOP earth

4 Discussion

Proposed here GISS to NRM for arctic and subarctic seaports while climate change and Covid-19 pandemic can be used in educational and training purposes. Note, tasks of training will require a developed learning base within special geo-information systems (GIS) laboratory. It can be undergoing with virtual reality (VR) technologies [18], that can reduce total cost of learning process.

5 Conclusions

In paper, we present results of NRM digitalization for arctic and subarctic seaports while climate change and Covid-19 pandemic. While research, we used Foresight technologies, theory of decision, risk management, methods of data bases constructing, web-technologies and virtual reality tools. As study result, we proposed a block model, that combines the investment objectives with cost of adequate NRM for arctic and subarctic seaports adapted to climate change and Covid-19 pandemic conditions. As research result, we suggest to use GIDOP Earth and GIDOP EOS, including its LV product, as the main technological tools within GISS to NRM for arctic and subarctic seaports adapted to climate change and Covid-19 pandemic conditions. We demonstrate possibilities of proposed GISS. As essential result, we propose to use developed GISS for educational and training purposes. The research results presented in this article has significant scientific novelty and can be useful for private investors, public environmental organizations of the civil sector and state environmental control bodies. They can be used in training and educational purposes, including development of Master's programs in environmental economics.

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Digitalization Strategy in the BRICS Countries: Towards the Partnership

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Abstract. The scale of the global digital economy is huge, and in the future the process of economic integration will be dominated by knowledge-intensive technologies and IT industries. The world's largest international organisations and economic powers are actively responding to the trend of the digital economy by constantly suggesting and updating their policies and directions for the development of the digital economy. BRICS is a representative group of the largest emerging economies in the world?Brazil, Russia, India, China and South Africa. These countries are actively developing the transition to a digital economy and improving national information and communication technology infrastructure. This study focuses on the strategy and policies for developing the digital economy in the BRICS countries. The aim of the study is to develop a set of strategies for international cooperation on the digital economy within the BRICS framework. The results of the study show the common features and differences in the digitalisation process of the BRICS countries, allowing for the development of comprehensive measures to support BRICS activities in this area. The practice-oriented recommendations consider such options as improvement of domestic development, maintenance of equitable multilateral dialogue, promotion of research on the BRICS digital economy and addressing non-traditional security issues in the development of the digital economy in the post-pandemic period.

Keywords: Digital economy · Digital technology · BRICS · ICT · Internet of things · Industrial policy · Industry 4.0 · Post-pandemic economy

1 Introduction

In 2016, at the G20 Summit in Hangzhou, China, the G20 Digital Economy Development and Cooperation Initiative was launched, defining the digital economy as a broad range of economic activities that include using digitized information and knowledge as the key factor of production, modern information networks as an important activity space, and the effective use of information and communication technology (ICT) as an important driver of productivity growth and economic structural optimization [1]. This approach to defining the conceptual framework objectively reflects the essence of the digital economy at the present stage.

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In recent years, the BRICS countries have consistently stated at BRICS summits and various international events that they intend to actively develop the transition to digital economy and improve its network infrastructure. BRICS was first dedicated to the development of information and communication technologies at the Durban Summit (2013). The common vision of the BRICS countries in promoting ICT, including hardware, software and services, was also reflected at the Fortaleza Summit (2014) to promote sustainable social and economic development. This idea continues to be developed at subsequent BRICS Summits in Ufa (2015), Goa (2016), Xiamen (2017), Johannesburg (2018) and Brasilia (2019) [2]. The Goa Summit is particularly noteworthy, as under the Indian BRICS presidency there have been discussions on cooperation in ICT and the digital economy [3]. As a result of the Goa Summit, the BRICS vision of ICT has been enriched with new elements?the tasks of preserving peace and security, protecting human rights and combating terrorism. Accordingly, BRICS offers an open, inclusive and secure cyberspace, while the five participating countries are gradually increasing their level of cooperation in the digital economy. Multilateral cooperation in this area is expected to be strengthened through further BRICS summits and working mechanisms [4].

As an important representative group of emerging economies, BRICS holds key positions in the global political and economic governance. In order to further strengthen the strategic cooperation of the BRICS in the field of digital economy to enhance the international reputation and influence of BRICS, it is reasonable to study the development and prospects of digital economy in BRICS. This study examines the status and policies of the digital economy in the BRICS countries and aims to develop strategies to deepen international cooperation in the digital economy within the BRICS. The results of the study show a strategic analysis and policy review of the digital economy in Brazil, Russia, India, China and South Africa, which define the national priorities and development of digitalization in these countries. The discussion part of this study describes common challenges and solutions to the digital economy in the BRICS, and provides detailed recommendations and strategic actions to further strengthen cooperation in the digital economy.

2 Materials and Methods

The methodology of this study is based on a comparison of the national digital economy policies of the BRICS countries, using systematic analysis. The main indicators for assessing the digital economy in the BRICS countries are Internet penetration, the number of Internet users and the volume and turnover of e-commerce. Static indicators and analytical reports prepared by official bodies of the BRICS countries or specialized scientific institutions (e.g. E.T. Gaidar Institute for Economic Policy, China Academy of Information and Communications Technology), consulting and public organisations (McKinsey & Company, Brazilian Association of Software Companies, GSMA etc.) are used to determine the characteristics and characteristics of digital processes in the five countries.

3 Results

For all BRICS countries, the digitalisation of economy is particularly relevant, so it is important at this stage to consider the national digital economy strategy and its current status.

Brazil. A more pressing challenge for the Brazilian government is finding ways to modernise industries with the support of science and technology in order to increase the international profile of the Brazilian economy on all sides. In Brazil, the National Strategy in Science, Technology and Innovation (ENCTI 2016?2022) was adopted in 2016, bringing together the strengths and development potential of all sectors of the economy and setting a goal of 2% of GDP to be achieved by 2022 [5].

In terms of supporting the development of science, technology and innovation, various measures have been taken to support the real economy. For example, cooperation between research institutes and small and medium-sized enterprises in the area of technological innovation has been strengthened in order to increase the motivation and innovative potential of enterprises and the community. Special start-up incubators and business accelerators have been set up at the federal and regional levels, and the policy of supporting venture capital and bank loans is aimed at supporting the creation of high-tech companies and promoting industrial and digitalisation modernization in Brazil.

As of June 2019, the number of Internet users in Brazil had reached 149 million, with an Internet penetration rate of 70.2% [6]. Brazil has a robust ICT market with 1.5 million people employed and is expected to account for almost 11% of GDP in 2020 [7]. According to the Brazilian Association of Software Companies, total investment in ICT reached $97 billion in 2018. With IT alone, the total investment volume reached $47 billion. As a result, Brazil was among the top ten countries in the world in terms of IT investment and ranked first in Latin America, with IT growth in Brazil of 9.8% [8]. Brazil is the largest e-commerce market in Latin America. In Brazil, 58 million consumers made at least one online purchase in 2018, representing 27% of the country's population. E-commerce sales in Brazil grew to $15 billion in 2018, with more than half (54.2%) of e-commerce sales made in one payment [9].

Brazil?s digital economy is currently focused on projects related to the Internet of Things and Artificial Intelligence. Brazil is improving coverage of 4G, the 5G ecosystem, broadband networks, cloud computing and e-government. In 2017, the Internet of Things: An Action Plan for Brazil was launched as part of Brazil's integrated digital economy strategy [10]. The programme will contribute to a wider use of Internet technologies across the country and a deep integration of the Internet with the public and state spheres. As noted by Falch, M., Leonardo, E & Iaskio, S., the Brazilian Government regards broadband as an important tool for the economic and social development of the country, both for the population and for private companies [11].

Russia. Russia is an active supporter of the development of the digital economics concept. In key sectors of the country's economy, appropriate plans have been developed for the implementation of digital technologies. In 2018, Russian President Vladimir Putin signed Executive Order on National Goals and Strategic Objectives of the Russian Federation through to 2024. National projects are 12 essential components that cover three main area of activity?human capital, comfortable living environment and economic growth. The ??Digital Economy?? is one of the national projects of the ??economic growth?? area.

The ??Digital Economy?? project is being implemented in 2019?2024 with a total budget of 1.837 trillion rubles and 6 specific programmes at the federal level: normative regulation of the digital environment, personnel for the digital economy, information infrastructure, information security, digital technologies and digital government. The main objectives of the National Project of Digital Economy are: removing Internet barriers and making the network accessible to all; achieving 5G network coverage in large cities; protecting the information security of the government, business and population; increasing economic efficiency through the use of new technologies; developing a digital workforce for the future; and facilitating investments in new areas and increasing the weight of the digital economy in GDP.

According to research conducted by the National Research University of the Higher School of Economics [12], in 2017, internal costs for the development of the digital economy amounted to 3,324.1 billion rubles (3.6% of GDP). The share of households with access to the Internet in the total number of households was 76.6% (2018). According to Rosstat data for 2016, the share of Internet users in the total population was 67.9% (i.e. 99.7 million people). The E.T. Gaidar Institute for Economic Policy found that about 35?43% of the total population (41?51 million people) is engaged in online shopping. It estimates that Russian e-commerce market (domestic and cross-border) will reach to 2.78 trillion rubles by 2024 [13] (Fig. 1).

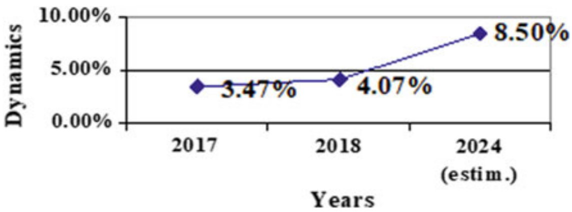

Fig. 1. Share of e-commerce in retail turnover in Russia [13]

The development of the ICT sector in Russia is accelerating, mainly due to the development of broadband Internet access, the penetration of smartphones and the growth of mobile Internet subscribers. On the one hand, Russia has developed a telecommunications market with broad coverage and stable services, characterized by a high degree of digitalisation and competition. These infrastructures have led to the development of related industries and the use of new technologies in industry and trade, including the IoT, AI and blockchain. On the other hand, Russia has a rather powerful training system and the number of technical talents is increasing accordingly. In this context, a new economic ecosystem based on smart cities, smart transport and other digital technologies is gradually maturing and developing [14].

India. In its 12th Five Year Plan (2012?2017), India stressed the importance of telecommunications development and proposed to strengthen support for mobile communications and broadband Internet access. Under the Plan, India launched the ?Digital

India? national strategy in 2015, which provides for universal broadband access, provision of communication services throughout the country, expansion of telecommunications and network coverage in rural areas, bridging the ?digital divide?, establishment of data centres, creation of new jobs, acceleration of e-government and international competitiveness [15]. Moreover, India has launched the Smart Cities Mission, which is developing 100 smart cities across the country, making them citizens friendly and sustainable.

India is one of the largest countries in the world with over 560 million internet users (2018), second only to China. According to a forecast by McKinsey & Company [16], India will increase the number of Internet users by about 40% to 750?800 million and will double the number of smartphones to 650?700 million by 2023. Between 2017 and 2018, the major sectors of the digital economy in India accounted for about $170 billion, or 7% of GDP. According to the Ministry of Electronics and Information Technology, India is the second fastest growing digital economy in the world, and India could create up to $1 trillion in economic value from the digital economy in 2025 [17].

The most important sectors in India's digital economy are ICT (hardware, software and IT services), financial services, work and skills, agriculture, education, logistics and retail?all of which are the fastest growing sectors in the country. In addition, it is important to note the outlook for the Internet economy (primarily e-commerce) in India. The e-commerce market in India is expected to reach $200 billion in 2026, which is the fastest growing market in the world, compared to $48.5 billion in 2018 [18]. This growth is primarily due to the rapid penetration of the Internet and smartphones. India also has a large number of micro, small and medium-sized enterprises (MSMEs) that provide key financial services, technology and talent training, and which undoubtedly play an important role in the country's digital economy.

India has long enjoyed traditional benefits and growth potential in software and telecommunications, and has created a large number of jobs, while using new digital technologies to improve broadband and mobile phone coverage. The Mobile Economy Asia Pacific 2020 (by GSMA) shows that India's performance is growing rapidly, for example, the penetration of communications is increasing from 78% (2019) to 85% (2025), and the adoption of smartphones from 67% (2019) to 84% (2025). The report also indicates that India will become one of the largest smartphone markets in the world in 2025 with 1.041 million users [19]. Meanwhile, India has a high level of international cooperation in telecommunications, and cloud technology and information security are also important links in India's digital economy.

China. China attaches great importance to the development and management of informatisation and internet processes, coordinating major informatisation and cybersecurity issues in the political, economic, cultural, social and military fields within the country. In 2015, a proposal for the construction of the ?Internet Power? project was included in the strategic structure of China's 13th Five-Year Plan, becoming an important component of the country's social and economic development in the coming years. In 2017, new plans were formed for the implementation of innovative projects such as the ?Internet Power?, ?Digital China? and ?Smart Society?, aimed at stimulating the development of the digitalisation of China's economy in a new era by promoting the deep integration of the Internet, big data, artificial intelligence and various economic sectors, thus contributing to the sharing economy and new growth points.

The China Academy of Information and Communications Technology (CAICT, a specialized think-tank) has been publishing since 2015 the annual White Paper on Digital Economy Development in China. The latest CAICT document shows that: in 2019, the added value of China's digital economy reached 35.8 trillion yuan, or 36.2% of GDP, an annual increase of 1.4% points [20]. It is important to emphasise that the digital economy has indeed entered a new era of development, as with the advent of a smart community, relying on big data and knowledge-intensive technology, lifestyles are changing dynamically. ?Internet?+?? has been widely integrated into all layers of society. Against the backdrop of realisation of Digital China, local government is purposefully promoting e-government. There is a deep integration of trade and service activities using information technology. New business ecosystems continue to appear, becoming a new entry point into the Internet [21].

According to The China Statistical Report on Internet Development [22], as of June 2020 in China: the number of Internet users has reached 940 million with an Internet penetration rate of 67.0%, with 99.2% of Internet users using mobile phones to access the Internet. It should be noted that 285 million internet users (30.4%) are in rural areas and 654 million people (69.6%) are in cities. China became the world's largest online retail market for the seventh consecutive year. There is a total of 749 million internet shop users, including 747 million mobile internet shop users. China also ranks first in the world in mobile payments, with total turnover reaching 196.98 trillion yuan. There is a total of 805 million online payment users, of which 802 million are also mobile payment users. Digital technologies for online marketing and transactions are developing dynamically, as are technologies for e-commerce platforms by supporting micro-small businesses, and by using big data and artificial intelligence to expand mobile payment scenarios. It is also worth noting the rapid construction of the new generation 5G telecommunications system in China. To date, the number of terminals connected to the 5G network has exceeded 66 million and over 400,000 5G base stations have been opened.

South Africa. South Africa has taken major steps to develop its digital economy, such as the National Integrated Information and Communication Technology Policy White Paper (2016) [23]. The White Paper covers infrastructure development, legal regulation, economic integration, education and other aspects and is a key strategy for building an inclusive and innovative society based on digital technology and knowledge in South Africa.

In 2017, the Internet for All Initiative was proposed, and it is planned to connect 22 million people currently without an Internet connection to the Internet by 2020, as well as 100% broadband penetration [24]. In 2018, South Africa published White Paper on Science, Technology and Innovation: Draft, which clearly states the need to promote technology in the digital economy. The document defines a long-term informatisation policy for the next 5?15 years, proposing the use of artificial intelligence and information and communication technologies for economic development and increased competitiveness. It emphasises the crucial role of science, technology and innovation and strengthens research and innovation in advanced production and information and communication [25].

Between 2010 and 2017, there was a significant decrease in the growth rate of value added in ICT. The share of ICT sector value added in South Africa's GDP is 2.1% (2014) [26]. According to the State of the ICT Sector Report in SA (by Independent Communications Authority of South Africa), the revenue from telecommunication services increased by 3.6% from 187 billion rands in 2018 to 194 billion rands in 2019, while total investment in telecommunications decreased by 17.1% from 46 billion rands in 2018 to 38 billion rands in 2019. The country's population coverage of 4G/LTE services increased from 85.7% in 2018 to 92.8% in 2019 [27]. Internet penetration is 47% and is expected to reach 60% by 2021, while mobile penetration is 65% and continues to rise. GSMA predicts that by 2025 South Africa will have almost 73 million smartphone connections and will account for almost half of all IoT cellular connections in sub-Saharan Africa (49%) [28]. Compared to other regions, the overall level of e-commerce in Africa is still low but is growing rapidly. In 2019, e-commerce turnover in South Africa was $3 billion. However, 35% of South Africans made at least one purchase online [29].

Overall, ICT service provision in South Africa has improved in recent years but has declined in some areas due to economic conditions. The efficiency and impact of the digital economy and the digitalisation of industry in South Africa are still relatively low, with the Internet infrastructure being the biggest challenge. However, digital technology is developing in all sectors of the South African economy and has great potential for the future. The current focus of the South African digital economy is on mobile payments and electronic commerce. It is also worth noting that South Africa, as one of the countries with the highest level of digital infrastructure on the African continent, has advantages in developing 5G, cloud computing, IoT and AI.

4 Discussion

The following proposals for cooperation in the development of digital economy in the BRICS countries are presented for discussion:

Firstly, the continuing development of the digital economy and improvement of internal development in the BRICS countries. International cooperation is based on domestic policy. The BRICS countries can strengthen cooperation in areas such as 5G, AI, big data and blockchain. In addition to building ICT infrastructure, the BRICS countries can also focus on developing innovative transport infrastructure investment projects through existing multilateral development banks (e.g. the New Development Bank), including roads, railways, power grids, water facilities, ports, logistics systems and other major industrial support areas. In addition, the BRICS countries need to strengthen the scientific and technological cooperation, especially in the research area of ICT and ?Internet?+?Industry?. As part of the BRICS cooperation mechanism, the possibility of establishing a special international centre for cooperation and research in the digital economy could be explored with a view to fully integrating the research and development capabilities and human resources of the five countries in related fields, focusing on the creation of series of projects to meet the needs of the five countries, and facilitating the transformation of scientific and technological developments and their industrial application.

Secondly, maintaining an equal multilateral dialogue within BRICS. The BRICS countries should seek common ground while preserving differences, reduce disagreements and engage in multi-channel dialogue to address uneven development. In building a digital economy, each of the five countries has its own strengths, but at the same time has many different constraints on development. In order to maximize the development of the digital economy in BRICS, the five countries need to be encouraged to increase investment in their real economy, which is the foundation of the digital economy as the basis for the new technological revolution. BRICS countries can promote the deep integration and use of high and new technologies in the real economy and industrial production, including in key areas such as AI, big data, digital twin, blockchain, cloud computing and Internet?+?[5]. On the other hand, the BRICS countries, with their large populations and varying levels of development, must continue to promote sustainable development in their countries and invest more in education, health and poverty eradication. The digital economy is mainly based on scientific and technological resources and information technology, and therefore it is necessary to create research and digital infrastructure and increase investment in research, education and Internet penetration. At the same time, the BRICS countries should improve the integrated management and service system for mobile Internet and promote further development of e-government, taking into account the realities of rural areas.

Thirdly, focus on non-traditional security challenges in developing the digital economy [3]. For example, against the backdrop of the global Covid-19 pandemic in 2020, human security and health are facing unprecedented challenges, while the world economy is experiencing the worst downturn since the Great Depression of the early twentieth century. As countries enter a period of continuous co-existence of Covid-19, the digital economy continues to develop further, and new forms of business, industrial models, e-commerce, mobile payments, smart cities, smart logistics, and contactless and distance working concepts and practices are constantly changing. The digital economy, which largely guarantees basic economic activities and social life, will further strengthen its position and role in the long term and is one of the most important means for human society to overcome the pandemic.

5 Conclusions

There is no doubt that the national interests of the five BRICS countries always determine their line of conduct within the BRICS. In general, the development of the digital economy in the BRICS countries is based on the continuous development of information and communication technologies and other cross-cutting branches of applied sciences. Advanced technologies are mainly used in various traditional sectors of the economy, such as industrial production and the service industry, but are also widely represented in innovative industries such as new materials, nanotechnology, aerospace technology, digital currencies, electronic payments, e-commerce etc. These new changes have given an impetus to the growth of the global economy and, at the same time, have encouraged countries to invest in key areas of basic and applied sciences and technology, emphasizing the importance of international cooperation.

Sustainable development of the digital economy is a complex and comprehensive task that requires joint efforts and cooperation of governments, businesses, communities and peoples in the long term for the final transition to the digital economy. In the post-covid period, the international community should strengthen communication and cooperation in the field of public health and seek to broaden international consensus. In this process, the role of new ICTs and the digital economy is particularly visible, with the Internet of Things and big data analysis providing important benchmarks for the prevention and control of the COVID-19 pandemic, and the new generation of biomedical technologies being used to develop the effective vaccine against the virus, further facilitating the integration of innovations from the digital economy into the real economy.

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Digital Medicine Labelling and Traceability in Russia

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Abstract. The labelling has become widespread. The changes affected the legislation of different countries, mainly in the West. Label is a barcode on the product packaging, an identifier containing information about the product. Marking is needed to identify counterfeits. Logistic information systems allow to optimize the connections between system elements. IT companies offer their solutions for transparent tracking of products. SAP SE has launched SAP Advanced Track and Trace for Pharmaceuticals (ATTP). The IT solution specified in the paper serves to ensure patient safety. This new marking and traceability solution helps the pharmaceutical business to keep track of products, collect data from logistics, manufacturing business processes and communicate with regulatory authorities. This paper discusses the main business processes associated with the adoption, movement and disposal of medicine after the entry into force of the laws on mandatory labeling using the example of a multifunctional health complex. The research focuses on minimizing costs and changes in the organization's work, implementing the SAP ATTP solution, interacting with the existing SAP ERP system. By choosing this solution, it will be easier for the user to adapt to new realities faster.

Keywords: Circulation of labeled medicines · Packaging labeling requirements · Mandatory labelling · Data matrix · Traceability system · SAP ATTP

1 Introduction

The problem of illegal products is relevant for the whole world. The governments of various countries are planning to oblige to label most of the goods to solve this problem. Modern means of identification are so diverse that the manufacturer has a wide range of options for applying data about the product, methods of transportation and additional information [1]. Transport signs contain information about the characteristics of the goods in order to preserve the contents and also warn employees of logistics companies about dangerous goods. Ecolabels are most often used on imported goods that contain information about packaging materials and disposal methods. Certification labels are marks of conformity of product quality to certain standards. This mark informs buyers

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about the quality of products. The listed signs refer to graphic means of product labeling. Graphic symbols save space on packaging, but require decoding of the data.

The most famous type of markings is trade markings, which include graphics and text. The trade mark contains information about the product, its composition and manufacturer. Manufacturers often use this type of marking also for advertising purposes. For example, line codes are no longer printed as a separate independent picture, they are applied to a label with a trade organization's logo, or printed on a color branded sticker of a product manufacturer. For the first time in Russia, product labeling was introduced on alcoholic and audiovisual products as well as tobacco products.

Nowadays the concept of "product labeling" is increasingly mentioned in the news, especially the labeling of medicine during a pandemic of a new coronavirus infection, when the issue of medicines is acute. Marking is the application of a unique code to goods, which can then be considered a 2D scanner. This approach allows to identify each unit of goods, track the movement of products along the distribution network and prevent the spread of counterfeit products.

2 Materials and Methods

In Russia the project is underway on mandatory labeling of medicines with two-dimensional Data Matrix codes—the development of an international independent not-for-profit organization for the standardization of accounting for GS1 logistic units. GS1 standards improve efficiency, safety and traceability in physical and digital supply chains in many sectors of the economies of countries around the world [2]. The systems created by the association use standards for location (GLN), batch (AI 10), logistics (SSCC) and consumer units (GTIN) in commodity circulation allowing the transfer of information. Inspection of secondary (consumer) packaging is carried out in GS1 systems because they must be barcoded, that is why labeling the primary MPs packaging is meaningless without secondary packaging. Labeled data includes the name of the drug, the form, the barcode of the drug, the size and number of containers, the batch number of the product, the dates of the transaction and shipment, the name, the address of the sender and the recipient. GS1 systems allow encryption of any additional information: weight, batch and batch number, expiration date, date of manufacture. The enacted law influenced the control of all units of the supply chain MPs in the United States [3].

In October last year Russia passed a number of federal laws to create a national system for traceability of goods. The National Traceability System is an information system that provides storage, processing, collection, accounting of data on goods included in the system and control over transactions with goods included in the list of goods subject to traceability. The purpose of the creation, implementation and maintenance of the national system of traceability of goods is to control the turnover of goods from the manufacturer to the end consumer. The law will fully enter into force on July 1, 2021, but labeling of some goods (shoes, cameras and others) is already required. Since July 1, 2020, mandatory labeling has affected medicinal products. The aim of the labeling project is to combat the production and circulation of counterfeit and falsified pharmaceutical products. To implement the conceived project, an information system to monitor pharmaceutical products circulation (IS MDLP) for medical use was developed, the operator of which was the Federal Tax Service of the Russian Federation. A year ago, the business faced the problem of entering information on medicinal products (MPs) into the IS MDLP Companies needed to improve the IS, which records the movement of material and technical resources, or to install ready-made tested solutions for integration with IS MDLP. In our opinion, the problem of transferring information to the national system about the logical chain in organizations throughout the entire MPs life cycle is relevant.

At the moment, there remains a fairly large number of medical organizations that are not ready for innovations in the field of labeling and integration with the information system for monitoring the movement of medicines. The reason for this was a lot of accumulated problems in medical organizations, for example, technical problems (lack of barcode scanners, networks), problems with personnel, the unavailability of IS to integrate with MDLP and work with labeled MPs or its absence in a medical organization.

The analysis of research on the topic of drug labeling allows to say that the work pays great attention to the aspects of the functioning of the marking management system, traceability.

The papers describe the need to use automatic identification technologies, which will allow transferring information about labeled MPs to IS MDLP from the manufacturer to the end consumer using identification means. A means of identification is a unique character sequence, a kind of machine-readable marking applied to the MPs package by labeling or printing. The MPs manufacturer performing the prepackaging (packaging) stage of MPs is the issuer of identification means and engages in labeling the consumer (secondary) medicinal product packaging, if it is absent on the primary MPs packaging [4].

The information transferred to the information system is a legally significant document flow between the subjects of drug circulation and IS MDLP. Since medical institutions will have to enter information into the IS MDLP on the arrival, shipment, write-off, withdrawal from circulation of drugs, the process of introducing work with labeled MPs will protect the population of the Russian Federation from counterfeit drugs on the market [5].

The paper also describes the problem of prohibiting posting to the warehouse and sending to the MPs divisions until the system verifies the authenticity of each consumer package. In this regard, when preparing an information system to work with IS MDLP, the following aspects must be taken into account. Data exchange should be carried out in automatic mode (API), which is especially important for large MPs. It is necessary to carry out operational, chronological control over the timely entry of information into the IS MDLP [6].

It is worth noting that the labeling process has proven to be too expensive for entities that produce low-end MPs. The costs of purchasing, installing and installing the necessary equipment are quite sensitive. This problem can provoke an increase in the price of MPs, which will negatively affect the consumer [7].

For the full functioning of the IS for labeling, MPs traceability, it is necessary to train personnel, prepare production facilities, there must be the necessary equipment, specialized devices for reading bar codes [8]. The German company SAP SE has localized a global product labeling solution for the Fair Mark requirements. The adaptation was made on the basis of the SAP ATTP solution in accordance with the current requirements of Russian legislation [9]. SAP is one of the partners of The Center for Research in Perspective Technologies (CRPT) and in the future, according to the state schedule for the introduction of labeling of various categories of goods, plans to release the updates necessary for the system [10].

The Fig. 1 shows the scheme of data distribution between information systems. Data from the SAP ERP system goes to SAP ATTP and then to the government system. The responsible specialist based on the need for medicinal products, creates a purchase order, completes the receipt or transfers of medicinal products in the SAP ERP IS. To register the receipt of medicines, the responsible specialist enters the necessary data and scans the DataMatrix codes. During the process of saving the purchase order, the system automatically determines which materials belong to the marked goods and transfers the information to the SAP ATTP system. Messages to the national product marking and tracking system (chestnyjznak.rf) are prepared automatically at the time of the receipt/write-off document generation in the FI module, at the time of the movement document generation in the MM module in the SAP IS. Messages are generated in the SAP ATTP system according to the pre-configured settings.

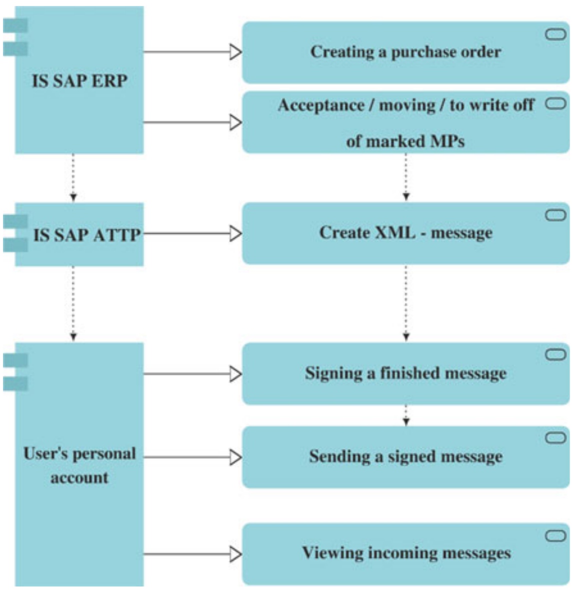

Fig. 1. Data distribution scheme between information systems

Materials from ERP can be integrated into APTP as goods. In this case, the required attributes can be maintained exclusively in the ERP system [11]. Goods in the APTP are primarily identified using the GTIN (GS1 classifier). Accordingly, those materials that have a GTIN specified can be integrated into the ATTP. One material may have different GTINs for different units of measurement (for example, for a blister and a common box). In this case, APTP creates two article records with the same material number. The application of an identification code on the packaging is performed by the manufacturer of medicinal products which prepares the preparations. The data are applied using identification instruments, on the secondary (consumer) package of the medicinal product, and in its absence—on the primary package [12]. Unlabelled drug packages manufactured before mandatory labeling may be sold before the expiration date.

In Russia 3 levels of the MPs packing hierarchy are described:

- Primary packaging—the place of storage of the drug itself (tablets—in a blister pack, liquid—in ampoules).
- Secondary (consumer) packaging—packaging that the final consumer (buyer) sees at points of sale.
- Tertiary (transport) packaging—used for transportation.

The following points are necessary to work with labeled goods:

- Enhanced Qualified Electronic Signature (UCEP). It will be required for authentication in the system.
- 2D barcode scanner for receiving and selling.
- For large batches, a data acquisition terminal is required.
- Update the firmware of the online cash register, prepare the workstation and train employees.

The drug labeling process includes:

- Registration on the site chestnyjznak.rf.
- Placing DataMatrix code on all medicinal product packages.
- Transfer of ownership between legal entities with indication of DataMatrix product codes.
- Scan all codes at disposal.

3 Results

The object of the paper was a health-improving complex in the Leningrad region, where laboratory tests, functional and ultrasound diagnostics can be carried out. For treatment and recovery, modern medical equipment and procedures are used, a hydropathic establishment and a halochamber are equipped. There are several buildings and warehouses where additional equipment, medicines and medicines are stored. The complex already has an ERP system SAP R/3 with all the main modules (FI, FI-AA, CO, MM, SD, HR) [13]. In connection with changes in legislation, the company had a need to implement a new SAP ATTP solution, which would allow reporting to the state information system [14].

A survey was conducted of the company, analysis of current and compilation of new business processes, as well as diagrams of business processes associated with the accounting and movement of drugs [15].

After receiving the primary documents for the supply (invoice and invoice), the storekeeper, based on the purchase order, draws up the arrival of medicines. At the same time, using the DataMatrix code scanner, the GTIN and SGTIN of the product are read. After scanning of all medicines, a delivery confirmation is carried out and a material document is generated. Delivery data is transmitted to the ATTP system for accounting of marked goods and automated generation of XML messages for transmission to the Chestny ZNAK IS [16]. The responsible specialist, using his personal account, checks the generated XML messages, signs them and sends them to the Chestny ZNAK IS. When MPs is shipped from the warehouse, the sender sends a message to IS MDLP containing the date of the transaction, its type, sender and recipient identifier, contract, its type, purchase price, VAT amount. The recipient carries out acceptance at the MPs warehouse and sends a confirmation to IS MDLP. The deadline for submitting information to IS MDLP is 5 working days, but before the next operations with the goods.

If it is necessary to carry out the movement of medicines between different places of activity, the storekeeper draws up the request. DataMatrix codes of medicines are scanned, a material document for movement is formed, information is transferred to the ATTP system. The responsible specialist, using his personal account, checks the generated XML messages, signs them and sends them to the Chestny ZNAK IS.

When moving MPs between the buildings of the complex, it is necessary to send a message to the system for monitoring the movement of MPs, which contains the date of the operation, identifiers of the place of shipment and acceptance, as well as a list of unique identifiers for packages. It is easier to move MPs between warehouses or departments since the data is already loaded during the receipt of drugs. It is required to prepare the basis for moving, choosing a place from those indicated in the license for medical or pharmaceutical activities.

If it is necessary to dispose of medicines, the storekeeper draws up a write-off certificate. DataMatrix codes of outgoing medicines scans, a material document for write-off forms, information transfers to the ATTP system. The responsible specialist using his personal account checks the generated XML messages, signs them and sends them to the Chestny ZNAK IS. When a medicinal product is withdrawn from circulation, a message is sent to IS MDLP containing the date of the operation, the identifier of the place of destruction, the type of withdrawal from circulation, the details of the original document, the basis for transferring it to destruction.

As a result of the redesign of business processes, logistics links of the medical complex and the implementation of the solution for labeling and tracking of drugs and medicines SAP ATTP, the labeling process is significantly simplified, minimizing the costs of legislative requirements [17]. Special packages for countries greatly simplify communication with government agencies, you no longer need to waste time complying with changes in legislation. SAP ATTP can function autonomously, but in this variant it is an addition to the existing ERP system. The solution makes data exchange between systems possible.

4 Discussion

Six months later the first results of the mandatory labeling are visible. The project made it possible to identify drugs in pharmacies intended for hospital patients. Low-cost medicines were sold by unscrupulous employees of medical institutions. Labeling is able to identify such cases, making the drug market more transparent [18]. Mandatory labeling of drugs, which began on 01.07.2020, will not provoke an increase in cost or shortage. To avoid a deficit, a number of measures are envisaged. For example, foreign manufacturers can barcode their drugs at customs. In addition, Russian and foreign manufacturers have the right to apply to the interdepartmental commission under Roszdravnadzor to obtain consent to import or put into circulation unmarked MPs. In terms of price increases, CRPT is obliged to provide labeling codes for drugs below RUB 20 free of charge. If a medicine costs more than 20 rubles, then the cost of labeling at 50 kopecks per code is insignificant.

In reality, there is a shortage of drugs in pharmacies and medical institutions. Since October, there has been a wave of demand for medications that are associated with the treatment of a new coronavirus infection, despite the fact that they are dispensed with a doctor's prescription and are prescribed only for severe illness. Pharmaceutical companies did not have time to produce medicines, and distributors could not cope with the load and turnover, reflecting the movement of medicines in the system [19]. Thus, with the introduction of mandatory labeling, the speed of movement of drugs between distributors and pharmacies has decreased.

In November after simplifying the labeling and traceability of medicines, the situation improved [20]. Now pharmacies can sell drugs after notifying the system of their arrival without waiting for registration confirmation. In our opinion, this change made it possible to facilitate the supply of drugs to pharmacies. Representatives of the CRPT noted that currently only 10% of the total quantity of labeled drugs is in circulation.

Simplified goods acceptance mechanisms in the drug labeling system will remain until July 1, 2021. There are 6 months left until the end of the simplified mode of operation, but even now only 8% of operations in pharmacies and less than 1% in medical organizations have gaps in the chain that can be traced. To sum up, the quality of work in the marking system has improved. This will allow to switch to a full-fledged work format after the abolition of the simplified regime. Today the system is stable, 90% of documents are processed in less than 10 min, there are no delays in the supply of drugs.

5 Conclusions

In this paper, were analyzed the impact of regulatory legal acts on labeling and traceability of pharmaceuticals on the pharmaceutical business, changes in its work. When implementing the requirements, it is necessary to revise the logistics processes that have been built in companies for years. Organizations also needed systems that were integrated with existing solutions. One of such solutions was the systems of the international association GS1 and the German company SAP SE, which minimize the time and costs for updating the IP, compliance with the labeling rules.

The solutions help companies navigate the transition to mandatory drug labeling. As a result of redesigning business processes, logistics links and the implementation of labeling and tracking solutions, the drug labeling process is greatly simplified, and the costs of legal requirements are minimized. Localized software packages make it easier to interact with government agencies, changes to laws and regulations are included in fix packs.

The paper describes the benefits and harms of the introduction of mandatory labeling. The project will depend on the business processes of firms resulting from the adaptation of the technologies used in the segment [21].

In the future, it is possible to introduce mandatory labeling for many more products. The impact of the transition to mandatory product labeling has yet to be assessed.

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The Use of Digital Data Aggregators in the Development of Urban Infrastructure

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Abstract. Currently, one of the key tasks in the sphere of territorial development is the integration of digital technologies into the human environment in order to improve its quality, comfort and safety. Despite the active spread of modern technologies within the framework of the smart city concept, observed in the last decade, the level of digital transformation of particular cities, regions and countries is uneven. In the conditions of digital economy, the basis for the functioning of territories is the introduction of digital platforms as aggregators of various information and communication systems, portals and structures. The article discusses some practical examples of the use of digital data aggregators; gives a description of the concept of digital platforms from both technical and socio-economic points of view. The evolution of digital platforms as the basis for the development of urban infrastructure were assessed, and the scale of platform development depending on the levels of integration of urban systems and technological equipment of territories was also considered. As a result, the conclusion was justified that in the conditions of digital economy, it is necessary to combine both open data provided free of charge to all users of the platform rationally and introduce the practice of charging fees for certain databases, the use of which may be necessary for commercial organizations in order to develop and improve products and services.

Keywords: Digital platform · Smart city · Living environment · Digital technology · Infrastructure

1 Introduction

In the context of the transition to a digital economy, one of the key tasks in the development of the human environment is the introduction of the smart city concept, which is associated by both the growth of the urban population and the whole process of digital transformation of urban infrastructure. Currently, platforms for digital interaction of citizens with authorities, utility providers, as well as a variety of commercial organizations, from housing booking and car sharing to aggregators of consumer goods and services, are becoming widespread.

The main goal of urban infrastructure development is to create an environment favorable for the life of the population and doing business as one of the ways to increase the

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rates of economic growth of particular regions and the country as a whole. According to experts, the introduction of smart city technologies can reduce the number of crimes by 30–40%, reduce the time spent on using transport by 15–30 min per day, reduce water consumption by 25–80 L of water per person per day and increase the speed of emergency services response by 20–35% [1].

Within the framework of the sixth technological paradigm, the achievement of this goal is associated with the digitalization of the life processes of cities (within the framework of a smart city and other concepts [2]), which is expressed in the transformation of approaches to collecting and analyzing data based on the introduction of digital aggregator platforms that allow managing most accurately and promptly the processes inherent in a particular territory. The purpose of this study is to analyze the practical experience of implementing digital platforms in the world practice of infrastructure development, as well as to assess the evolution of digital platforms in the field of urban infrastructure.

2 Materials and Methods

Currently, various digital platforms in the sphere of collection and analytics of data regarding the territory and vital activity of the population are becoming more and more widespread. The platforms are designed to act as an aggregator for three key components of a smart city—sensors, communication methods between systems and open data portals.

In recent years, the scientific community has been interested in the issues of digital transformation of healthcare (online consultations, applications and specialized sensors for remote monitoring of patients' condition) [3], energy saving (piezoelectric technologies, renewable sources) [4], blockchain application [5], which is associated with the transition to a higher level of development of the smart city concept, which in turn implies a qualitatively new approach to solving problems in the sphere of functioning of the human life environment based on the comprehensive penetration of technologies into the urban infrastructure.

Currently, the leaders of digital transformation of the urban environment, according to McKinsey estimates, are New York, San Francisco, Chicago, Stockholm, Amsterdam, Copenhagen, Barcelona, Helsinki, Singapore, Seoul, Melbourne, Shanghai, Hong Kong [1]. In accordance with the IMD Smart City Index 2019, cities such as Zurich, Oslo, Geneva, Dusseldorf and Vancouver are also most successfully implementing digital technologies [6].

As a rule, digital platforms are considered from the point of view of commercial organizations such as Apple, Alibaba, Uber, AirBnB, etc. [7], however, within the development of territories, it is not so much the commercialization of the platform that is important as its functionality and objectivity. One of the possibilities of using digital platforms is the unification of information from commercial organizations, utilities, statistics authorities, etc., which can subsequently be used as a potentially new source of income for the city budget [8].

For example, Copenhagen was one of the first of its kind to implement the City Data Exchange (CDE) platform, which is cloud storage of data from a variety of private and public sources. This platform accumulates all information about the life of the territory and transforms it into data that can be analyzed: some data is publicly available, but other is provided for a fee, which is important for developers of smart city solutions. On the one hand, the city receives additional income that can be spent on improving the life of the population, and on the other hand, the scientific and business community gets access to reliable, "cleaned" information to create and/or improve digital products and services.

Singapore is one of the most developed cities in terms of using digital platforms. Smart Nation Platform is an integrated system of sensors and electronic portals that allow not only collecting data, but also promptly reacting to emergencies. The digital platform is characterized by such areas as [9]:

- digital identification of a person (biometrics, digital signature, creation of a single card accepted for all transactions and services in the city);
- electronic payments;
- development of services in the sphere of health care and social support (electronic medical records, monitoring systems for the elderly population—sensors that respond to the sounds of falling, atypical actions);
- simplification of registration and doing business;
- acceleration of the process of data exchange between various departments, including due to the spread of cloud technologies;
- expanding the network of sensors that control processes in various areas—from water consumption to the spread of Dengue fever associated with weather conditions;
- modernization of the transport system (contactless payments, autonomous transport, optimization of traffic flows).

In general, the concept of a smart city, despite the different levels of development in certain regions and countries [10], is aimed at simplifying communications between economic entities. In our opinion, it is exactly the spread of the practice of introducing digital data aggregators as a connecting link between many separate systems and portals that is the main direction of urban infrastructure development in the digital economy.

3 Results

The concept of a digital platform can be viewed from both technical and non-technical (emphasis on communications) points of view. In accordance with the first, platforms are understood as the technological basis for the functioning of many digital systems, products and services [11, 12]. In addition, it is noted that digital platforms are able to adapt to innovations, as technologies change rapidly and platforms must be able to expand in order to meet fully the requirements for digital smart city systems [13]. In accordance with a non-technical point of view, digital platforms allow forming multilateral networks between suppliers of various goods and services and the population, which leads to a reduction of time spent on solving a particular problem (task), and also generally simplifies the interaction of all related parties in the process of urban infrastructure functioning [14–16].

A gradual increase in the importance of information for the effective functioning and development of infrastructure has been going on since the 1950-s, when knowledge became one of the factors of production, the requirements for the qualitative characteristics of the workforce increased, the pace of introduction of new technologies accelerated. In the period 1930–1980-s the concept of the Informational City dominated. Within the framework of this concept, based on the emergence and rapid development of information and communication technologies (HTTP hypertext transfer protocol, HTML syntax, web browsers, addressing in the global network based on URL addresses, web servers and web pages), all processes of the infrastructure functioning were transformed [17].

Further, in the 1980-s-2010-s the Informational City has gradually transformed into a digital one, due to the creation of the PHP programming language, SQL databases and other technologies that have become the basis of many digital platforms—from social networks to city portals designed to provide state and municipal services to the population in electronic form [18].

Since 2010, the development of digital technologies has made it possible to transfer to the concept of a smart city, within the framework of which digital platforms are no longer segmental systems, but are united into a single structure consisting of three levels. The first level of digital platforms in a smart city includes physical aspects—detectors, sensors, meters, cameras, etc. The second level consists of data transmission facilities, network communication technologies designed to accumulate data of the first level. The third level is associated with the analysis of the collected data for modeling possible scenarios for the development of certain spheres of the city's life and their totality in order to develop the most optimal solutions for managing the development of urban infrastructure.

Of course, the considered stages of development of digital technologies were not implemented throughout the indicated time periods everywhere. An assessment of the development of digital platforms in smart cities can be based on studying the level of integration of city systems and the level of technological embeddedness of the territory (Fig. 1).

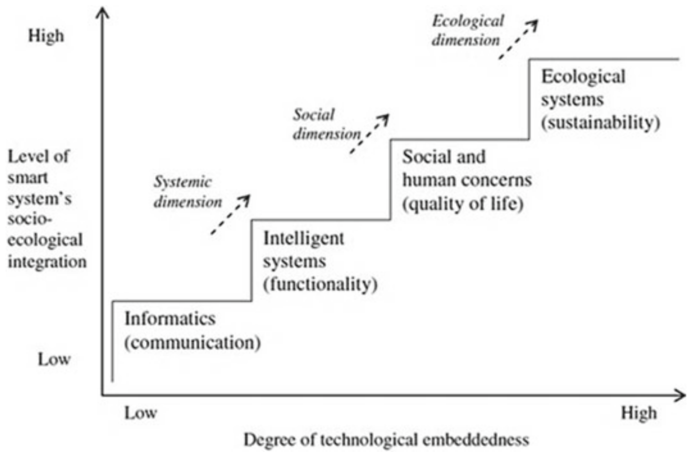

Fig. 1. Levels of development of digital platforms of smart cities [19]

The development of digital technologies makes it possible to transfer from platforms aimed at simplifying communication to intelligent systems with more functionality and then to platforms that solve social problems and improve the quality of life of the population. The most advanced digital platforms also include environmental aspects to ensure sustainable development of territories.

Let us note that the development of digital platforms in a smart city is associated with interdisciplinary interaction of experts from various spheres—urban planning, economics, management, ecology, psychology, health care, education and many specialties of technical and informational orientation (analysts, developers, etc.).

Thus, the evolution of digital platforms, their gradual transformation, connected with the development of technologies, and integration into the concept of a smart city is a key direction for improving the functioning of urban infrastructure in the digital economy. Digital platforms become a connecting link between a variety of actors (population, utility providers, government, scientific community, commercial organizations). In our opinion, the development of digital platforms should be based on an interdisciplinary approach, since the achievement of a wide range of goals facing these platforms requires considering the theory and practice of different areas of scientific knowledge.

4 Discussion

The concept of a smart city includes the following key elements: separate digital platforms and services, the Internet of Things, distribution of smart phones, cognitive computing, big data, open data, 3D printing, robots, drones and unmanned vehicles [20]. Unified digital platform of a smart city should be an organically functioning combination of all the above elements, since only with the help of the simultaneous application of various technological solutions it becomes possible to analyze data about the territory and develop optimal managerial decisions.

Significant amount of aggregated information to be processed is of particular importance within smart cities in general and digital platforms in particular in order to create data sets. These data sets are interesting for analysis by both government agencies and private organizations that are ready to acquire them to improve their own products.

Data arising in the process of city functioning is divided into the following categories [21]:

- data related to the housing and utilities sector (water supply, electricity, transport, telecommunications);
- data characterizing the social aspect (health care, education, culture and sports, emergency response services, interaction with authorities);
- data aggregated from social networks (subject to compliance with the privacy policies of certain platforms);
- data characterizing the state of the environment (level of air pollution, noise), traffic congestion, economic activity of the population, crime rate, etc.

Currently, more and more attention of the scientific community is paid to the formation and use of open data within the digital platforms of smart cities. Open digital data is provided to all users of the platform free of charge, which, for example, in the UK contributes to the acceleration of economic growth through the intensification of scientific developments both in the field of information and communication technologies and science in general [20]. In our opinion, the introduction of open data requires a high degree of reliability of the digital platform, transparency of its functioning, openness for platform users. In addition, over time, more and more data will be aggregated by smart city systems, so it is important to consider that the digital platform should be adaptive to changing environmental conditions, as well as be able to provide data online to provide related parties with the most relevant information.

Nevertheless, from the point of view of financing the implementation and maintenance of the functionality of the digital platform, one of the areas of use of the collected data is to provide them for a fee to interested parties who want to have statistics on one or another aspect of the city's life in order to develop or improve their own product (service). In general, the main participants of the digital platform are the population, the state and organizations [22]. For the population, digital platforms, first of all, represent one of the ways to simplify communications within the city. The state can use platforms to maintain law enforcement in the territory, accelerate interaction with residents of the territory.

However, it is commercial organizations that have a financial interest as a result of their activities: on the one hand, they can invest in the digital platform of a smart city, and on the other hand, they can acquire data aggregated by the platform, since access to objective information presents an opportunity of development for them in connection with the necessity to adapt to the needs of city residents. Accordingly, digital platforms are not only a means of improving the quality of the living environment, but can also be used as an additional source of financing for the development of urban infrastructure by combining open data with data provided for a fee.

5 Conclusions

Thus, in the digital economy, digital platforms become the basis for the functioning of territories. It becomes possible to integrate segmental urban and private information systems, networks of sensors and cameras into a unified structure exactly on the basis of the platforms. Aggregation of data within the digital platform allows not only improving the quality of managerial decisions, but also acts as a basis for the spreading of the practice of interdisciplinary interaction.

The presence of structured and objective information about the functioning of the urban infrastructure allows conducting a comprehensive research in the development of the living environment, affecting problems in various areas of knowledge. As a result, the introduction of digital platforms into the urban environment not only affects the quality of life of the population, but also contributes to the intensification of the development of the city and the region as a whole due to the emergence of a unified digital data base that accumulates the needs of economic entities and characteristics of individual spheres of the city's life (transport, healthcare, education, etc.), which leads to a gradual transformation of the territory. Thus, digital platforms as an integral element of the concept of a smart city are one of the areas of formation of the digital economy, within which the functioning of infrastructure is based on the use of digital technologies.

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Information-Infrastructure Mechanism for Managing Industrial Enterprise Self-Development in the Setting of Digitization

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Abstract. At present, many Russian industrial enterprises pose one of the most significant questions about how they can increase their competitiveness. Modern transformation of the Russian economy is focused on the use of innovative techniques and approaches to the industrial enterprise management. There is an important task for industrial enterprises: to learn how to function under new conditions of digital transformation of industry focusing their attention on their self-development. The purpose of the article is to reveal the innovative mechanism to the industrial enterprise management. This approach is targeted at the self-development processes. In addition, the purpose is to explain their influence on the competitiveness of the enterprises. The article is based on the deep theoretical research of the industrial enterprise self-development management, such methods as economic and mathematical modeling, graphic methods of scientific learning being used. The informational and infrastructural mechanism of the industrial enterprise self-development management has been developed. The functions, new properties and methods of their fulfillment within the informational and infrastructural mechanism of the industrial enterprise self-development management, including information technology portfolio, have been defined. The integration of all information systems is an indispensable condition for the further digitalization of an enterprise and for the increase of its competitiveness. The introduction of transverse digital technologies will allow enterprises to compete successfully on the existing markets and to manufacture highly technological products and services for new markets.

Keywords: Information and infrastructure mechanism · Industrial enterprise · Digitalization · Competitiveness · Innovative approach

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1 Introduction

In the setting of the industry digital transformation, indigenous Russian enterprises manufacture products with a relatively high degree of complexity [1]. Hence, a competitive advantage can be achieved only by those producers who will be able to offer products that consistently exceed consumer expectations and to quickly adapt to changes in consumer preferences [2].

Strengthening of consumer requirements to quality of the manufactured products and implementation of information and telecommunication systems [3] in the infrastructure of industrial enterprises management signify the need to restructure the existing enterprise management system [4]. Not incidentally, one of the main problems currently faced by indigenous producers is difficulty to establish, maintain and increase the level of competitiveness of the manufactured products and the enterprise as a whole [5]. We believe that this challenge can be addressed through the use of innovative methods and approaches in the process of industrial enterprise management.

Nowadays, the management science undergoes a period of change. The basic management paradigm founded on administrative hierarchy tends to increasingly give place to the new management concept centered on self-managing systems [6]. Such systems go beyond flexibility of management structures. The key feature of the self-managing systems is their focus on the innovative and creative constituent of the human potential [7, 8]. These new qualities of company human resources facilitate development of effective self-organizing and self-developing management systems where human potential is fully unlocked, especially under the influence of intrinsic motivation and multi-level leadership [9].

Notably, the terms "self-organization" and "self-development" appear to be conceptually close. However, this is but a superficial understanding [10]. We propose to determine "self-organization" as follows. "Self-organization" refers to internal transformation processes of the industrial enterprise which emerge without interference from the outside and are directed at improvement of change management efficiency in the organization at the level of tactical planning.

As to "self-development", we propose to regard it in the following context. "Self-development" is a transformational breakthrough directed at shaping the "vision"—the desired image of the company's future—which takes into account the processes of the industrial enterprise's self-organization and determines the results of strategic planning.

Thus, the self-development process of an industrial enterprise can be viewed as the main, central component of the self-managing system of any organization; the component that provides the procedure for systematic change of the enterprise's operation. It is important to mention that a transformation requires not only the mechanism of change but also the description of the change management procedure [11].

We propose to consider the information and infrastructure mechanism for managing self-development of an industrial enterprise which would not only reflect the transformations in the organization's operations but also facilitate improvement of the company's competitive ability as a whole, taking into account the industry's digital transformation.

The purpose of the article is to reveal the innovative mechanism to the industrial enterprise management.

2 Materials and Methods

The paper is based on in-depth theoretical research of the problem of managing the industrial enterprise's self-development. Modeling of the information and infrastructure mechanism for managing the industrial enterprise's self-development is based on the summarized views of contemporary representatives of the field, taking into account the existing practice. The graphic method for presenting the functions of the information and infrastructure mechanism for managing the industrial enterprise's self-development enabled determining these functions and singling out new qualities and methods of implementation for those functions, thus shaping an information technology portfolio.

3 Results

Based on the analysis of contemporary monographs and periodicals, and also on the study of author reviews and thesis works dedicated to the topic of self-development of industrial enterprises, we can see that the questions of importance of informational, infrastructural and other kinds of support of the enterprise's operations in improving the level of their competitiveness have been discussed repeatedly [12].

However, in the course of our research, we have come to a conclusion that in considering the processes of self-development in the industrial enterprises, the authors fail to discuss in sufficient detail such fundamental questions as shaping the supportive environment at the enterprise for launching and managing the self-development processes, establishment of the necessary self-development management centers, and provisions for proper information and resource support [13].

Hence, the industrial enterprise self-development management process should account for such criteria as conscious management of information flows which underlie corporate knowledge management at the enterprise; corporate knowledge digitization; self-development management through management centers; and shaping the necessary environment at the enterprise [14].

In view of the foregoing considerations, we have developed an information and infrastructure mechanism for managing the industrial enterprise's self-development taking into account the industry's digital transformation (Fig. 1). The proposed information and infrastructure mechanism for managing the industrial enterprise's self-development consists of conditions for implementation of the mechanism, its structural design in form of the new logical structures, and time-based structure of operations in form of the information and resource support.

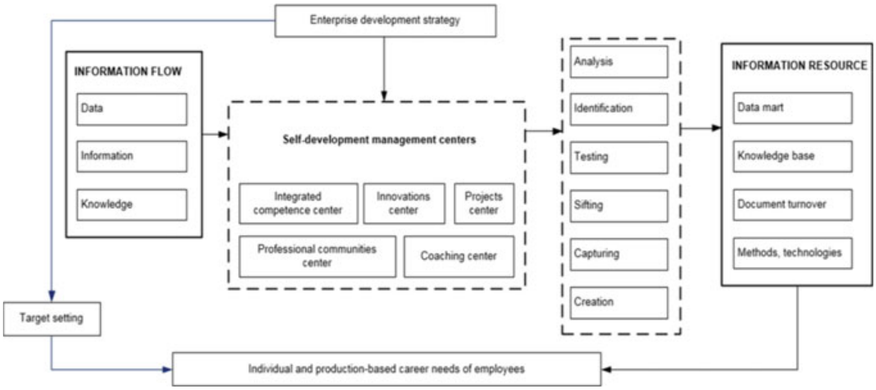

Fig. 1. Information and infrastructure mechanism for managing the industrial enterprise's self-development (compiled by the authors)

Conditions of effective functioning of the information and infrastructure mechanism for managing the industrial enterprise's self-development are found in the enterprise's cultural environment. This environment can be presented in the format of the corporate culture and brand that emerge on the basis of the values, mission and synchronized prospective targets of the enterprise, taking into account the individual and organizational career development needs of employees [15].

Shaping a cultural environment at the industrial enterprise which would be comfortable for the launch and management of the self-development processes is a complex and multi-faceted procedure. It is notable that the cultural environment is an inherently highly effective mechanism as it is closely related to the intrinsic drivers of motivation. Culture can present a fertile soil for development of proactivity and creativity in each employee, and can be regarded as the basis for self-development of employees and the enterprise as a whole [16].

Structural design of the proposed mechanism implies establishment of new logic structures which can be presented in form of self-development management centers. According to our understanding, such centers include an integrated competence center, a center for innovations, a center for projects, a center for professional communities, and a coaching center.

Employees of industrial enterprise self-development management centers should have professional, personal and special competences in the framework of their center; should be in possession of management competences in regard to the enterprise's operations (on such levels as: conceptual, strategic, tactical and operational); should be empowered to manage the enterprise's self-development activities; should perform special functions related to self-development initiation and management at the enterprise [17].

An important supporting structure of the self-development management mechanism at an industrial enterprise is its information and resource support [18]. This process can be regarded as a competently structured activity which is directly related to work with information. The information and resource support enables collection, analysis, systematization and storage of information, and assists "translation" of the information flow into an information resource under supervision of the integrated self-development management centers. This helps consolidate knowledge and best practices at the enterprise (data mart, knowledge base, documentation, methods, technologies) directed at regular support of internal transformative processes for generation of self-organization and self-development of an industrial enterprise [19]. Importantly, the data mart is a special storage of theme-based data related to various aspects of the enterprise's operations.

In the course of development of the industrial enterprise self-development management mechanism accounting for the digital transformation of the industry, we have determined the main functions and described the essence of their qualities. Besides, we have specified the methods for implementation of these functions, including the information technology portfolio (Table 1).

Table 1. Main functions, new qualities and methods for implementation of the functions within the scope of the information and infrastructure mechanism for managing self-development of an industrial enterprise, including the information technology portfolio

Functions	New qualities	Common methods for functions implementation	Information technology portfolio
Diagnostic function	• Quick search and analysis of resources (including information search) in the internal and external environment • Identification • Testing • Sifting and capturing results • Assessment of information reliability, objectivity and integrity • High speed of task solving and time saving • Identifying leaders, experts, ideas, innovators, external communities and stakeholders, best practices and faults • Search for "data storage" sources	• Databases, statistical data • Audit methods: SWOT analysis, PEST analysis, competitive analysis, 4 P and 7 P analysis, company resources analysis • Studying the scientific and periodical literature, mass media data analysis • Sociological surveys and studies • Tests, interviews, cases and modeling of situations • Sociogram	• On-line databases and knowledge bases, including "Experience of global and Russian successful companies" • On-line professional communities • Systems of analytical programs: Beatrix, Faraon, SAPR, Amma etc. • Internet and intranet, social networks, learning portal • Rating portals • Statistic resources

(*continued*)

Table 1. (*continued*)

Functions	New qualities	Common methods for functions implementation	Information technology portfolio
Planning and forecasting function	• Reduction of uncertainty and risks • Systematic and ordered approach • Improvement of confidence and competitive position • Transparency and clarity • Quick adaptation and response to challenges • Planning of talent pool and career development of personnel	• Strategic and tactical planning • "Thinking backwards" concept—modeling of the present from the future • Building a competence model for specialists, personal and professional development mapping • Strategic and expert sessions • Models of interaction with state regulation infrastructure	• Imitation technologies: moderators, imitators, simulators • On-line professional communities • Systems of analytical programs: Beatrix, Faraon, SAPR, Amma etc. • Internet and intranet, social networks, learning portal
Control function	• Ensuring collection, preservation and circulation of information resources at high speed and with high accuracy of information delivery • Accumulation of social capital • Knowledge base for future processes • Work with external and internal information: limitation and engagement, safekeeping of confidential information • Ensuring the necessity and sufficiency principle • Safety and confidentiality	• Sociological surveys and research; • Tests, interviews, case studies, situational modeling • Rating assessment based on the employee development competence model • Temporary succession planning • 360 model • Career development roadmap • Teambuilding events	• On-line databases and knowledge bases, including "Experience of global and Russian successful companies" • Systems of analytical programs: Beatrix, Faraon, SAPR, Amma etc. • Imitation technologies: moderators, imitators, simulators • Learning portal, intranet, internet • Long-distance coaching

(*continued*)

Table 1. (*continued*)

Functions	New qualities	Common methods for functions implementation	Information technology portfolio
Production automation function	• Integration of all information systems of the enterprise • Standardization of processes • Systematic production management and control	• Tools for production design and preparation • Production planning	• PDM—summary details of the designed product and production technology • WMS—stock inventory data system • CRM—relations with clients and contractors • MES—inter-shop planning • ERP—production planning and management system • MM—data module for use of a finished article by a consumer

4 Discussion

Shaping a cultural environment at the industrial enterprise which would be comfortable for the launch and management of the self-development processes is a complex and multi-faceted procedure. A favorable cultural environment may both strengthen and weaken all processes that are being launched. Unlike administrative management models, culture is a non-formalized environment which is based on traditions, artefacts, personal examples, leadership activity and the team principle. In other words, the cultural environment should be based on values that take a long time to be cultivated.

The proposed industrial enterprise self-development management centers can facilitate quick transfer of knowledge, capabilities and skills to employees; quick testing of best practices; instant involvement of personnel into the work processes through increase of intrinsic motivation; hence, inevitably, satisfaction of personal needs of employees and achievement of the enterprise's goals [20].

Any management mechanisms, including those of the industrial enterprise self-development management, shall be also regarded in other aspects than ensuring the necessary conditions and criteria. Any mechanism should reflect the functions and methods which will facilitate transformations in the organization's activity. It is also critical that all these changes are directed at improvement of the enterprise's functioning [21].

5 Conclusions

In conclusion we can, with reasonable certainty, state that the proposed mechanism for control of an industrial enterprise's self-development goes beyond the timely response to challenges of contemporary economy. Its introduction can help industrial enterprise executives launch the process of unlocking the inner reserves of human potential. We believe that integration of all information systems is a necessary condition for further digitization of an enterprise and for improvement of its competitive ability.

Based on the analysis of digital platforms developmental trends, one can conclude that individual elements of production automation should be combined into a single PLM system. PLM (Product Lifecycle Management) is a procedure for managing an industrial enterprise in the setting of industry digital transformation which reflects the product's full life cycle, starting from conception through design and production to sale, after-sale operation and disposal. PLM is not simply a software product. It is a business strategy for continuous improvement of the product at all stages of the "quality loop" [22]. Introduction of pervasive digital technologies will help industrial enterprises successfully compete in the existing markets and manufacture new hi-tech products and services for new markets.

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Forecasting Digital Economy Development Trends Based on Scientometric Data Monitoring

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Abstract. At present, digital economy makes a significant contribution both to the world's economy development and to the various countries' economies, and it is reasonably one of their priority development directions. In accordance with this, the development trends of the digital economy based on scientometric databases' study were determined. The purpose of the research is to determine a role of the digital economy in the modern processes of the global transformation and to forecast development trends in the digital economy based on the scientometric database study. The analysis was undertaken on the basis of the international bibliographic and abstract database Scopus and the database of the Russian Science Citation Index RSCI. As research methods, the methods of correlation and regression and mathematical statistics were used. The conducted study shows that an interest in the digital economy is increasing year by year. A system decomposition (a model) of the digital economy is presented. It is noted that in the field of the digital economy, the most part of the publications is currently dedicated to studies on digital technologies' application. Based on the scientometric databases' analysis within the interval between 2013 and 2019, the digital economy development trends are identified. The presented study allowed forecasting the main development trends of the digital economy in Russia, that makes it possible to determine the priority areas for the country's economy development, and it forms the idea about the further research areas.

Keywords: Global transformation · Digital economy · Digital technologies · Trends · Scientometric analysis

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1 Introduction

Digital One of the most important world trends of the XXI century is a structural transformation of the global economy, related to the deep integration of information and telecommunication (digital) technologies in real economic processes [1]. Transformational effects from the information and telecommunication technologies implementation extend to all spheres of socio-economic activities, necessitate a radical review of the management principles of the national economy's innovative development [2].

The leading role of information digital technologies [3] is in the effective development of national economic systems contributed to the appropriation of the modern type of economy such names as "digital economy", "API economy" [4], and "electronic economy".

The digital economy is one of the main trends of the latest decade, which emergence can be associated with the widespread Internet penetration worldwide in the mid-1990s. By the end of the 2000s, with the beginning of the widespread penetration of the smartphones and mobile Internet in the society, the digital economy had begun to experience a rapid growth [5].

An issue what the digital economy comprises is still controversial. It is considered that the term "digital economy" was firstly introduced by Don Tapscott, who published a book "The Digital Economy: Promise and Peril in the Age of Networked Intelligence" in 1995 [6], which, to a great extent, turned out to be a prophetic and correctly identified new development vector for both information and telecommunication technologies, and the economy as a whole.

At present, there is no common understanding of what "the digital economy" is. The digital economy can be considered from various points of view, including the following definitions [7]:

- a type of economy characterized by the active implementation and practical use of digital technologies for collection, storage, processing, and transformation and transmission of information in all spheres of human activity;
- a system of socio-economic and organizational-technical relations based on the use of digital information and communication technologies;
- this is a complex organizational-technical system in the form of a set of various elements (technical, infrastructural, organizational, software, regulatory, legislative, etc.) with distributed interaction and mutual use of economic agents for knowledge exchange in conditions of permanent development.

A key role in determining a digital system is exchange of knowledge and technologies that enable it, and people who are able to participate in the following exchange and manage it.

As early as July 2017, the consulting company McKinsey conducted a study "Digital Russia: new reality" [8], where it showed that a potential economic effect of the Russian economy digitalization would increase country's GDP by 4.1–8.9 trillion rubles by 2025 (in 2015 prices), which would be from 19 to 34% of the total expected GDP growth. According to the company, a share of the digital economy in the country's GDP is 10.9%

in the United States, 10.0% in China, 8.2% in the European Union, 3.9% in Russia as of 2015.

The presented data show that the digital economy makes a significant contribution both to the world's economy development and to the various countries' economies, and it is reasonably one of their priority development directions [9]. Respectively, an urgent task is digital economy's trends identification which will determine global trends for the near future.

In accordance with this, the authors attempted to determine the development trends of the digital economy based on scientometric indicators' study. In the field of this area of research, it can be commended the work of Chandra [10] and Lychagin [11] on scientometric methods' application. The following article represents a new stage of the authors' research [12] in the field of the data scientometric analysis on digitalization issues. At the same time, the analyzed period was updated and expanded to 2019–2020, the RSCI and Scopus databases were chosen as the sources of the analyzed data, and a wider focus on topics of digital economy was considered.

The purpose of the research is to determine a role of the digital economy in the modern processes of the global transformation and to forecast development trends in the digital economy based on the scientometric database study.

2 Materials and Methods

The universal bibliographic and abstract database, that is posted on the portal https://Scopus.com, and the Russian Science Citation Index (RSCI) database, posted on https://elibrary.ru/portal, were used to conduct the research. All the materials, available on the indicated databases, were involved in the search. The analysis was undertaken on the basis of information search in publication titles, annotations and key words. The analysis was conducted as of August 28, 2020. One of the research indicators is a number of publications. A search query of the following type TITLE-ABS-KEY ("digital economy") was carried out for the research.

3 Results

As part of the national program "Digital Economy" a list of the main cross-cutting digital technologies is presented: 1. Big Data; 2. neurotechnology and artificial intelligence; 3. distributed ledger systems; 4. quantum technologies; 5. new production technologies; 6. the industrial Internet of things; 7. components of robotics and sensors; 8. wireless technology (Wi-Fi, RFDI, 5G and more); 9. virtual and augmented reality technologies. Based on the above, a system decomposition of the digital economy (a digital economy model) can be represented in Fig. 1.

The digital economy is a direction that attracts considerable attention of Russian and foreign scientists. Within the framework of the digital economy, the authors indicate the following research areas: industry 4.0, digital technologies, digitalization, digital transformation, digital platforms.

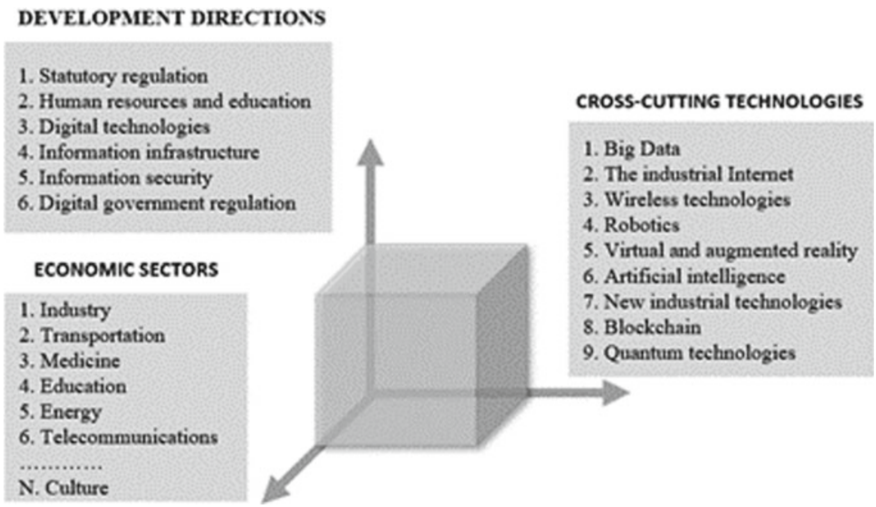

Fig. 1. A system decomposition of the digital economy (compiled by the authors)

At the same time, if the concept of digitalization is reflected in all sectors of the national economy, the digital platforms are a relatively new research area, as evidenced by the data obtained (Fig. 2).

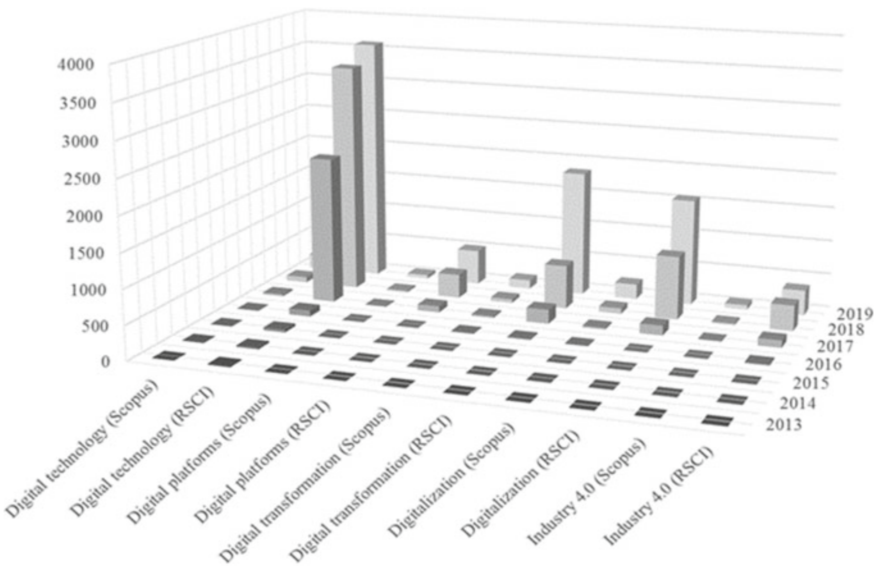

Fig. 2. Publication activity in the main areas of the digital economy (compiled by the authors)

An analysis of the Scopus database allowed to reveal that in the period of 2013–2019 the largest number of published studies on digital economy was done in the USA, Great Britain and Russia. That is why, it is precisely in these countries it will most likely be possible to see the active digital economy development and an increase in its share in the national economy structure of the countries in the nearest future. As can be seen, the greatest interest is focused on the research in the field of the digital technologies. In 2019, a number of publications on "Digital transformation" increased by 2.9 times according to the RSCI data, and a number of publications on "Digitalization" and "Indusrtry 4.0" increased by 2.7 (RSCI). According to Scopus, the leading countries in the number of publications on digital technologies for the period of 2013–2019 are the USA, the Russian Federation and Great Britain. Three leading countries in publications in the field of Industry 4.0, digital technologies, digitalization, digital transformation, and digital platforms are the USA, Russia, Great Britain and Germany.

Due to the fact that the largest number of publications was identified in the digital technologies' direction, below are the study results of this direction of the digital economy development (Table 1).

Table 1. Publication activity dynamics in the field of digital technologies according to Scopus/RSCI

Technologies	2013	2014	2015	2016	2017	2018	2019
Artificial intelligence	6/1	9/5	14/10	17/15	37/72	61/162	174/622
Augmented reality	11/0	14/0	13/0	13/12	29/26	41/49	65/117
Robotics	9/1	6/2	6/3	11/5	18/12	29/50	57/127
Mobile systems	1/5	1/4	1/6	1/17	2/28	3/55	5/83
Blockchain	0/0	0/0	0/3	1/6	6/104	26/313	66/614
Internet of things	4/0	8/0	5/4	34/18	43/77	83/120	128/283
Additive technology	0/0	0/1	0/11	0/16	0/22	1/44	4/77
Quantum technologies	0/0	0/0	0/0	0/0	0/2	2/7	2/28
Advanced manufacturing technology	0/0	0/0	0/0	1/2	0/10	1/19	3/31
Big data	5/10	7/13	16/18	42/42	52/97	107/249	185/602
Unmanned vehicles	0/0	0/0	0/0	0/1	0/2	0/2	0/17
Cybersecurity	1/8	9/14	3/22	11/23	15/64	26/165	40/378

According to Table 1, studies in the field of quantum technologies, unmanned transport, and advanced production technologies as topics of the digital economy, began in Russia relatively recently, from 2016 to 2017. Studies in the field of blockchain, as topics of the digital economy, appeared in Scopus only in 2016, and studies on unmanned transport, as topics of the digital economy, are not presented in the Scopus database. Thus, there is no reason to believe that a significant business breakthrough will occur here, however, these areas have great potential.

As you can see, the publication activity of the studied areas is increasing from year to year. Table 2 presents the ranked data of the topics under consideration by number of publications as of 2019.

Table 2. Ranked indicators of digital technologies development in 2019

Technologies	RSCI (%)	Position in RSCI	Scopus (%)	Position in scopus
Artificial intelligence	20.9	1	23.9	2
Blockchain	20.6	2	9.1	4
Big data	20.2	3	25.4	1
Cybersecurity	12.7	4	5.5	7
Internet of things	9.5	5	17.6	3
Robotics	4.3	6	7.8	6
Augmented reality	3.9	7	8.9	5
Mobile systems	2.8	8	0.7	8
Additive technologies	2.6	9	0.5	9
Advanced production technologies	1.0	10	0.4	10
Quantum technologies	0.9	11	0.3	11
Unmanned transport	0.6	12	0.0	12

As it can be seen from Table 2, at the moment the greatest business development potential is laid by the Russian researchers in the field of artificial intelligence, blockchain, big data, cybersecurity and the Internet of things [13, 14]. The Scopus database studies show (Table 2) that the greatest potential the practical implementation have is in the area of big data, artificial intelligence the Internet of things, and blockchain. Publications on the artificial intelligence are owned by the authors from Great Britain, Italy and the USA, in descending order. The blockchain studies are mainly conducted in Great Britain, the USA, Germany, Italy and Russia. Of all the considered areas of digital technology, Russia leads in the field of cybersecurity, ahead of the United States, China and other countries.

4 Discussion

In Russia, a starting point for the digital economy's development can be considered a message from the President of the Russian Federation to the Federal Assembly of 5 December 2016—"it is necessary to launch a large system program to develop new generation economy, so called digital economy" [15]. At present, the National Program "Digital Economy in the Russian Federation" has been developed [16] which is being implemented by a decree of the President of the Russian Federation of 7 May 2018 "The national purposes and strategic development objectives of the Russian Federation for the period until the year 2024" [17]. In accordance with the national goals that are defined in the following decree, new projects (programs) have been developed. One of such national development programs is "Digital Economy" (hereinafter referred to as the program). The program is designed to create favorable conditions for the knowledge society development in Russia, as well to increase citizens' welfare and their quality of life. It is assumed that this will happen via the increase in availability and quality of goods and services produced as part of the digital economy and with the help of the awareness level and digital literacy increase [18]. The Program "Digital Economy" includes six main development directions (federal projects): 1. digital environment statutory regulation; 2. information infrastructure; 3. personnel for the digital economy; 4. information security; 5. digital technologies; 6. digital government regulation.

One of the most significant federal projects for the economy development is "Digital Technologies". It should be stated that at present, digitalization encompasses all sectors of economy, foreign economic activity and even everyday (household) people's life. However, the digital transformation and the main economy sectors' digitalization (industry, energy, transportation, healthcare, education, construction) have become particularly important, since the digitalization effect will be significant [19, 20]. This is primarily due to the fact that the latest digital technologies and platforms are fundamentally changing business models, while significantly increasing their efficiency due to the absence of intermediaries and the presence of network (synergetic) effects.

5 Conclusions

The study shows that interest in the digital economy and digital technologies is increasing from year to year. The nature of the annual increase in the number of publications can indicate that the following area of knowledge is in the active phase of research. Therefore, the results of applying the acquired knowledge will have an impact both on the economy and society development in the nearest future. At the moment, the greatest potential for the business development is laid in the field of artificial intelligence, blockchain, big data, cybersecurity and the Internet of things by the Russian researchers. It is worth noting that in the direction of cybersecurity Russia is steadily occupies the first positions in the number of publications. Foreign specialists see the greatest potential for practical implementation in big data, artificial intelligence the Internet of things, and blockchain.

The presented study allowed to determine the forecast of the main development trends of the digital economy in Russia and abroad.

The authors see the further research in scientometric indicators analysis in addition to the digital technologies area and other fields of the digital economy development, such as: personnel for the digital economy, digital government, digital infrastructure. A deeper differentiation and analysis of the sub-technologies applied in the sectors of the national economy is also required.

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Production Process Data as a Tool for Digital Transformation of Metallurgical Companies

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Abstract. Big Data analysis is becoming an everyday task for companies all over the world, including Russian companies. Due to advances in technology and the reduction in the cost of storage systems, companies can now collect and store large volumes of heterogeneous data. The important step of extracting knowledge and value from such data is a challenge that will eventually be met by all companies seeking to maintain their competitiveness and place in the market. However, companies face several challenges when it comes to collecting, pre-processing, and integrating data into cohesive data sets designed to deliver analytics. In this article, the above problems and possible solutions are illustrated using the example of cleaning, integration, and normalization of data obtained in the measurement of indicators for the Vanyukov melting furnace process. The article considers an approach to the study of metallurgical processes using the analysis of large operational control data sets. Standard methods of processing the data sets of operational process control are used. The correlation analysis of the main process parameters is carried out. The results are interpreted for their further practical application.

Keywords: Digitalisation · BigData · Data analysis · Data preprocessing · Correlation coefficient · Production statistics

1 Introduction

Many Russian companies have embarked on the digital transformation, expecting various effects, e.g. increased operational efficiency and cost reduction, the improvement [1, 2] of customer interaction processes, and others. But despite the observed progress, the average level of use of digital technologies and innovations in Russian business remains low. According to the joint research "Digital IQ in Russia 2020" by PwC and ABBYY, the average score of the companies' digital maturity level is 2.8 out of 5 [3, 4].

The technologies used for digital transformation by companies in different industries vary significantly. For metallurgy, according to the report of the consulting company KPMG, the three leading digital technologies are robotization (83% of the surveyed companies in the industry tested the technology), BigData (67%), and Industrial Internet of Things (IIoT) (50%) [5–7]. The latter two technologies, when used together, can provide a greater impact to the company than individually [8]. IIoT gives data sources

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that are next processed by BigData technologies [9–11]. However, such shared use of technologies is hampered by several problems with collecting, pre-processing, and integrating data into joint arrays—data sources for analytics. In this article, these problems and possible ways to solve them are illustrated by the example of cleaning, integrating, and normalizing data obtained during the measurement of indicators for the process of melting materials in Vanyukov's furnace.

The purpose of the study is to obtain valuable information from operational process control data by developing an algorithm for the preprocessing of large data sets.

2 Materials and Methods

2.1 An Overview of Existing Approaches to Handling Large Volumes of Production Data

There are various approaches for pre-processing and integrating data. The first one is the use of DBMS and SQL language tools [12, 13]. The advantage of this approach is the ease of adding new data sources and ample opportunities to combine data sets. Most modern relational DBMSs support fast integration with xlsx or csv files, but successful integration requires not only a suitable file extension, but also the proper format of the data [14]. For example, it is necessary to consider the type of decimal separator, which is required when loading the data into the DBMS. If the initial numeric data is represented in the "number" format with a comma delimiter, then replacing it with a dot may be quick enough. However, if the numeric data is represented in "text" format, its conversion may cause different problems. Moreover, the further processing of such data will be difficult [15, 16].

Another approach is to process data directly with Excel tools. But it is suitable only for small-sized tables due to limitations on the number of rows to be processed and performance constraints. Integration of multiple data sets using this approach is complicated, and what is most important, it does not guarantee data consistency [17].

The third approach, which has been applied in this study, is the direct use of programming languages and the implementation of all pre-processing procedures via them. The object-oriented language Python offers great opportunities for data processing and analysis. All examples of program code shown below are presented in this language.

2.2 Description of the Raw Data

Vanyukov process operational control data vary in nature and are measured in different quantitative and qualitative scales with diverse frequency of sampling. Depending on the sampling frequency, they can be divided into two streams [18, 19]: parameters that characterise the furnace loading (high frequency signals) and parameters that reflect the concentration of the main components in the smelting products (low frequency signals). The furnace loading information flow is characterized by a small (1 min) level of discreteness. This is caused by occasional fluctuations in the hydraulic characteristics of the piping; variations in the voltage supply to the power and measuring units; fluctuations in the gas pressure in the line or irregularities in the response of actuators that drive control valves, dampers and batch injectors, etc. The information flow regarding the concentration of major components in the melt products (melt product composition) has a discreteness of 2 h for matte and 8 h for slag, due to the chemical analysis of the melt products.

The first problem with data can be the particular data format [20, 21]. The initial data for the current study are three MS Excel tables: “Process Indicators”, “Matte”, and “Slag”. The “Process Indicators” table consists of 217,908 lines containing the measurement values of such indicators as pressure, flow rate, the temperature of the oxygen-air mixture (CMC); conveyor speed and performance; level, speed, and performance of feeders; natural gas consumption and temperature; oxygen content in PIC; the temperature of the exhaust gases in the pharmacy; flow temperature. In total, this table contains measurements for 40 different indicators that can affect the result of the melting process, in particular the proportion of non-ferrous metals in matte and slag, presented in the tables “Matte” (1856 lines) and “Slag” (453 lines), respectively [22, 23].

The next problem is the content of the raw data, the presence of value missing. There are two main approaches to dealing with missing values [24]. For small data sets, missing values are more likely to be replaced by the average of their nearest neighbors or a group within a certain range. However, this approach may distort the validity of the subsequent predictions. For large data sets, it is often preferable to remove rows containing missing values, whereby the missing values can then be further recovered from the predicted values of the models. This study involves rather large data sets, with the number of omissions being negligible, so in the first stage of processing the empty rows have been removed, using the dropna () method.

2.3 Stages of Operational Data Processing

From the description of the raw data, we observe that all datasets have different size, that leads to the need to group the data for further analysis and the construction of predictive models. Aggregation of the data has been performed in pairs for the data sets “Process Indicators”—“Matte” and “Process Indicators”—“Slag”. The following shows an example of aggregation for the first pair.

The period of the matte measurement is every 2 h, while for the process indicators the period of measurement is 1 min. To work successfully with these data sets it is necessary to initially bring them to the same period. A new DataFrame has been created to store the aggregated values. The average of all “Production Indicators” measurements over the two hours preceding the matte measurement is taken as the new indicator value. The np.mean() method with the condition is used for this purpose. The resulting values are added to the DataFrame using the concat() function.

Once the same measurement periodicity has been reached, it is convenient to consolidate the data into a single merged set. In the study, we use the method merge(), which is similar to the JOIN method in SQL. This method requires the proper selection of the parameter for the type of merge. If the “inner” parameter is chosen, the values occurring in both sets are merged; in the case of the “outer” parameter, the merge occurs across all values. For correct joining, the index “helper” has been introduced, which can be used as the criterion for outer merging.

A similar procedure of data aggregation is performed for the pair of data sets "Production indicators" and "Slag". The obtained aggregated data sets are suitable for dependency analysis and prediction.

3 Results

To examine the correlation between the indicators, the coefficients should be calculated. The problem worth paying attention to is the different dimensionality of the values. The requirement for the normalization is determined by the correlation coefficient applied. If the Pearson coefficient is used, the values need to be normalized beforehand. For this purpose one of the normalization methods can be utilized. The most common are decimal scaling, Min–Max scaling, and Z-score standardization. In this study we apply the MinMax() method, which provides a linear transformation, scaling with a minimum value of 0 and a maximum value of 1.

To visualise the correlations the "seaborn" library has been used. The resulting heater correlation matrix is shown in Table 1.

Table 1. Calculation of correlations and the results

	[Cu]	X1	X2	X3	X4	X5	X6	X7	X8
[Cu]	1								
X1	−0.14	1							
X2	−0.12	0.87	1						
X3	−0.15	0.83	0.73	1					
X4	−0.15	0.89	0.8	0.69	1				
X5	0.18	−0.72	−0.69	−0.52	−0.82	1			
X6	−0.14	−0.081	−0.087	0.062	−0.13	−0.024	1		
X7	−0.1	−0.034	−0.0042	0.07	−0.071	−0.12	0.48	1	
X8	−0.18	0.1	0.11	0.26	0.059	−0.21	0.78	0.6	1

This matrix shows the correlation between the various indicators, but for the purposes of this study, the first row is of most interest. It indicates the influence of the production process parameters, such as the flow rate and temperature of the CMC, oxygen level and others, on the copper [Cu] concentration in the matte. Out of the 40 indicators presented in the raw data, only the 8 with the most significant correlations are plotted in the heater matrix [25].

The matrix is constructed using Pearson's linear coefficient [26]. The values of the correlation coefficients do not indicate the statistically significant influence of individual indicators on the output variable, as can be seen from Table 1.

The Pearson correlation coefficient estimates only the linear component of the relationship between variables. For non-linear relationships, Spearman and Kendall rank correlation coefficients are better suited. These coefficients have been calculated on the raw (non-normalized) data [27, 28].

The Spearman coefficient (see Table 2) allows quantifying the relationship between the parameters based on rank estimates. In its calculation, the ranks are assigned to each attribute, and then the rank correlation coefficient is obtained.

Table 2. Calculated spearman correlation coefficients

	[Cu]	X1	X2	X3	X4	X5	X6	X7	X8
[Cu]	1								
X1	−0.14	1							
X2	−0.1	0.9	1						
X3	−0.17	0.83	0.76	1					
X4	−0.16	0.88	0.83	0.7	1				
X5	0.17	−0.69	−0.7	−0.53	−0.77	1			
X6	−0.17	−0.096	−0.082	0.016	−0.12	−0.019	1		
X7	−0.15	−0.07	−0.023	0.024	−0.065	−0.16	0.86	1	
X8	−0.16	0.074	0.1	0.17	0.064	−0.23	0.8	0.88	1

Kendall rank correlation coefficient can also be used to determine the relationship between process parameters (see Table 3).

Table 3. Calculated Kendall correlation coefficients

	[Cu]	X1	X2	X3	X4	X5	X6	X7	X8
[Cu]	1								
X1	−0.093	1							
X2	−0.07	0.74	1						
X3	−0.12	0.65	0.57	1					
X4	−0.11	0.69	0.64	0.5	1				
X5	0.11	−0.5	−0.51	−0.36	−0.58	1			
X6	−0.11	−0.06	−0.049	0.011	−0.072	−0.022	1		
X7	−0.1	−0.048	−0.012	0.016	−0.038	−0.12	0.72	1	
X8	−0.11	0.05	0.071	0.11	0.044	−0.15	0.62	0.73	1

As well as Pearson correlation, the values of Kendall rank correlations are small and cannot serve as a basis to conclude the influence of individual parameters on the output variable (concentration of copper in matte—[Cu]).

4 Discussion

Meanwhile, the analysis of the coefficients (Tables 1, 2 and 3) shows the correlation between "material consumption on the assembly line 31" and "oxygen concentration in CMS", which determines the depth of physical and chemical transformations for achieving the required matte quality. This correlation is expressed rather strongly (correlation coefficient lies within the range 0.7–0.9). The relationship between material consumption on the assembly line 31" and "consumption of CMS" is also significant (the correlation coefficient is 0.65–0.85) that shows good compliance of charging materials loading with the total consumption of CMS required by the technology. However, none of the input parameters has a significant impact on the copper concentration in matte (all correlation coefficients are insignificant (less than 0.2).

5 Conclusions

The paper considered the complexities that arise in the processing and analysis of data that are collected using IIoT technology for further identification patterns in the technological processes [29–31]. Among these complexities are differences in the frequency of farrowing of various sensors, variations in the formats of the collected data, and omissions in the data caused by multiple reasons. These challenges can be overcome by preprocessing the data using different software tools, all of which have specific capabilities and limitations [32].

The use of spreadsheet editors such as MS Excel or Google Sheets, for example, is limited to large data sets. Furthermore, the query language they support is much narrower than modern relational and object-relational DBMSs. Regarding DBMSs, data import/export problems may arise due to the peculiarities of data formats and types, especially the different variations of "date and time" formats. Thus, for the data investigated in this paper, the problems of import in DBMS Postgre SQL have arisen precisely because of the peculiarities of the "date and time" format. For this reason, it turns out to be more efficient to move all the data preprocessing procedures to the created client application in Python. This solution also has some drawbacks. In the process of development, we faced difficulties related to the peculiarities of the internal data structures in the used libraries of the language [33, 34].

The listed challenges and ways to overcome them should be taken into consideration when implementing IIoT and BigData technologies in companies.

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Reduction of Measurement Error of Axisymmetric Parts with an Optical System

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Abstract. As part of the study of compensation methods for the main sources of error in measuring systems that use a digital camera equipped with an entocetric fixed focal lens as a recording device for measuring information, a method is proposed to improve the accuracy of determining the main shaping dimensions of axisymmetric products of transport engineering, due to position control test object when calibrating the system. A design scheme and measurement ratios for determining the angular position of the test object are presented. The article presents the results of experimental studies, confirming the significance of the considered source of error for measurements with an accuracy of more than 0.1% and showing the possibility of determining the position of the test object with an error of less than 0.2%. The paper provides recommendations for the implementation of the considered methodology. The proposed method can be used both to correct the position of the test object before calibration and to introduce corrections to the measurement result.

Keywords: Parts transport machine building · Optical control method · Dimensional control · Axisymmetric products · Angular position control

1 Introduction

In the nomenclature parts of transport machine building, a significant share is occupied by axisymmetric parts, the main method of their manufacture is turning. Turning equipment in the machine-building industry accounts for 20–40% of the machine tool park.

One of the main indicators of the quality of metalworking equipment is the accuracy of processing, which is currently achieved mainly by constructive methods—increasing the accuracy of manufacturing units and rigidity [1–3]. And if on the universal equipment a qualified turner can compensate for some component errors, then the peculiarity of processing on CNC machines is that the accuracy of processing in them is entirely determined by the system of dimensional relationships between the elements of the technological system. And the change in the parameters of these links is a source of errors. Developed solutions for adaptation by indirect quality indicators (for example,

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power parameters) [4–6] or by the state of the cutting tool [7] and by product models [8] can only partially solve this problem.

Adaptive algorithms for controlling machine tool equipment based on direct quality indicators are practically implemented for a limited number of types of machine tools (for example, centerless cylindrical grinding). This is due to the lack of systems for integrated operational control of geometric parameters during processing. Control of products on metal-cutting equipment is carried out periodically and is ensured through the use of the coordinate method, which is implemented mainly by contact measuring heads [9].

The development of optoelectronics made possible to expand the use of optical tools for geometric control solving problems, an example of which can be a batch control system [10], measuring equipment from ViciVision [11] or optical micrometers Riftek RF65X series [12]. These systems use telecentric optical systems with a collimator illumination system, and they are based on the analysis of a 2D projected image of the plane of symmetry axisymmetric products. The measurement is usually carried out in transmitted light. The main advantage of telecentric optics is a constant magnification factor over the entire operating range [13] and, therefore, the absence of perspective distortions for extended objects. At the same time, telecentric systems also have significant drawbacks: the high cost of high-quality wide-aperture optics, the limitation of the field of view by the size of the objective (up to 350 mm), and restrictions on the layout of the optical system associated with the use of the measurement scheme in transmitted light [14].

Entocentric optical systems are not used for the control of axisymmetric products due to the fact that the following factors affect the accuracy of determining the dimensions of axisymmetric objects by the projection method using a digital camera: parameters of the digital camera (resolution, matrix noise), aberrations of the camera lens, the accuracy of the workpiece installation, the projection error of a entocentric lens, the error from reflection and background illumination.

The development of microprocessor technology and digital image processing technologies make it possible to use algorithmic methods to compensate for measurement errors. It is possible to establish the relative position of the controlled object and the digital camera, and to compensate for the aberrations of the optical system if the position of the controlled object is known relatively by implementation of a calibration procedure for a test object with known properties [15–18]. Calibration establishes an unambiguous relationship between the test object and its image, and allows you to take into account the distortion of a particular optical system. The method of errors compensation for a passive optoelectronic system at a stationary position of the object allows to ensure the accuracy of control of linear dimensions comparable to the resolution of a 5MP digital camera. The conducted research can be useful not only for the machine-building industry, but also for other industries, such as metallurgy, where the tasks of automated control of technological equipment elements determine the level of automation.

The aim of the research is to improve the automated tools of metrological support of operational control for the production and operation of transport vehicles through the use of optical measuring systems that implement the spatial method of optical radiation with 2D resolution.

2 Materials and Methods

A feature of the control of bodies of revolution using entocentric lens during the calibration operation is in necessity to ensure the condition of perpendicularity of the test object in the plane passing through the optical axis and perpendicular to the axis of symmetry of the part. Since registration of a body of revolution image, we obtain an image of its projection in a plane perpendicular to the optical axis, then rotation of the test object relative to the symmetry axis of the test item from the specified position will cause an error Δ_k, the value can be determined by the following dependence.

$$\Delta_k = D * (1 - \cos\beta),$$

where β is the angle of inclination of the test object, *D* is the diameter of the test item.

It is possible to clearly represent the size of the error in determination of the dimensions based on the graph in Fig. 1. The figure shows the dependences of the change in the controlled diameter depending on the angle of inclination of the test object.

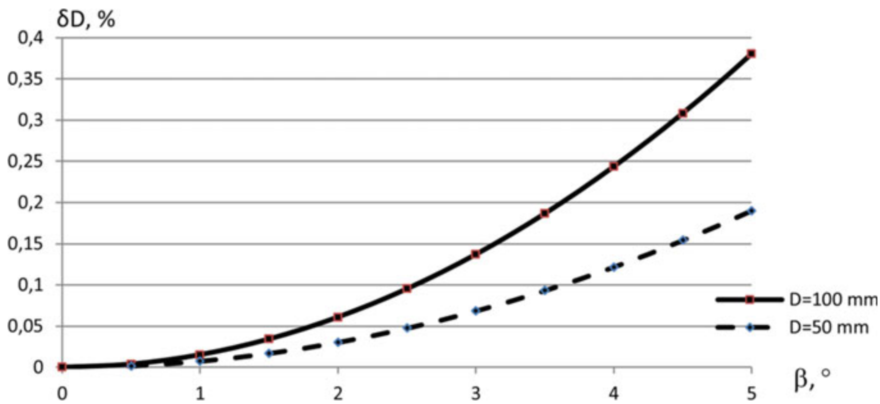

Fig. 1. Graphs of the error dependence in determination of the bodies of revolution diametrical dimensions on the test object inclination angle (compiled by the author)

Based on the obtained values and taking into account the resolution of the used camera, it is possible to set the maximum permissible deviation of the test object, which must be maintained during the calibration procedure.

3 Results

Since the optical axis is not an explicit base for position determination of the test object, it is necessary to develop an algorithm for the parameters determination of its position based on the analysis of the test object image parameters. The basis for this algorithm is the provisions of classical geometric optics, which quite correctly describe the formation of an image, without involving the theory of diffraction. Based on its positions, each straight line has a conjugate straight line in the image space. Based on this position, if the distance AB = CD (see Fig. 2), then the equality of their images AB′ = CD′, when they are symmetrically located relatively to the optical axis, will mean their equal distance from the main plane and the observance of the condition of perpendicularity of the test object optical axis. If this condition is not met, the tilt angle can be determined by comparing the sizes of the AB′ and CD′ images.

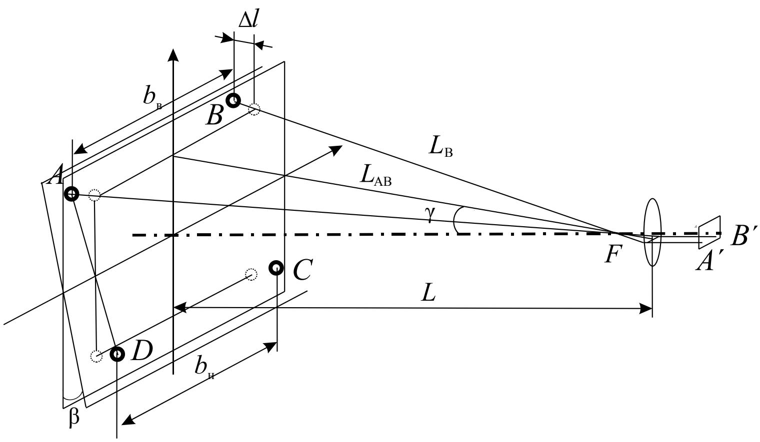

Fig. 2. Design scheme for monitoring the position of the test object (compiled by the author)

The known parameters for the calculation are the parameters of the test object and, accordingly, the dimensions AB = CD, the dimensions of the images $AB_{p}^{'}$ and $AB_{p}^{'}$ determined in px and the focal length of the lens f. To simplify the derivation of dependencies, we will introduce several assumptions. We will assume that the segments AB, CD and AD, BC are located symmetrically about the optical axis. At small angles of inclination of the test object (up to 5°), such assumptions will not cause serious errors.

To determine the angle of inclination of the test object βit is necessary to determine the value of Δl-the displacement of the image along the optical axis. For accepted small angles of deviations β, the error of the path of the rays determined by the angle γ is neglected. Then

$$\beta = \tan^{-1}\frac{2\Delta l}{AD} \tag{1}$$

the basic dependences of geometric optics are used to calculate Δl, based on which it can be written that the linear increase in V_{AB} can be determined

$$V_{AB} = \frac{AB'}{AB} \text{ and } V_{AB} = \frac{f}{X_{L_{AB}} - f} \tag{2}$$

Taking the simplification of the smallness of the angles from Fig. 3 can be determined

$$X_{L_{AB}} = \frac{L_{AB}}{\cos\gamma} \tag{3}$$

where $\gamma = \tan^{-1}\frac{\left(AD_p^{\prime}+BC_p^{\prime}\right)\cdot p}{4f}$, $AB_p^{\prime}$, $BC_p^{\prime}$, $CD_p^{\prime}$, $AD_p^{\prime}$ is the distance between the control points [px], *p*—pixel size.

Equating 2 and substituting 3, we determine the displacement of the image along the optical axis

$$\Delta l = \frac{L_{AB}}{\cos\gamma} - \frac{L}{\sin\gamma} \tag{4}$$

Using the assumption about the symmetry of the segments and substituting the dimensions of the images in px, we define the distance to the test object as

$$L = f \cdot \left(\frac{2}{\left(\frac{AB_p^{\prime}\cdot p}{AB} + \frac{CD_p^{\prime}\cdot p}{CD}\right)} + 1\right) \tag{5}$$

Then, on the basis of dependencies 1, 4 and 5 and simplifying the obtained expression, we obtain the dependence for calculating the angular position of the test object

$$\beta = \tan^{-1}\frac{2f \cdot \left(\left(\frac{AB}{AB_p^{\prime}\cdot p} + 1\right) - \left(\frac{2}{\frac{AB_p^{\prime}\cdot p}{AB} + \frac{CD_p^{\prime}\cdot p}{CD}} + 1\right) \cdot \sqrt{1 + \left(\frac{\left(AD_p^{\prime}+BC_p^{\prime}\right)\cdot p}{4f}\right)^2}\right)}{AD} \tag{6}$$

To implement the considered technique, software was developed in the LabVIEW.

The possibility of using the derived dependence to determine the position of the test object under the accepted assumptions was tested in the course of experimental studies. For this a stand was developed, where a LIR-158A 500-05-PI angular displacement transducer with a resolution of 15″ with a LIR-510A-00 digital display device was used as a position sensor.

Figure 3a shows a graphical representation of research results. Since the design of the stand does not provide for the initial unambiguous determination of the position of the elements of the measuring system relative to the optical axis, the initial value of the reference system was shifted by −2.42° The next series of measurements was carried out relative to the calculated position corresponding to the condition of perpendicularity of the test object of the optical axis. In Fig. 3b is a graph showing the discrepancy between measured and calculated values.

Assessment of the influence of the choice of reference points on the accuracy of determining the angle of inclination of the test object for three values of the angle $\beta =$ 0.41, 0.66, 0.87°and 1.18°.

Figure 4 shows the results of evaluating the influence of the choice of control points on the accuracy of determining β.

It can be seen from the graph (Fig. 4) that the error in determining the angle of inclination can reach $\Delta\beta_{\theta} = 0{,}2$, which significantly affects the measurement accuracy, and therefore the requirements for the symmetry of the location of the reference points when determining the position of the test object should be adhered to.

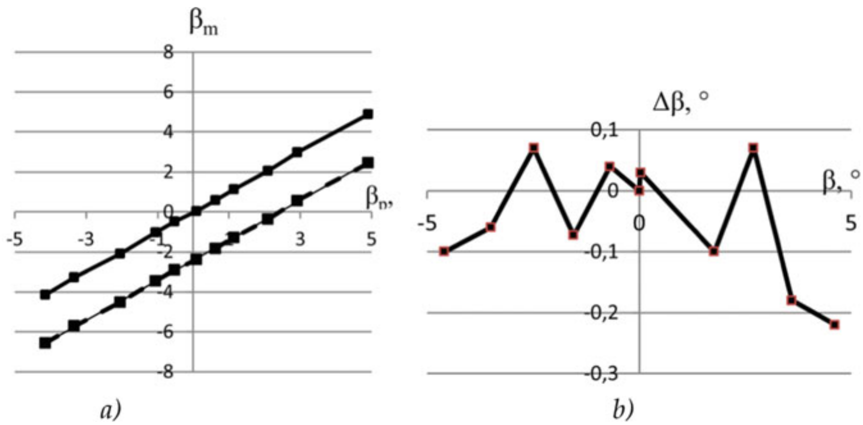

Fig. 3. Graphs of dependence: **a** measured values of the angles of inclination of the test object β and calculated β, **b** errors in determining the angular position of the test object (compiled by the author)

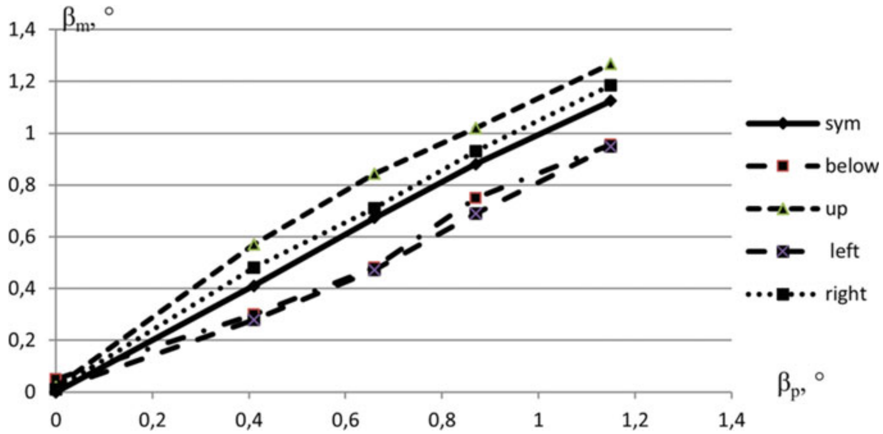

Fig. 4. Calculated values of the inclination angle of the test object when selecting control points with horizontal and vertical displacement (compiled by the author)

To assess the influence of external factors, a series of experiments was carried out with different illumination levels (485, 980 and 770 lx) in reflected and transmitted light, the results of which are presented in the form of graphical dependencies in Fig. 5. Illumination was controlled by a Precision Mastech Enterprises MS6610 light meter.

To assess the error of the algorithm for determination of the inclination angle of the test object in the working range (±1°), to reduce the influence of recognition of the centers of marker points, it was used on the test object by 340 points of Ø2 mm. 7 points were selected within the working range (±1°) −(1,03°, 0,75°, 0,51°, 0,21°, 0°, −0,21°, −0,51°, −0,75°, −1,03°) for which the accuracy of the measurement results was estimated. The possibility of determining the angular position with an error $\delta = 0.2°$

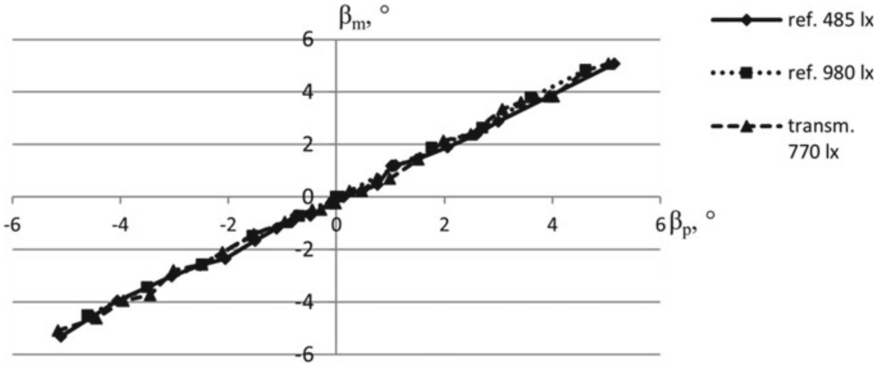

Fig. 5. Graphs of the values of the angles of inclination of the test object β and calculated β at different levels of illumination in reflected and transmitted light (compiled by the author)

was evaluated. On the basis of the first series of 5 measurements for each selected value and the estimate of S_x from the condition $\geq \frac{t_{\alpha,m}^2 * S_x^2}{\delta^2} = t_{\alpha,m}^2 * \left(\frac{S_x}{\delta}\right)^2$, the final choice was made $n = 8$. The results of the experimental evaluation of the error of the algorithm for determining the angle of inclination of the test object are summarized in Table 1.

Table 1. Estimation of the error of the algorithm for determining the angle of inclination of the test object

Parameters	Tilt angle of the test object, °								
	1.005	0.75	0.51	0.21	0	−0.21	−0.51	−0.75	−1.03
M	1.093	0.729	0.486	0.263	0.026	−0.209	−0.492	−0.688	−0.998
$\overline{\Delta}$	−0.088	0.021	0.024	−0.053	−0.026	−0.001	−0.019	−0.062	−0.032
S	0.058	0.083	0.085	0.006	0.070	0.084	0.082	0.021	0.063
δ_{exp}	0.136	0.196	0.200	0.015	0.166	0.196	0.193	0.051	0.149

To assess the significance of the influence of the test object inclination angle on the results of measurements of the diametrical dimensions of the "shaft" type part with a nominal Ø25 mm, a series of experiments were carried out. The evaluation of the measurements results of the axisymmetric part was carried out for two values of the inclination angle calibration plane $\beta_m = 0.23$ and 4.15° at various different levels of illumination (530, 960 and 660 lx) in reflected and transmitted light.

4 Discussion

Estimated sample standard deviation $S_x = 0{,}094{,}661$. The theoretical value of the Student's test at a significance level of 0.05 and the number of degrees of freedom m = 20–1 = 19 will be $t_{\alpha,m} = 2{,}022{,}691$. The experimental value of the Student's criterion is equal to $t_{\exp} = 2.768902$. Since $t_{\exp} > t_{\alpha,m}$, then with a probability of 95% the null hypothesis is not accepted and therefore the position of the angle of inclination of the test object affects the measurement error. The average value of the error value $\Delta d = 0.064$ mm, which is 0.26%.

With usage of the algorithm for the test object inclination angle calculating it is required that the location of the control points is equidistant relative to the axis of test object symmetry. Failure to comply with this condition leads to the appearance of additional methodological error.

The maximum error in determining the position in the investigated range of deviation of the test object ±5° does not exceed 0.22°. In the operating range of deviations ±3°, it does not exceed 0.1, which corresponds to the assumptions made in the calculated dependencies.

5 Conclusions

Based on the results of the study, it can be concluded that the developed technique and software can be used to reduce errors in determining the geometry of the main shaping dimensions of axisymmetric parts transport machine building when using control systems that implement the spatial method of optical radiation with 2D resolution and use a digital camera equipped as a recording device for measuring information lens with a entocentricfixed focal length, when calibrated.

The proposed method for determination of the test object position can be used both to correct the position of the test object before calibration and to introduce corrections to the measurement result.

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Digital Information Resource for Renovation Projects

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Abstract. The issues of compliance with modern requirements for the quality of living environment and the comfort of living are becoming increasingly important in the condition of constantly increasing share of the urban population and urban residential stock. Since more than a third of residential buildings in Russia were erected during the period of mass industrial housing construction and this residential stock has significant physical and functional wear and tear, it is necessary to increase the scope of renovation transformations. This requires the formation of a modern information resource about the state of the residential stock, social and engineering infrastructure. Renovation should keep up with the pace of digitalization of all spheres of human life, including the construction industry. The article discusses the main problem areas of the existing renovation system, identifies difficulties in the formation of a digital information resource for renovation, inherent in both international and domestic practice. The paper defines the stages of formation and content of a digital information resource. As a result of the study, the proposed recommendations make it possible to use the digital information resource of renovation projects for all related project participants.

Keywords: Renovation · City residential stock · Digital technologies · Digital information resource

1 Introduction

The need for renovation transformations of built-up areas is currently beyond doubt. In the Russian Federation, the share of the urban population and urban residential stock is steadily increasing. For example, in 2019 the urban residential stock amounted to 2,841 million square meters of total area, i.e. 73.66% (calculated based on [1]). This trend has been traced over the past decades. In 2000 the share of urban residential stock reached 72.48% [1]. Almost the entire urban residential stock is concentrated in apartment buildings, where about 65% of the country's population lives.

Analyzing the distribution of residential buildings by construction time, we note that more than a third of all residential buildings (35% or 958,589 apartment buildings) were

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erected in the period from 1946 to 1970, and 45% (1,217,665 residential buildings) were built from 1971 to 1995 (calculated by [2]. Such significant scopes of new construction during these years made it possible to meet a set of minimum residential requirements.

Since the existing system of overhaul is aimed primarily at reducing the scope of dilapidated and emergency residential stock, the development of renovation in all constituent entities of the Russian Federation seems to be predetermined.

However, for the transition to large-scale renovation, first of all, it is necessary to have reliable and complete information about the state of the residential stock, social and engineering infrastructure in the reorganized territories. The rapid development of new information and communication technologies changes the nature of the acquisition and formation of information resources. In addition, information is a kind of raw material for human mental activity, which generates knowledge [3].

The purpose of this work is to develop a modern information resource for renovation projects based on the analysis of world and domestic experience in the use of digital technologies in this area. In our opinion, the implementation of renovation programs depends on the quality of the initial information, since this makes it possible to determine the need and priority of repair measures.

2 Materials and Methods

It is necessary to work out issues that may entail a number of difficulties for all participants in the process: residents, investors, authorities in order to start and successfully implement renovation programs throughout the country.

Since one of the main tasks of housing policy is to increase the comfort of housing, the physical and functional wear and tear of residential buildings should be eliminated. To solve this problem, the state corporation "Fund for Assistance to Reformation of Residential and Communal Services" was created in 2007. The constituent entities of the Russian Federation received financial support for the overhaul of apartment buildings and the resettlement of citizens from emergency residential stock. Although the results of the work of regional operators in most regions of the country were recognized as positive, significant problems were identified in the course of implementation of targeted overhaul programs [4–6]:

- groundlessness of the established minimum contribution for the overhaul of common property in an apartment building, taken as the average value from the experience of the established practice of performing repair work;
- groundlessness of the annual increase in the amount of the established minimum contribution;
- likelihood of risks of depreciation, loss or misallocation of financial resources as a result of "freezing" of funds of owners of premises for overhauls for a long period;
- lack of mechanisms for budgetary co-financing of costs for overhauls of common property in apartment buildings.

At present, when the transition to large-scale renovation of built-up areas is planned, problems of the development of built-up areas are additionally added to the problems of overhauls of separate residential buildings. The most problematic areas of the existing renovation system, in our opinion, are the following:

- lack of a clear strategy for working with developers on renovation programs;
- the lack of a generally accepted methodology for determining the choice of territory to be renovated;
- lack of mechanisms for budgetary co-financing during the renovation of social and utility facilities, engineering and transport infrastructures, landscaping;
- lack of support mechanisms for privileged categories of citizens; for those on the waiting list; for low-income citizens who want to improve their living condition [5].

The identified problems are illustrated by the implementation of renovation programs in St. Petersburg. In 2000, the Government of St. Petersburg adopted Resolution No. 4 "On the regional program for the reconstruction of residential buildings of the first mass series in St. Petersburg" [7]. The relevance of the planned activities was determined by the scale of the residential stock of this period of housing construction—2,400 residential buildings in 100 living areas, its progressive physical wear and tear (21–40%), high energy consumption (threefold excess of the standard). Specific fuel consumption per 1 m^2 of the total area in this building is 2.5–3 times higher than that of Western Europe and North America. The program noted that the bearing capacity of the structures of these buildings is high, which means that their reconstruction is an alternative to the development of new territories for housing construction. Residential buildings of the first mass series (five-story large-panel (1lg-507, GI, 1-335, OD), brick and large-block structures (1-528, 1-527, built from 1958 to 1970, occupy 6.8% of the total residential stock of the city, which is 8.9 million m^2 of housing. Nevertheless, this program was not widespread and only a few individual houses were reconstructed as part of its implementation. On May 6, 2008, the Law of St. Petersburg No. 238-39 "On the target program of St. Petersburg "Development of built-up areas in St. Petersburg" was adopted [8]. As part of the program, 23 residential areas are to be renovated with the demolition of 1.2 thousand residential buildings and the construction of 8.44 million m^2 of new housing, designed for 450 thousand people. But over the past time, about 600 thousand square meters have been built. It means that the implementation is only 7%.

When considering the world and domestic practice of renovation [9, 10], it should be noted that primary attention is paid to the formation of the initial array of information. However, this formation is connected with significant difficulties, the main of which are:

- lack of clarity of the principles of collection, processing and formation of information array by various departments, managerial and statistics authorities, including the inclusion or exclusion of indicators from statistical reporting;
- inaccessibility of official information and statistics on the structure of ownership and property of owners, only detailed information on municipal buildings is available;
- division of information between local, regional and state authorities, consolidation in a single data register is not always carried out;
- conducting systematic research only for housing construction, for social infrastructure objects such research is irregular [8].

The availability of data of various types (numerical, graphic, textual, temporal, spatial) requires the use of modern information technologies that allow them to be processed and combined [11, 12]. The program "Digital Economy of the Russian Federation" implies the possibility of integrating digital technologies to improve construction processes, and the federal project "Digital Construction" provides for the transition to digital modeling (BIM) technology for effective management of all objects throughout the life cycle, information security requirements, quality control of projects and facilities. By 2024, digitalization of the construction industry should be carried out [13].

Thus, the formation of a digital information resource of renovation projects is a necessary element of the formation of the entire renovation system on a national scale. On the one hand, it is necessary to increase the scope of renovation in the regions, on the other hand, renovation should not lag behind the pace of digitalization of construction, since the quality of life in the future will increasingly depend on the use of information and communication technologies.

3 Results

To develop scientifically based managerial and organizational decisions on the renovation of built-up areas, it is necessary to form an initial array of information.

The reason for the renovation of residential areas is the inadequacy of the needs of the population. During the life cycle, buildings are changed and adapted to the requirements of generations: users, residents and owners. The main criterion that determines the need for renovation is the degree of wear However, wear and tear of the building is not directly related to the age of the building, but rather to the use and needs of the user. Renovation projects usually have new problems that are not present in new construction. Among them, we note the following ones:

1. Physical limitations due to the current state of the building, such as limited space or limited capacity of systems;
2. Limited working area;
3. Uncertainty about the current state of the building [14, 15].

To reduce the impact of these problems, potential threats must be detected as early as possible. Thus, the current state of residential buildings, infrastructure facilities and their capacity should be known at the beginning of the development of renovation programs. If there is not enough information, decisions made in uncertain conditions can lead to additional risks for the implementation of projects.

Thus, the preliminary stage of renovation is a comprehensive analysis of the built-up area based on an assessment of the technical condition of the residential stock and infrastructure.

In Russia, the data of such analysis is not sufficiently comprehensive and reliable. The main sources that form the information resource are materials of a complete survey of the entire residential stock. So the statistical reporting reflects data on the emergency state of the residential stock, the time of construction and the degree of wear and tear, on the living conditions of the population. Information about existing buildings is stored in an unstructured manner; it is not represented in computer-aided design (CAD) or building information modeling (BIM). In practice, data is collected through manual measurements, examination of existing construction documents in hard copy.

In St. Petersburg the last complete house-to-house survey was carried out in 1967–71 and then the data was supplemented by an additional survey conducted in 1979–1984. Subsequently, until now, there has not been a complete house-to-house survey of the city's residential stock.

In addition, buildings and infrastructure facilities are undergoing modernization, reconstruction and overhaul. Both modifications and deviations from the original building structure, equipment, as well as wear and tear and defects are often undocumented or available only in an outdated and unstructured way. Thus, incomplete, outdated or fragmented information about existing buildings and infrastructure predominates, which complicates the planning of renovation programs and projects.

Currently, the technical condition of buildings or a certain building is checked manually or using stationary laser scanning, which requires a lot of efforts of qualified personnel and expensive equipment.

With the spreading of digital technologies and their use in the collection of information and design, it was proposed to solve these renovation tasks by modern methods using the world experience of digitalization of the data of reconstruction and renovation projects.

The formation of a digital information resource of renovation projects by us based on the use of modern digital technologies is proposed to be conducted in several stages (Fig. 1).

The first stage involves a detailed collection of information about the building and infrastructure facilities.

This information can be classified as static and non-static. Most of the structural properties are static and only the state of the building is non-static information. Space properties are more evenly split between static and non-static information. Problems found in a building are one-time events that can be added to static information [16].

In recent years, large amount of research has been carried out in the sphere of registration and reconstruction of three-dimensional media in order to increase the speed and level of specification of information collection and reduce the amount of processing of initial data. It is worth noting the papers of Western experts who proposed various measurement algorithms [17].

We believe that for these purposes it is possible to use a combined system called ResourceApp, consisting of a hardware sensor with software modules. The mobile system allows you to inspect the building and simultaneously record, analyze, reconstruct and store the building digitally. For this, the Kinect sensor receives clouds of points, and the developed algorithms analyze them in real time. Based on this information, a 3D model of the building is automatically obtained. The generated information is then used for optimized project scheduling using an algorithm to solve the multi-mode resource constrained project scheduling problem (MRCPSPB). Unlike existing approaches, the system allows for mobile recording of the building during the passage throughout the building and object detection. In addition, on the basis of automatically received and processed data using sensors, the system performs complex project planning using available

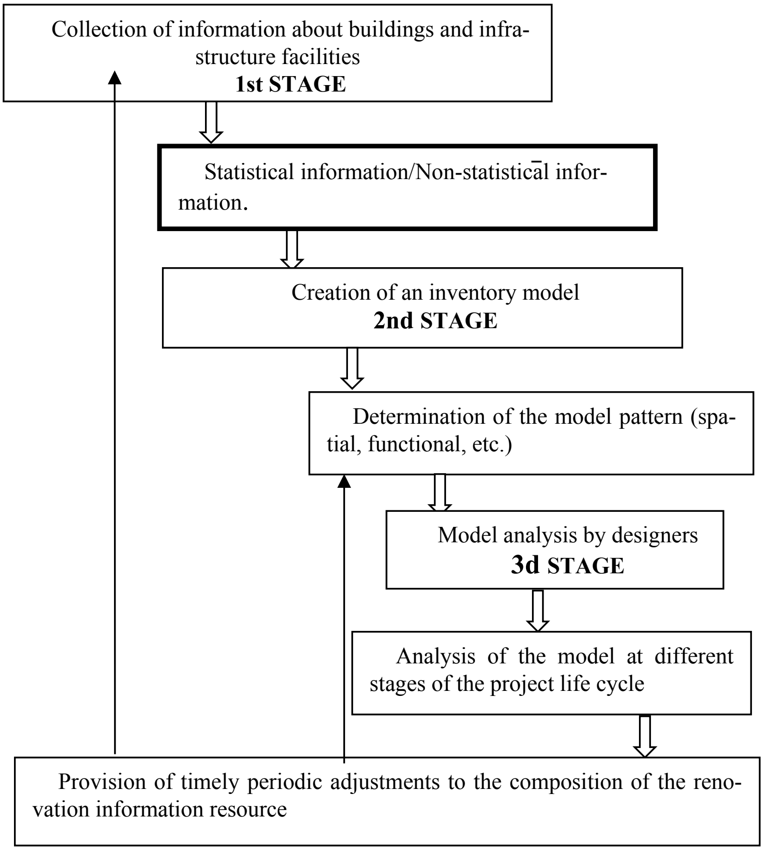

Fig. 1. Stages of digital information resource formation for renovation projects

resources and the necessary actions. As a result, time and costs are optimized, taking into account the secondary recovery of raw materials, the use of renewable resources, personnel qualifications, on-site logistics, storage and processing options [17].

The second stage is to create an inventory model.

The inventory model is defined as “all historical data, survey data, measurements, etc., information [and even knowledge] about an existing building in an accessible and usable format” [18]. Inventory model can improve data management, planning, decision making and profitability of upgrade projects. This emphasizes the need to keep building information up to date.

The inventory model should contain the main structures and visualize those areas that are out of service. Information is needed about the reasons and timing of changes and updates. Information on the quality of the living environment, potential health hazards, use and quality of utilities should also be added. Information on architectural-spatial, planning characteristics should be added [19, 20].

The inventory model must be available prior to the design of the reconstruction or renovation project.

The third stage involves a comprehensive analysis of the inventory model by the participants developing the renovation project.

Thus, the digital information resource of renovation projects is constantly evolving and transforming in accordance with the constantly increasing requirements for the quality and comfort of life. Initial information for renovation acts as the initial element that determines the effectiveness of transformations of built-up areas.

4 Discussion

The development of a digital information resource for renovation makes it possible to increase the efficiency of the renovation process, including also as the result of the effective interaction of the developers of the renovation project [21]:

- design requirements are known for designers on the basis of inventory model data;
- the requirements for the spatial structure are known for architects;
- for investors there is an opportunity to calculate investment costs;
- for BIM specialists, the inventory model can serve as a working “inventory”.

In the previous sections, we examined in detail the issues of an information resource for project developers. However, one of the main participants in the renovation process is the population living in the territory to be renovated. Therefore, we will focus on the formation of an information resource for citizens [22].

In our opinion, territorial information centers should be created, where residents will be able to receive free consulting and legal services. At the same time, the principles of information openness and transparency must be ensured. Before the voting process on the inclusion of a house in the renovation program, citizens should receive information about all the characteristics and features of the project, the future appearance of the residential district. But the most important thing is the possibility of providing housing to replace the demolished or reconstructed one. The information should also be available both on the websites of the renovation project investors and on the official websites of city and regional renovation programs.

In addition to residents, information should also be provided to owners of non-residential premises. It is fundamentally important to explain to citizens the principle of equivalence and equal significance of the apartments and non-residential premises provided.

Since local authorities are also interested in the implementation of renovation projects, information on the renewal of social and engineering infrastructure should be provided at the same time.

A similar awareness practice exists in Western European countries, and such centers are created by both local authorities and investors.

In today’s fragile conditions, when the financial resources of regional and city budgets are very limited, more and more attention is paid to the effectiveness of territorial renovation programs. Therefore, the modern information base as an initial element of renovation projects undoubtedly requires further research.

5 Conclusions

The introduction of modern digital technologies takes place in all spheres of human life. First of all, their use and development should help to improve the comfort of the urban environment, improve the quality of life and safety of living. The spread of digital technologies in the process of construction and renovation is becoming its integral part.

Particularly close attention is being paid today to the development of renovation programs—since it is planned to pass a law on national renovation at the legislative level. The start of collection programs requires the formation of a digital information resource. The attention of the professional community around the world is aimed at improving the renovation processes, since in all developed economies the renovation of built-up areas is carried out on a larger scale than new construction. Thus, in conclusion, we note that the improvement and implementation of digital technologies requires the participation of all participants in the renovation project.

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Forecasting the Indicators of Socio-Economic Development of the Region: Methods and Results

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Abstract.
Objective The analysis of the possibilities of using formal methods in the forecasting system of indicators of socio-economic development of regions based on informal logic. Research Methods. Informal logic, correlation and regression analysis, apparatus of neural networks. Results. The analysis of the use of formal forecasting methods (correlation and regression analysis and the apparatus of neural networks) showed that their results correspond to those obtained on the basis of an informal logic algorithm used to justify and calculate a number of socio-economic indicators of the region's development (using the example of the Voronezh region) taking into account their variability values in the conservative, base and target scenarios of strategic planning. The results obtained using various formal methods correspond to the actual and those calculated using the scenario approach and demonstrate very high accuracy. At the same time, it is necessary to note the results of the formal forecast of some indicators that are poorly logical and do not coincide with the actual ones even in the short term, and the "delayed response" of official statistics to the changes that make it difficult to predict and identify deviations necessary to adjust strategies.

Keywords: Forecasting · Socio-economic development · Indicators · Region

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1 Introduction

Forecasting indicators of the socio-economic development of the regions has become particularly relevant in connection with the adoption and implementation of the federal law on strategic planning [1]. The complexity of its practical implementation is noticeable even due to the fact that over the past six years since the adoption of the law, not all subjects of the federation have developed and adopted strategies until 2030 or 2035, while continuing to work on the implementation of documents designed for the period until 2022. The complexity of developing strategies results from many circumstances, including the low accuracy of forecasting indicators and a wide range of socio-economic indicators as a consequence of: high variability of regional conditions, asynchronous development of territorial and functional subsystems of a country and regions [2], underdeveloped relationships between institutional systems that ensure compliance with the principles of corporate social responsibility [3], excessive centralization of the budget system, which was established through the mid-1990s of the twentieth century [4], periodic crises of national and planetary scale. Under these conditions, the improvement of methods is a necessary condition for increasing the accuracy of forecasting.

2 Methodology

The research method in this article is informal logic. It is also the traditional and basic method for forecasting the socio-economic development of regions (and a number of other socio-economic systems). With regard to strategic planning of the regions, the method is implemented through a rather complex algorithm aimed at convergence the positions of various expert groups in order to, bring the predicted values to some "consensus" value during the discussion. As a rule, several expert communities take part in the development of the forecast: regional deputies, representatives of relevant departments of executive authorities, members of specialized public organizations (OPORA, Union of Industrialists and Entrepreneurs, etc.), educational personnel of universities, employees of research institutes.

Naturally each of these groups uses formal methods of analysis and fore-casting. However, in their "pure form" the results are not submitted for discussion, but are subjected to logical analysis and intuitive data processing at the stage of forming the opinions of each group. Argumentation in the process of discussion is based primarily on qualitative assessments of the predicted processes. In the course of repeated discussion of the results of each group and their justification during the discussion, a result is determined that all participants consider acceptable (in any case, this applies to the formal and informal leaders of each expert group).

As a rule, a wide discussion of the results presented in the preliminary forecast by specialists (and not specialists) in the process of "public hearings" does not lead to any changes in the values of the indicators. The subsequent submission of the forecast to the specialized departments of the federal authorities, usually leads to some adjustment of the results. Thus, the forecasting procedure goes through several stages of an informal rationale, in which the quantitative analysis makes up only a fragmentary basis of the forecast.

One of the requirements for forecasting the values of indicators of socio-economic development in the framework of strategic planning until 2030 or 2035 is scripting. In the regions various designations of scenarios are adopted: pessimistic, realistic, optimistic, basic, target, etc. It hardly makes sense to name some scenario "realistic", since the others in this case must be considered "not realistic" that contradicts the general logic of forecasting. In the Voronezh region, it is accepted to divide scenarios into conservative, basic, and target. With a certain degree of conditionality, they can be called pessimistic, moderately optimistic and optimistic. Naturally, this implies discrepancies in the values of the predicted indicators, sometimes very significant ones. In general, this adequately reflects the variability of the socio-economic situation that arises due to the internal causes and external factors.

In practice, the most general and "stably resisting changes" indicators (population, expected life expectancy, etc.) in large socio-economic systems (country, federal districts, large regions) are accurately projected for the short and medium term. Expert forecasting of private indicators—(migration growth, investment in a particular industry, the number of small enterprises, the volume of innovative goods, works, services, etc.) gives a significant error. The discrepancy between the values of indicators in different scenarios is also very significant. For example, in the "Strategy for the socio-economic development of the Voronezh region for the period until 2035" (hereinafter referred to as the "Strategy"), the projected excess of the population in 2024 under the target scenario is only 2.3% relative to the conservative scenario, life expectancy is 6,2%, GRP—25.9%, the volume of innovative goods—32.4% [5].

This article analyzes the results of the forecast of quantitative values of two parameters of the socio-economic development of the Voronezh region, which can be regarded as private and, therefore, difficult to forecast, using correlation and regression analysis and the apparatus of neural networks. Currently, the latter are most actively used to predict financial phenomena [6] and relatively few—for complex socio-economic phenomena. Among the indicators adopted for analysis there are the costs of technological innovation and the number of advanced manufacturing technologies used. When choose indicators the authors proceeded from their importance for the socio-economic development of regions and the complexity of forecasting [7–11].

The indicators for the period 2000–2018 that are logically related to them have also been selected for the study: the volume of innovative goods, works, services; number of advanced technologies used; number of enterprises and organizations; economically active population; gross regional product per capita; investment in education [12, 13]. Correlation matrices, which are presented in Tables 1 and 4, have been constructed in order to determine the input data for the study using the Statistica 13.0 software.

The regression equations have been calculated using official statistics for the period 2000–2017 [12, 13] by the following functions: linear, logarithmic, power, polynomial, and by using the natural logarithm. Of the four functions, the one with the highest determination coefficient was selected for calculating the indicators. In all cases, the best forecast accuracy is ensured by the use of linear functions.

The forecast has been carried out for the period 2018–2024, based on the fact that 2024 is the limiting year for the use of source data for 18 years for both correlation and regression analysis and for neural networks.

Table 1. The correlation matrix of the indicator "costs of technological innovation".

Indicator	The coefficient of determination
The volume of innovative goods (works, services), million rubles	0.82439
The number of advanced technologies used, units	0.695595
The number of enterprises and organizations at the year-end, units	0.674699
GRP per capita, rubles	0.919331
Investment in education, million rubles	0.934739

When using neural networks, the approaches taken earlier to predict a number of indicators of the socio-economic development of the Voronezh region were taken into account [15, 16].

3 Results

The calculations carried out using correlation and regression analysis have shown a high degree of connection between the indicators presented in Table 1.

This allows applying the source data obtained for the period 2000–2017 to predict their dynamics using both the correlation and regression method, and neural networks.

The forecasting results based on the conducted analysis are presented in the Table 2.

Table 2. Forecast values of indicators of socio-economic development of the region for the period 2018–2020*.

Var	Years						
	2018	2019	2020	2021	2022	2023	2024
1	11,098.3	11,776.5	12,454.6	13,132.8	13,811.0	14,489.1	15,167.3
2	33,481.9	35,550.5	37,619.1	39,687.7	41,756.3	43,824.9	45,893.5
3	2370.7	2434.3	2497.9	2561.5	2625.1	2688.6	2752.2
4	62,137.9	63,130.8	64,123.7	65,116.6	66,109.5	67,102.4	68,095.2
5	376,031.0	398,733.0	421,435.0	444,137	466,839.0	489,541.0	512,243.0
6	4536.9	4805.7	5074.5	5343.2	5612.0	5880.8	6149.5

* Designations in the table: Var—indicators: 1—technological innovation costs, million rubles; 2—volume of innovative goods (works, services), million rubles; 3—number of advanced technologies used, units; 4—the number of enterprises and organizations at the year-end, units.; 5—GRP per capita, rubles; 6—investment in education, million rubles

The graphical interpretation of the dynamics of costs of technological innovation in the Voronezh region is presented in Fig. 1.

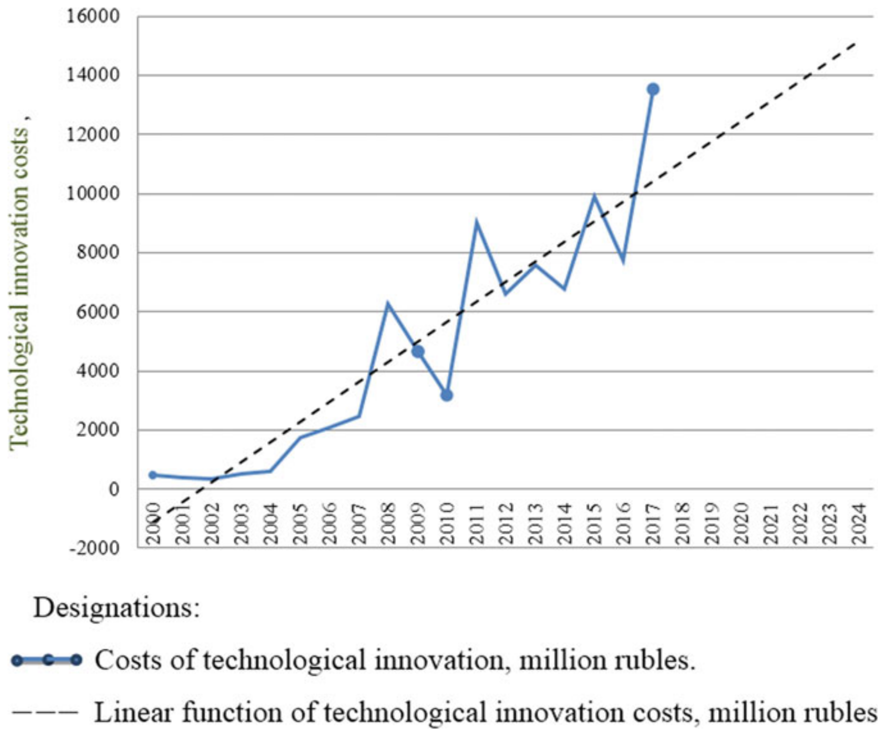

Fig. 1. Dynamics of costs for technological innovations of the Voronezh region (million rubles).

As you can see, the linear dynamics of the process is quite pronounced. However, fluctuations in individual years are quite noticeable. This makes forecasting for each specific year difficult; deviations in annual indicators projected on the basis of a linear trend from future actual values must inevitably be quite significant. The forecast for the medium term can be more reliable.

Note that one of the main disadvantages of correlation and regression analysis is the abstraction from the interaction of the analyzed process from the influence of other subsystems of the region. This drawback can be filled using neural networks [17]. In this regard, their capabilities are used [17–19] to predict the costs of technological innovation in the region.

In the process of the research 1000 neural networks were built using the software Statistica 13.0. The minimum error value was observed in the neural network MLP 5-11-1 with an acceptable distribution of errors (in the range of 0.02–0.22) and low values of standard deviations. The logistic function was used on the input layer of the MLP 5-11-1 neural network under study, and the hyperbolic function was used on the output. The hidden layer of the network under study contains 11 neurons. The learning error in this case was zero that means the neural network is fully trained [19]. The sensitivity analysis showed that all indicators are highly significant in predicting the costs of technological innovation using the specified neural network. The forecast was carried out using the additional indicator “change in costs of technological innovation”. This approach allows narrowing the range of predicted values. In addition, the network is confronted with a more difficult task than forecasting volumes directly, since the latter change, on the whole, uniformly, and the deviations over the years are quite significant, as it can be seen in Fig. 1.

The values of the indicator "costs of technological innovation", calculated using correlation and regression analysis and the neural network, are presented in Table 3.

Table 3. Forecast values of the costs of technological innovation in the region.

Year	Neural network data		Data of correlation and regression analysis (linear function)	Deviation, million rubles
	Forecast change in costs of technological innovations, million rubles	Costs of technological innovation, million rubles	Costs of technological innovation, million rubles	
2018	−9.28	13,509.4	11,098.3	2411.08
2019	7.06	13,516.5	11,776.5	1739.97
2020	1.57	13,518.1	12,454.7	1063.39
2021	0.42	13,518.5	13,132.8	385.65
2022	0.13	13,518.6	13,811.0	−292.38
2023	0.05	13,518.7	14,489.1	−970.49
2024	0.02	13,518.7	15,167.3	−1648.6

Table 4. Correlation matrix of the indicator "the number of advanced technologies used".

Indicator	Coefficient of determination
The volume of innovative goods (works, services), million rubles	0.695595
The number of advanced technologies used, units	0.678407
The number of enterprises and organizations at the year-end, units	0.776501
GRP per capita, rubles	0.747738
Investments in education, million rubles	0.712265

On the basis of Table 3, it should be noted that the forecast according to the regression equation is generally more optimistic than the forecast of the neural network. At the same time, in the period 2018–2021 there can be observed higher values of the indicator obtained based on the forecast of the neural network. However, during this period of time, a gradual reduction of the gap between the indicators calculated by the two forecasting methods is predicted. In 2021, the forecast values are converging, and then the primacy in the “level of optimism” is passing over to the correlation and regression analysis. Thus, the fluctuations between the values of indicators in the context of optimistic and pessimistic forecasts can be observed.

According to the Federal State Statistics Service, in 2018 the volume of costs of technological innovations in the Voronezh region amounted to 12,725.1 million rubles [14]. The arithmetic average between the forecast values is 12,303.85 million rubles. The deviation of actual values from the “neural network” forecast was +8.9%, from the “correlation-regression”: −10.8%. As it can be seen, the deviation, although quite significant, fits into the framework of deviations provided for particular indicators in three different scenarios. It may be said that, in fact, the dynamics of costs of technological innovations occurs according to the basic scenario.

The authors suggest analyzing the results of forecasting the number of advanced technologies used in the region. All initial conditions and the methodological approach are fully retained. Source data is obtained from official materials of the Federal State Statistics Service [12, 13]. The results of the data processing are presented in Table 4.

It can be seen that the coefficients of determination of this indicator with the associated ones are, firstly, lower than those previously analyzed, and secondly, their values are very close, which can be interpreted as an equally probable effect on their growth in the number of advanced manufacturing technologies used. In the course of the study, as in relation to the costs of technological innovation, 1000 neural networks were designed, among which the neural net-work MLP 5-8-1 was selected, characterized by a minimum error (from −0.004 to 0.22).

Hyperbolic function was used on the input and output layers of the neural network MLP 5-8-1. The hidden layer of the analyzed network contains 8 neurons. The neural network learning error was of zero value. The sensitivity analysis showed that all of the above indicators are highly significant in predicting the number of advanced technologies used. The values of the predicted indicator are presented in Table 5.

It is clearly seen that the “neural network” forecast is less optimistic than that obtained using correlation and regression analysis. The growth of the indicator values according to the linear forecast should occur rapidly. The difference between the indicators is growing and in 2024 it is 840.21 units.

The neural network predicts a sharp drop in the indicator in 2018, then, its stabilization for the entire forecast period. The actual number of advanced manufacturing technologies used—2678 units [14], exceeded the values of both the “pessimistic” forecast of the neural network and the “optimistic” one, obtained on the basis of the linear trend characteristic for the period 2000–2017.

The explanation of the “pessimism” of the neural network cannot be strict; it can be assumed by referring to a graphical interpretation of the actual and forecasted dynamics of the indicator (Fig. 2).

The sharp changes in the number of advanced manufacturing technologies used in 2002–2003, 2006–2007, 2009–2010–2011 and then continued growth until 2017 with a more relaxed dynamics of indicators associated with it allowed the network to

Table 5. Forecast values of the number of advanced technologies used in the region.

Year	Neural network data		Correlation and regression analysis data (linear function)	Deviation, million rubles
	Forecast change in the number of advanced technologies used	Number of advanced technologies used	Number of advanced technologies used	
2018	−638.35	1899.65	2370.72	−471.07
2019	7.818	1907.47	2434.30	−526.83
2020	1.76	1909.23	2497.89	−588.66
2021	1.66	1910.89	2561.47	−650.58
2022	0.65	1911.54	2625.06	−713.52
2023	0.34	1911.88	2688.64	−776.76
2024	0.14	1912.02	2752.23	−840.21

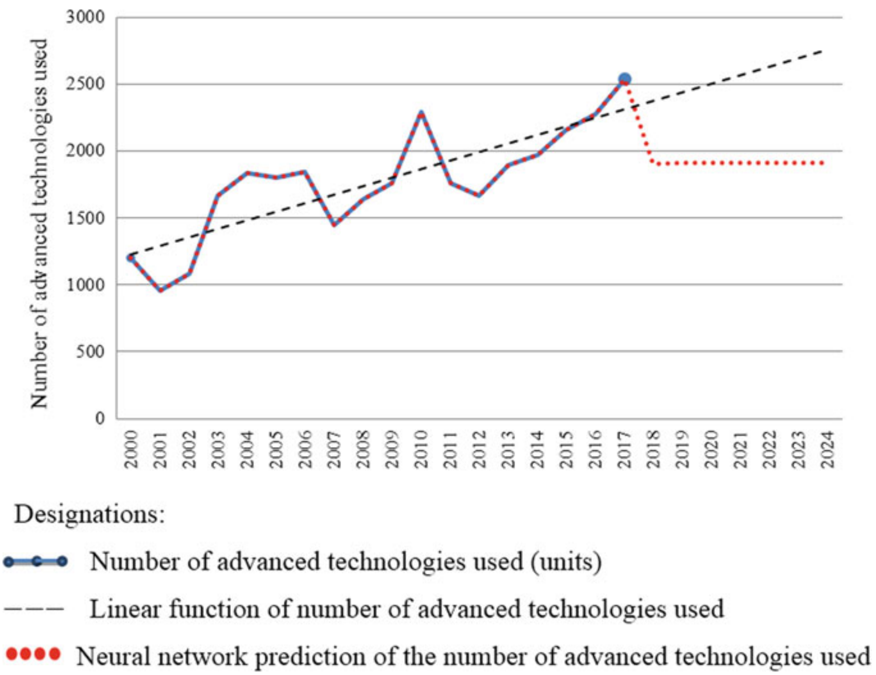

Fig. 2. Linear and neural forecast of the number of advanced technologies used in the Voronezh region.

"suggest" its decline in 2018 and subsequent stabilization. The neural network "aligned" the dynamics of related indicators.

Thus, it should be noted that, depending on the forecasting method used, the indicator "the number of advanced technologies used" gets different values. The forecast of the neural network indicates the stabilization of the values of the analyzed indicator at the level achieved in 2013–2014.

4 Discussion

Unfortunately, the results cannot be compared with the forecast presented in the strategy of socio-economic development of the region [5] since it lacks these indicators. In this regard, the authors turn to a comparison of other private indicators presented in this document and the official statistical document. Official statistics cannot be considered to be impeccable in terms of their accuracy, but at the same time there are no more reliable sources.

A quite general indicator is the volume of investments in fixed capital in the region as a whole in 2018: the forecast for the target scenario in the "Strategy" is 300.4 billion rubles; statistical data—279.2 billion rubles [14], the deviation from the forecast: −7.0%, which is less than the deviation between the values of the target and conservative (optimistic and pessimistic) forecasts for 2019 (forecast for the scenarios for 2018 was not made) in accordance with the "Strategy" (8.5%) [5].

The volume of shipped own-produced goods in industry: forecast for the target scenario "Strategy": 526.4 billion rubles [5], statistical information −569.1 billion rubles [14], the deviation from the values of the target forecast: −8.1%. Deviations of the indicator values for the target and conservative scenarios account for 8.2% [5].

The indicator reflected in the "Strategy" as "innovative activity of organizations" as at 2018 is missing in the 2019 reference book [14] therefore, comparison with the data of the "Strategy" [5] is impossible.

Another indicator from the "innovative development" block is "the pro-portion of innovative goods, works, services in the total volume of goods shipped, work performed, services"—in the "Strategy" −6.3% [5], according to the statistics −5.9% [14], the deviation: +0.4% points =+6.3% of the "Strategy" data. It should be recognized that for a private indicator, the accuracy is very high, for comparison—in accordance with the "Strategy" the difference in the values of the indicator for target and conservative forecasts is 0.9% points (16.0%).

5 Conclusion

The analysis of the informal logic algorithm and the results of its application for predicting the parameters of the socio-economic development of the region (on the example of the Voronezh region) and using formal forecasting methods (correlation and regression analysis and the apparatus of neural net-works) showed that, on the whole, they fit into informal forecasting logic.

The results obtained using various formal methods are close to the actual ones and those calculated using the scenario approach.

In order to increase the accuracy of forecasting it is essential that the period between actually achieved results is reduced and reflected in official statistics, the duration of which currently reaches two or more years for a number of indicators.

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Quantitative Assessment of the Reliability of Production Systems in High-Tech Production

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Abstract. The article considers a production system in the form of a linear technological chain, the elements of which are production subsystems—work centers. Each subsystem is both a consumer and a supplier of products. The negative impact of random factors is the reason for the delay in delivery of products on time. The behavior of subsystems is analyzed, which is as follows: a subsystem can skip the amount of delay and pass it along the process chain to a subsequent subsystem; partially compensate for the delay and pass part of the delay; fully compensate for the delay. The following concepts are introduced: delivery delay—input deficit; transfer of all or part of the delay along the process chain—residual deficit. The function of costs for regulating external instability is defined, which includes two parameters: the value of the input deficit and the value of the residual deficit. As a controlled variable, the "deficit compression ratio" is proposed, which reflects the degree of reduction of the input deficit in the subsystem. A solution to the problem was obtained for the subsystem and a policy for regulating the residual deficit was formulated. To obtain statistical characteristics of input and output deficits in the form of average values, a simulation of the functioning of subsystems as controlled queuing systems is proposed, which is relevant for high-tech production, in which work centers act as production subsystems.

Keywords: Input deficit · Residual deficit · Penalty function · Deficit compression ratio · Reliability · Mathematical modeling

1 Introduction

Modern industrial (machine-building, instrument-making, etc.) enterprises with a discrete nature of production are quite complex in the composition and relationships of their production units. Depending on the degree of cooperation, which is determined based on the average number of connections between the main equipment, the production units of such enterprises can be formed on the basis of a linear, subject or technological principle.

At the same time, the current stage of development of industrial production is characterized by the need to take into account a number of factors that fundamentally change approaches to the organization, formation and management of production systems [1], which include.

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Use in production practice of modern technologies that radically change the line of products that can be offered to the buyer;

Changing consumer preferences, which is expressed in a constant, steady growth in demand for small volumes of extremely diverse products with functions that are necessary only for the customers themselves.

The effect of these factors on the production system is expressed in an increase in the range of products produced against the background of a decrease in its output, reducing the cycle of product changes and accelerating the dynamics of production processes. And the associated increase in costs dictates the need to choose such forms of organization and management of production that could ensure the establishment of rational production relations and proportions between individual divisions (production subsystems) at a given level of reliability and efficiency of the production system as a whole.

The problem of reliable and efficient functioning of production systems is multidimensional [2, 3]. Indicators of performance and quality of work, including reliability, of production systems can be studied and evaluated by various methods [4–10] depending on the tasks of the study, however, considering the problem of their reliability, it seems that the solution of the problem follows from the solution of a more general problem—the correlation of costs and results.

The characteristics of stable, reliable functioning of production systems should be considered as the results obtained when solving the problem of effective functioning of the system in time [11].

2 Materials and Methods

The studied production systems have a complex, usually multi-link structure with a huge number of economic, organizational and communication links [12], so the stability of their functioning depends on the activity of their constituent elements, each of which in turn is affected by various disturbances that are random in relation to a separate division. We consider a production system in which the topology of work centers in high-tech production is a sequential technological chain.

In accordance with the type of movement of labor items used, each division, having completed the finished part of the production process, transfers products to the next division in the chain "supplier–consumer" within the specified time frame. Under the action of random disturbances (both external and internal), in discrete production, there is a mismatch between the actual delivery dates of products and the planned ones. Therefore, under the delivery of products "on time" in practice, we understand the time interval adopted in the current system of operational and production planning as a planning and control period. This standard shows the accuracy with which production units set delivery times for products to adjacent units in the process chain. Thus, if the production units in the chain "supplier–consumer" ensure the receipt of products during the planned control period, it is considered that the system meets the specified criteria for efficiency and reliability. Quantitative assessment of the reliability of the production system (as well as individual divisions) is advisable to determine using statistical models that describe the probability of receipt of products in the interval of the planning and control period and characterize its stability. At the same time, instability should be understood as a violation of the delivery time of products outside the planned control period, which leads to misalignment of relations in the chain “supplier–consumer”.

The reliability of departments and the production system as a whole is determined based on the amount of losses from instability. Losses from instability determine the amount of additional costs in other departments throughout the supply-consumer chain. These costs perform a compensatory function for their intended purpose and are intended to completely or partially neutralize the consequences of instability, which is transmitted through technological connections to the divisions of the production system. The amount of costs to fully or partially eliminate the consequences of instability is determined by the level of reserves created in each production unit, as well as between them. Each division has both internal and external reserves. Internal reserves are defined as: reserves of production capacity, stocks of work in progress, etc. Reserves of finished products that act as external reserves are factors that ensure the stability of relations between them. The most practical methods of reserving are volumetric and temporary.

Based on the statistical model of the movement of labor items over time along the technological chain “supplier–consumer”, the instability of the subsystem can be described in the form of average delays in the delivery of products to related departments. It is the size of these delays that characterizes the level of redundancy, as well as the size of the losses that occur in the division that consumes products. Thus, the comparison of redundancy costs and losses from instability of the unit allows you to determine the level of its reliability and the production system as a whole.

Due to intra-production reasons, caused mainly by the action of random factors, the products of production divisions may be late relative to the planned delivery dates to the consumer division, that is, there is an intra-production deficit. As a unit of measurement of the degree of misalignment of relations between functioning divisions, the number of calendar days of delay of the planned accounting unit (order) relative to the planned deadlines is used. Thus, the deficit, without a cost measure, is measured in days of delay relative to the planned period. The costs of the consumer of this product, which are caused by the need to neutralize fully or partially the consequences of this delay, are the damage that the supplier subsystem causes to the consumer subsystem as a result of the product being late on time.

We introduce into consideration the cost function on the regulation of foreign instability and the required variables [13]. Let us denote the average delay duration (input deficit) in the initial production unit in the course of the technological process by the set of planning and accounting units through θ_0. In turn, the considered division, being an intermediate link in the technological sequence of manufacturing the final product, can itself be a source of shortfalls, that is, it can function with an average output deficits θ. The process of restoring consistency, which consists in partially or completely neutralizing the input deficit, requires additional labor and material costs in the division. By its content, the costs incurred are the costs of regulating external instability—Z. The amount of these costs is a loss to the consumer, and therefore must be compensated either by the division that is the source of the deficit, or by the system in the form of penalties imposed on it—S. The amount of the penalty is the amount of expenses that the subsystem needs to reserve in order to neutralize the remaining deficit. When considering the function, we omit the subsystem indexes to simplify writing.

For each subsystem, the cost function for regulating external instability has the form $Z(\theta_i, \theta_{i+1})$, $i = 1(1)m$, where the residual deficit of the previous subsystem is the input to the subsequent one. The function that characterizes the amount of costs required to fully compensate for the input deficit should reflect the growth of the division's resource costs for each additional unit of delay in the input deficit, that is, it should have the form of a convex downward increasing function. We assume that for the purposes of the study, it is sufficient to determine the costs by a function that depends on two parameters—the value of the input and output deficit.

With the existing intrinsic instability and input deficit, the residual deficit is always a positive value. With a relative balance of throughput capacities of equipment groups and low load factors, the minimum residual deficit is small and may not be taken into account when coordinating the production relations "supplier–consumer" over time, especially since "precise" coordination is actually understood as ensuring delivery in a certain interval (planning and control period). However, as the load factors increase, while the input deficit remains at the same level, the minimum possible amount of the remaining deficit increases, since it is determined by the smaller amount of reserves remaining at the disposal of the division.

The cost function for regulating external instability, being a function of two variables $Z(\theta_0, \theta)$, reflects a variety of processes, ways of using and the degree of involvement of internal regulators to compensate for instability in a division that mobilizes both planned resources and reserves. The general nature of the dependence of costs on variables shows that the cost function for regulating external instability has a clearly expressed nonlinear form. When analyzing a function $Z(\theta_0, \theta)$ in order to further approximate it with simpler functions, it is most important to establish the relationship between the growth of the control cost function as a function of reducing the residual deficit. We will approximate the control cost function assuming that the relative increase in costs per unit of output deficit reduction is constant:

$$[dZ(\theta_0, \theta)/Z(\theta_0, \theta)]/(d\theta/\theta) = -\alpha \tag{1}$$

The solution of Eq. (1), using natural boundary conditions, allows us to obtain a function of control costs depending on the value of the input and residual deficit, for example, in the form of the expression:

$$Z(\theta_0, \theta) = \theta_0^{1+\alpha}(c + \theta)^{-\alpha}, \alpha > 0. \tag{2}$$

It is obvious that the most significant requirements are taken into account in the amount of expenditures directed in the division to regulate the output deficit and determined by the formula (1). Equality of the residual deficit zero $\theta = 0$—inclusively means that the input deficit is fully compensated and the control cost function must take the maximum value $Z(\theta_0, 0) = \max Z(\theta_0, \theta)$. Constant c and the exponent α allow you to flexibly change the shape of the lines of the cost function and thus ensure that they correspond to the actual values.

So, the cost function for regulating external instability of the form (1) is defined for all values of the arguments $\theta_0, \theta \geq 0$ and takes the highest value when the input deficit is fully compensated, that is, when $\theta = 0$. Parameter***c*** corresponds to the amount of control costs that is sufficient to completely neutralize the input deficit in the amount of θ_0.

For a linear function of the output deficit penalty $S(\theta) = \beta\theta$ the desired minimum of the amount of regulation costs and penalties is defined by the expression:

$$W(\theta_0, \theta) = \min_{\theta}\{Z(\theta_0, \theta) + \beta\theta\} \quad \mathit{if} \quad \theta_0, \theta \geq 0. \tag{3}$$

The solution of the problem gives the following result:

$$W(\theta_0, \theta) = \begin{cases} (\beta/\alpha)\theta_0^{1+\alpha}\tilde{\theta}_0^{-\alpha}k = W(\theta_0, 0), & \theta_0 \leq \tilde{\theta}_0 \\ (\beta/\alpha)\theta_0 k + \beta k\left(\theta_0 - \tilde{\theta}_0\right) = W\left(\theta_0, \hat{\theta}\right), & \theta_0 \geq \tilde{\theta}_0 \end{cases} \tag{4}$$

where $\tilde{\theta}_0$ the value of input scarcity when the unit is economically advantageous to compensate it completely independently; $\hat{\theta}$—the optimal value of the deficit, transferred to the division of consumer; value $k = c/\tilde{\theta}_0$. The graph of the function is shown in Fig. 1.

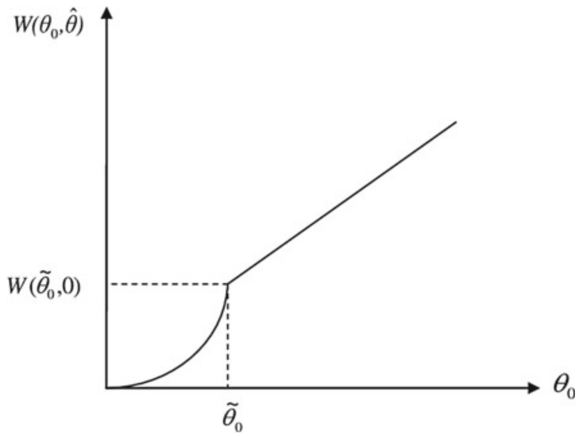

Fig. 1. A Graph of the cost function for regulating external instability of the production subsystem.

The deficit compression ratio can be used as a characteristic of the division's redundancy level:

$$CRD = 1 - k\left[1 - \left(\tilde{\theta}_0/\theta_0\right)\right] = 1 - [k - (c/\theta_0)], \quad \theta_0 \geq \tilde{\theta}_0. \tag{5}$$

In multi-nomenclature discrete production, obtaining approximate values of such important characteristics as input and output deficits in the form of average values for a set of processed planning and accounting units is possible when modeling the functioning of production systems as queuing systems (QS). First of all, this is relevant for high-tech production, in which robotic complexes (RTC) act as production subsystems [14].

Representation of the technological process in the form of a multiphase QS, in terms of which applications are identified with the work (lots of parts different names, accounting units) and the use of this approach to solving problems of bandwidth estimation RTC depending on the incoming flow of goods for processing in terms of application deserves attention.

We consider a production system whose subsystems are work centers. Functioning of each subsystem is interpreted with the help of the QS models. Each of the production subsystems processes the flow of products according to their route, and at the end of the process in the system, the flow enters another production system (for assembly or subsequent processing).

Let's consider a model description of RTC functioning. The main feature of the processes taking place in the center is the randomness of discrete events: the randomness of the time of stay of products for processing, the mass of incoming flows, the formation of queues, the action of disturbing factors at random moments of time and control actions. It should be noted that one of the most acceptable and well-known methods of studying this type of process, which allows us to obtain analytical dependencies between the technical and organizational-economic characteristics of the system and its parameters, is the theory of queuing.

In the production subsystem, for which an important indicator of functioning is the timeliness of performance of assigned work, the control parameter is the intensity of production of order elements on the RTC, which in terms of the theory of queuing corresponds to the intensity of service requests.

The management strategy for the intensity of service at the RTC can be very diverse. For example, a dynamic change in the intensity of service requests depending on the length of the queue or the length of waiting, the inclusion of shift modes, various options for managing the work of the main production workers and technical means.

Therefore, the queuing system with management is of increased interest to researchers, since by introducing a particular type of management in the process of servicing requests, the task can be reduced to optimization: by managing resources, with this type of management, it is possible to achieve such modes of RTC operation, in which performance indicators will correspond to the required level.

Consider the functioning of automated equipment in the RTC as a multi-channel queuing system with management, which is associated with a dynamic change in the intensity of service depending on the length of the queue. Specifically, the control consists in the fact that the service intensity $\mu_0 = 1/t$, where t is the average request processing time, is maintained as long as the number of requests n in the queue is less than N_1. With the accumulation of the number of requests in the queue, the service intensity increases with a jump when the number of requests L waiting for processing passes through one of the critical (threshold) values N_i where $i = 1,\ldots,m$ is the number of switching stages. In this case, the service intensity remains constant within each interval and is equal to μ_i.

Let us consider another type of control, which is more general in relation to the one considered: a multi-channel model with cyclic control.

In this case, the subsystem works as follows: requests are processed at an intensity of $\mu_0 = 1/t$, until their number in the queue, equal to n, is less than M. If the number of requests is greater than or equal to N, the service intensity increases to the value $\mu_1 = \mu_0 + \Delta\mu$ and remains equal to μ_1 until the number of requests decreases to M. A cycle is formed with a forward stroke on the section from M to N and the reverse-on the section from N to M. It is obvious that at $N = M + 1$, the system with hysteresis is transformed into a system with single-stage control. Changing the service intensity is equivalent to providing the subsystem with a temporary reserve, and, consequently, reducing the amount of the remaining deficit transmitted along the technological chain.

A mathematical model for determining the reliability of work centers and the production system as a whole can be formulated as follows:

$$\sum_{i=1}^{m} W(\theta_{i-1}, \theta_i) \rightarrow \min_{(\theta_1, \dots, \theta_m)} \tag{6}$$

It should be noted that the mathematical formulation of the problem can be expanded by introducing additional requirements: restrictions on the size of internal resources spent by divisions on redundancy, as well as system resources of the production system. The functional relationship between internal and system resources allocated for structural redundancy of production subsystems is defined using the expression (5):

$$\sum_{i=1}^{m} \varphi_i(CRD_i) \leq R \tag{7}$$

where R is the value of system resources allocated for redundancy of subsystems. For the general case, there are no effective algorithms for solving the problem of reserving subsystems. Moreover, quantitative measurement of the reliability of the functioning of divisions and the system as a whole is possible only with statistical interpretation of the input and residual deficit values. At the same time, there is a quantitative assessment of the reliability of subsystems $i = 1, \dots, m - 1$ and the system as a whole $i = m$ is $P_i = \left(\theta_i < \theta_i^{\text{opt}}\right) = F_i(\theta_i^{\text{opt}})$.

3 Results and Discussion

Therefore, the optimal policy for regulating the amount of the remaining deficit is that when the input deficit is within the division $0 \leq \theta_0 \leq \overset{\sim}{\theta}_0$, it is economically advantageous to compensate for the deficit completely due to the conditions of reservation in the division. With an input deficit $\theta_0 \geq \overset{\sim}{\theta}_0$, the optimal policy is to partially compensate for the deficit.

Depending on the ratio of constants that determine the coefficient k, the residual deficit may increase at a higher or lower rate relative to the increasing deficit at the input. For known values of k and c, the deficit compression coefficient corresponding to the minimum amount of regulatory costs and penalties is easily determined for the input deficit from expression (5).

To determine the statistical characteristics of the input and residual deficit, we used the applied results of the queuing theory as the most acceptable and currently known apparatus for studying such processes, which allowed us to obtain analytical dependencies between the technical and organizational and economic characteristics of the system. However, the applicability of classical models of queuing theory to the problems of analyzing production systems is limited by the fact that the model description is not adequate: in production systems, the emerging problems differ from the classical ones, which necessitated the development of queuing systems with control.

The resulting final formulas that characterize the modes of operation of queuing systems and the time parameters for servicing requests allow us to give a comparative assessment of the types of equipment operation control in robotic complexes. However, more important is the possibility, under certain assumptions about the distribution of moments of receipt of applications from one system to another, to calculate the average values of the input and residual deficit for the entire set of applications. The use of queuing systems with management made it possible to provide work centers with temporary redundancy and establish a relationship between the amount of residual deficit and the cost of reserving the subsystem.

4 Conclusions

Let us note an important circumstance. The concept of “reliability of the production system” and the related concepts of “redundancy”, “stability”, and “sustainment” make sense for stationary, relatively stable operating conditions of the production system. This means that the product parameters and structure of the production program remain constant on average for a certain period of time. If the structural shifts of the program and parametric changes in the product are so significant that the system falls out of stationary conditions, then the accepted level of reliability reserves may not be sufficient for stable operation of the system under the new conditions. In this case, the transition to new organizational and production conditions is necessary, which requires special reserves of adaptation [15]. In this case, the optimal composition and level of reliability reserves should be determined in relation to the new operating conditions of the system.

The model description of a production system by multiphase QSs assumes an exponential distribution of random variables. In practice, the movement of product flows in the production process is based on control parameters and decision rules. Therefore, the use of the exponential distribution law requires additional justification. However, the adoption of a different type of distribution of random variables necessarily leads to the use of the method of statistical tests in solving the problems under consideration.

It should be noted that general analytical methods for calculating the characteristics of a network of queuing systems require further research and development. The review of research in this area shows that there are not so many scientific publications on optimization of multiphase QSs, and the solution of problems of synthesis of optimal network dynamics is associated with significant difficulties. At the same time, modeling the functioning of a production system consisting of technologically interconnected RTCs in the form of multiphase queuing systems allows us to obtain approximate analytical solutions and use them as legal reference points for control parameters in production.

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Information Technologies and Marketing Communications in Territories Management

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Abstract. The article is devoted to the problems of information support for the development of territories. A mathematical model has been developed for assessing the potential of territories, depending on their functional target. The mathematical model is represented by a matrix consisting of a system of linear equations. These equations show the dependence of the criteria of the territories potential and the possibilities for their use. Among the criteria for the potential of the territory, indicators are highlighted that characterize the functional purpose of the territories. The system of criteria is directly dependent on the availability of resources on the territory. The second indicator for creating dependence is the indicator of the possibility of using territories. This indicator is associated with a specific infrastructure that allows using of the territory resources for a specific functional purpose. Based on the assessment that is carried out using this mathematical model, a database is created. The database is attached to digital maps of the territory. The software allows you to form queries and, with the help of filters, obtain results regarding the potential of a territory with one or another functional purpose.

Keywords: Software · Geodata · Mathematical model of territorial planning management · Digital marketing of territories

1 Articulation of Issue

The issues of information support of territorial development management processes have a great relevance. This is because of the development of digital technologies. The population's demand for digital services is growing. In conditions of limited social contacts, the remote form of obtaining information through digital resources is of particular

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importance. As a result, taking into account the faster receipt of large volumes of information and minimization of costs for managing territorial development, it is advisable to develop software products aimed at informatization of territorial management. The adequacy of the model proposed in the work, on the basis of which the territorial management system is formed, was tested for adequacy using statistical methods and the Kolmogorov–Smirnov criterion. The deviation in the distribution of the sample does not exceed 0.03, so the model is adequate and can be applied in practice.

2 Analysis of the Latest Researches and Publications

The relevance of the research topic attracts the attention of many scientists. So, the problems of territorial management were dealt with Pelorosso [1], Anna et al. [2], Naulta et al. [3], Schrotter and Hürzeler [4] etc.

A number of scientific works are devoted to the search for effective information systems for managing territories: Oliveira DaSilva and Souza Fernandes [5], Tache and Popescu [6], Billaud et al. [7], Tran et al. [8], Di Pinto [9] etc.

Since the development of digital technologies is constantly improving, it is advisable to continue research work in the field of finding solutions for information support for territorial management processes.

3 Purposes and Objectives

Based on the relevance of the research, the purpose of the article is to create effective information resources for managing territories.

To achieve the purpose, it is necessary to solve the following tasks:

- to determine the potential of the territories in accordance with their functional purpose,
- to develop a mathematical model for assessing the potential of territories,
- to offer a system of geolocation binding of territories with various functional purposes to digitized cartographic projections of territories in the form of software products,
- to propose a system of marketing communications for the promotion of a software product of information support for territorial development management.

4 Statement of Basic Materials

At the present stage of the development of society, an important aspect is the processes of information support for the development of territories. Territorial development management can be effective and mobile in the development of an information product that can ensure the selection, analysis, assessment and rational use of data in accordance with the assigned management task. In addition, the society, which is in the conditions of an overabundance of information, needs to form loyalty to the information products that are offered to the market in order to provide a territorial management system. To create loyalty, it is necessary to use marketing communications at the public administration level.

One of the effective methods of territory management is the accumulation of territorial potential information in specialized databases. Such databases exist in the form of a state land cadaster, a system for assessing and recording real estate for various functional purposes (industrial, residential, commercial), mapping service and tourist facilities in order to create an optimal system for their atomic search. Combining specialized databases into a single system for the purpose of integrated territorial planning and territorial management is of high relevance. It is advisable to consider a systematic approach to the creation of information programs for managing territories by developing complex databases in the article.

To create an effective information system for territorial management, it is necessary to define a set of criteria that can describe the function of territorial development. These criteria can be represented by a system of indicators that describe in detail the potential areas of use of territories taking into account their resource provision. The function of territorial development can be represented in the form of a matrix, which takes into account all elements of the criteria for territorial development. This set can be visually represented using the following formula (1)

$$\int \mathrm{TD} = [x_1; x_2; x_3 \ldots x_n] \tag{1}$$

where $\int$ TD—function of territorial development;

$x_{1,2,3..n}$—criteria for territorial development.

Territorial development is a complex concept. Therefore, it is advisable to assess the territory according to various criteria that can characterize the possibilities of its use. The proposed criteria for determining the function of territorial development are as follows:

- the ability to use land resources for agricultural purposes,
- the availability of natural resources for the development of various branches of industrial production,
- the possibility of using territories for commercial purposes;
- the possibility of using territories for residential development,
- the possibility of using territories for social purposes;
- the possibility of using territories for the development of tourism and recreation,
- the possibility of using territories for research purposes,
- nature conservation areas,
- areas unsafe for the population.

These criteria are defined as the main ones for creating a territory management database. To determine these criteria, the authors have developed a system of indicators for assessment, presented in the form of a matrix composed of a system of linear equations—formula (2)

$$\begin{cases} b_1 = a_{1j*x_1} + a_{2j*x_2} + a_{3j*x_3} + a_{4j*x_4} + a_{5j*x_5} + a_{6j*x_6} + a_{7j*x_7} + a_{8j*x_8} + a_{9j*x_9} \\ b_2 = a_{1j*x_1} + a_{2j*x_2} + a_{3j*x_3} + a_{4j*x_4} + a_{5j*x_5} + a_{6j*x_6} + a_{7j*x_7} + a_{8j*x_8} + a_{9j*x_9} \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ b_n = a_{1j*x_1} + a_{2j*x_2} + a_{3j*x_3} + a_{4j*x_4} + a_{5j*x_5} + a_{6j*x_6} + a_{7j*x_7} + a_{8j*x_8} + a_{9j*x_9} \end{cases}, \tag{2}$$

where

b_{1-n} the maximum indicator of the elements of the matrix for assessing the territorial potential;
n number of territories for analysis;
a_{ij} criteria for the functional purpose of territories according to the resource potential;
x possibilities of using the resource potential of the territory;
i criterion defined according to resource potential;
j analysis object (sample position).

As a result, a system of linear equations can be drawn up by analyzing the potential of the territories. This model makes it possible to use the system of indicators as a parametric assessment of the territory. The model is easy to use and can be used as a software product or as an application for a mobile phone. It is convenient for the end user. The maximum possible potential of the territory is proposed to be taken as 1. Starting from this point, the following gradation of criteria and possibilities of their use is proposed, the results of the gradation are given in Table 1.

Table 1. Graduation of criteria for the resource potential of territories and the possibilities of its use (developed by the authors).

Gradation	Resource availability criterion	The criterion for the possibility of their use
1–0.8 including	The maximum possible amount of resources according to the functional purpose of the territory	Creation of the most comfortable conditions for the use of these resources in accordance with the functional purpose of the territory
0.8–0.6 including	A significant amount of resources according to the functional purpose of the territory	The presence of the necessary conditions for the use of these resources in accordance with the functional purpose of the territory
0.6–0.4 including	Sufficient amount of resources according to the functional purpose of the territory	The presence of a minimum set of conditions for the use of these resources in accordance with the functional purpose of the territory
0.4–0.2 including	Low amount of resources according to the functional purpose of the territory	The need to create some additional conditions for the use of these resources in accordance with the functional purpose of the territory
Below; 0.2	Lack of the required amount of resources according to the functional purpose of the territory	Lack of conditions for the use of these resources in accordance with the functional purpose of the territory

Accordingly, the gradation proposed in the table above, an assessment of the potential of the territories is carried out for each type of functional purpose (proposed by the authors of the article).

Based on the results of the analysis, a territory assessment matrix is formed, the template of which is presented in Table 2.

Table 2. Territory potential assessment matrix template (developed by the authors).

Functional purpose	Resource availability criterion	The criterion for the possibility of their use	The maximum indicator of the elements of the matrix for assessing the territorial potential
Agricultural land (i_1)	a_{1j} = from 1.00 to 0.00	x_{1j} = from 1.00 to 0.00	b_n
Industrial production (i_2)	a_{2j} = from 1.00 to 0.00	x_{2j} = from 1.00 to 0.00	b_n
Commercial purposes (i_3)	a_{3j} = from 1.00 to 0.00	x_{3j} = from 1.00 to 0.00	b_n
Residential area (i_4)	a_{4j} = from 1.00 to 0.00	x_{4j} = from 1.00 to 0.00	b_n
Social facilities (i_5)	a_{5j} = from 1.00 to 0.00	x_{5j} = from 1.00 to 0.00	b_n
Tourist and recreational areas (i_6)	a_{6j} = from 1.00 to 0.00	x_{6j} = from 1.00 to 0.00	b_n
Research territories (i_7)	a_{7j} = from 1.00 to 0.00	x_{7j} = from 1.00 to 0.00	b_n
Conservation areas (i_8)	a_{8j} = from 1.00 to 0.00	x_{8j} = from 1.00 to 0.00	b_n
Areas unsafe for the population (i_9)	a_{9j} = from 1.00 to 0.00	x_{9j} = from 1.00 to 0.00	b_n

This matrix allows you to calculate both an integral criterion for assessing the potential of the territory, and its individual indicators for each functional purpose.

As a result of the potential calculations of the n-numbers of objects (territories), a database of results is created. This database is an information field for creating a geolocation program for determining the functional purpose of territories and assessing its potential.

This model was analyzed for adequacy using the methods of statistical verification of the adequacy of the athematic models. The assumption within the framework of the test was that the value of the parameter *a* or *x* or *b* differs from the actual indicators in practice by no more than a given value ε. However, the true value of the value ε is unknown.

As a result, we formulate the assumptions—formula (3)

$$(X(_n) -_m) = \varepsilon \leq \varepsilon*, \ n \in N* \tag{3}$$

where $X_{1,2,3..n}$ – criteria for territorial development.

n—sequence number of the sample.

x_m—arithmetic mean of the sample.

$(x(_n) - x_m)$—collection of random variables.

N—number of practical indicators.

ε*—practical indicators.

To confirm the hypothesis, it is necessary that the assumption (εi > ε*) has a random character, and not have a significant impact on the adequacy of the model.

The hypothesis was tested using the Kolmogorov–Smirnov method. The evaluation formula is presented—formula (4)

$$D_n = \sup S_x |F_n(x) - F(x)| \tag{4}$$

where sup S—the exact upper bound of the set S,

F_n—the distribution function of the studied population,

$F(_x)$—the normal distribution function.

The calculations showed that the empirical value of the Kolmogorov–Smirnov criterion is 0.8, and the critical value is 0.3. The consistency level is 0.03, which is valid. Thus, the proposed model has a homogeneous sample and is adequate.

The adequacy of the model proposed in the work, on the basis of which the territorial management system is formed, was tested for adequacy using statistical methods and the Kolmogorov–Smirnov criterion. The deviation in the distribution of the sample does not exceed 0.03, so the model is adequate and can be applied in practice.

By attaching the database to the digitized map of the area on which the analysis is carried out, information support is created for the processes of assessing land and determining their possible use. Filters are set for ease of use.

The first filter shows all territories that have the maximum possible and significant amount of resources according to the functional purpose of the territory (1–0.8 and 0.8–0.6 criteria). The second filter shows the creation of the most comfortable and the presence of the necessary conditions for the use of these resources in accordance with the functional purpose of the territory (1–0.8 and 0.8–0.6 possibilities). The third filter shows the optimal integral indicator of the elements of the matrix for assessing the territorial potential. This information system is clearly shown in Fig. 1.

This information system is required to perform the following functions:

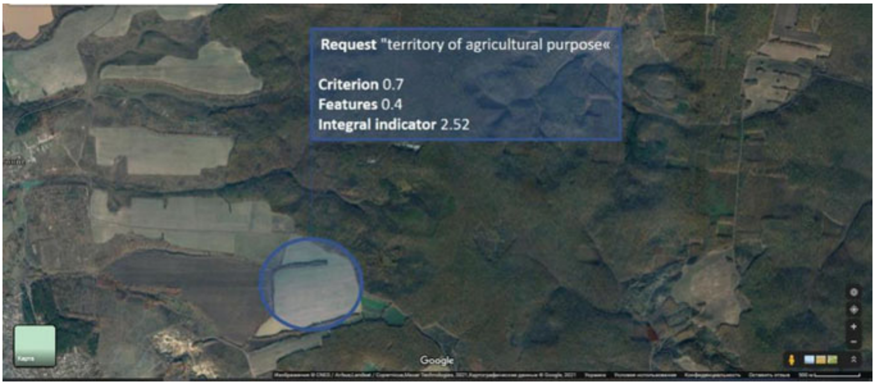

Fig. 1. Digital visualization of the cartographic projection of the information system for assessing the territorial potential.

- assessment of potential areas of territorial using,
- automation of the processes of searching for territories for acquisition for various types of activities,
- information support of investment activity and attractiveness of territories,
- assessment and audit of the rational territorial using,
- automation of processes for assessing the availability of resources,
- automation of land management processes, territorial development management.

This system is designed to create transparency and openness in territorial management processes, to create a positive investment climate. It does not threaten the security of territories, since it visualizes only potentially possible directions for territorial using, without clearly linking the calculation criteria to visual support. Therefore, the direct input for the evaluation is not visible to the end user. The end user can only evaluate the integral criteria, resource provision and opportunities for conducting a certain type of activity in the territory. It will become the basis for making management decisions regarding investment in certain territories. For public administration, this system will help to visually see the negative sides in the management of territories and to rationalize there.

For the active use of this information product, it is necessary to promote it on the digital services market using the marketing communications system in public administration. The most effective way to promote an information product is digital advertising. To maximize the coverage of potential consumers of the developed software product, it is proposed to use the resources of social networks and targeting advertising. This advertisement is tuned to the views of social media users according to a pre-selected target audience. The target audience for this type of software products can be characterized as a category of people aged 25–70 years, the interests of the target audience are: business, investments, information technology, real estate, economics and other similar interests. Payment for the development and promotion of this application can be covered by launching paid advertising in the application itself, as well as developing additional paid functions: additional search, descriptions of land registration processes, etc.

As a result, the promotion of the developed software product through digital marketing communications will ensure interest in the program from potential consumers, which will help to ensure more effective management of territories.

5 Conclusions

After analyzing, a number of conclusions can be made. Digital technologies are the most relevant for the development of a territorial management system. The problems in the management of territories are the low mobility of making managerial decisions, the lack of a relevant information base for making decisions in the territory management system. An important aspect of territory management is the definition of their functional name. The functional purpose of territories depends on the availability of different types of resources and opportunities for their using. To determine the potential of the territory, it is necessary to assess it according to the criteria and possibilities of using these criteria, depending on the possible functional purpose. The article proposes the implementation of a software product that is aimed at conducting such an assessment. For the assessment, a mathematical model was developed, represented by a matrix from a system of research. The mathematical model for assessing the potential of the territory allows to create a database. The database is attached to the digitized map of the territory. Possibilities are being created to form a system of profile requests, which make it possible to assess the functional potential of the territory. This software is necessary to automate territorial development management processes, as well as to create a transparent system for investing in land plots. The article proposes methods of digital promotion of a software product for its positioning in the application market. The adequacy of the model proposed in the work, on the basis of which the territorial management system is formed, was tested for adequacy using statistical methods and the Kolmogorov–Smirnov criterion. The deviation in the distribution of the sample does not exceed 0.03, so the model is adequate and can be put in practice.

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A Model for Digital Innovation Assessment and Selection

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Abstract. Nowadays, companies can acquire and sustain competitive advantage only through implementation of different innovations. In the majority of cases innovation is connected somehow with digital and information technologies. New digital technologies and products emerge with a very high speed, and companies usually implement them without justified selection and prioritization. Only 10% of them are completed successfully. Still the most commonly used approach for digital innovation projects assessment use financial metrics without due attention to the influence on company's strategic goals and product development. This research suggests a model for assessment and selection the innovative projects. Over several decades, a class of innovation adoption models that help to evaluate whether a certain innovation will be accepted by a company, its structure and employees, has been formed. However, they do not fully meet the needs of "digital" realities and need modification. The approach entails comprehensive evaluation of project's expected results in four areas: environmental, organizational, strategic and technological contexts. Suggested method is based on the modified Fleischer-Tornatzky innovation adoption model.

Keywords: Digital innovation · Innovation adoption · Innovation project assessment

1 Introduction

World practice and accumulated experience show that the welfare and competitiveness of the country is currently impossible without the innovating all sectors of the economy—health [1], production [2], civil engineering [3], agriculture [4], automotive [5] etc. The

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same is true for Russia—digitalization has become a strategic vector for the development of enterprises in all sectors [6]. The digital transformation of society has modified the very concept of "innovation". The competitiveness of an organization is currently determined not only by the rapid implementation of innovations based on digital and information technology in its day-to-day processes, but also by the ability to be effective in these innovative processes in the state of the economic uncertainty.

Currently, the concepts of "innovation" and "information technology" are often used synonymously. Thus, according to the McKinsey research [7], for most modern organizations, it is digital and information technologies that boost and provide the implementation of their innovative strategies. At the same time, statistics confirm that only 10% of them achieve commercial success [8]. The selection and implementation of innovative projects without an objective preliminary assessment of their quality leads to the following consequences:

- organizational resources are distributed irrationally;
- the planned project deadlines are violated;
- fact costs turn out to be much higher than the planned volumes;
- ongoing innovative projects do not lead to the achievement of strategic goals.

The concept of "innovation" in modern realities lies in its rapid implementation into the existing business processes for the achievement of maximum commercial success, what is possible only with the selection of appropriate digital and information technology. The described situation illustrates the necessity of objective methods of digital innovation assessment and selection for further implementation in the organizations.

Innovations and innovative processes are often associated with high investment risks, which is difficult to assess by the majority of expert methods. Hence, a problem lies in the following: on the one hand, society have a need to implement and boost digital innovations into the economy and organizations, but on the other hand, there is a clear lack of objective methods for their assessment and selection.

Purpose of this article is to develop an actual method for the identification and selection of digital innovations, taking into account the degree of maturity of the companies' business processes.

To achieve this goal, the following tasks have been solved:

- investigation of innovations assessment methods;
- updating the criteria for the selection of digital innovations;
- development of a new methodological approach and procedure.

2 Materials and Methods

2.1 Research of Approaches for Assessment and Selection of Innovations

A number of studies have shown that currently there are no adequate methods for assessing innovations [9] what justifies a need for an in-depth research.

Most commonly used methods for evaluation of innovation and innovative projects usually rely a lot on experts' experience and their subjective opinion or take into account only specific types of metrics. Usually researchers divide such methods into 4 groups [10]: financial, multi-criteria, ratio approaches and approaches for evaluating project portfolios.

In previous works [11] these approaches have been studied according to the criteria:

1. unit of analysis (information system/project/department/company/industry),
2. evaluation of the uncertainty in expected project results,
3. evaluation of the uncertainty in expected project deadlines,
4. evaluation of the influence of project results on a product/service added value,
5. quantitative evaluation,
6. qualitative evaluation,
7. methodological equipment of the approach,
8. complexity of the approach.

Financial approaches help to choose what innovative projects organization should invest in after a preliminary assessment of their potential cash flows. The most common methods of financial assessment include the rate of return method, the payback period method, the present project value method, and the internal share of profitability method.

Multi-criteria approaches usually assess project by an integral metric that include several indicators with weight coefficients. One of the most complete methods, taking into account various criteria for evaluating innovative projects, is the information economy method, as well as the SIESTA method (Strategic Investment Evaluation and Selection Tool Amsterdam) [12].

Ratio approaches involve the need to compare organizations with each other before making investment decisions. Speaking of digital innovations, ratio approaches allow innovations to be measured across various metrics, such as the share of IT investment income in a company's total revenues. However, it is not necessary that the metrics take into account only financial indicators—a number of IT employees, and for example, a number of business processes where an improvement is recorded after digital renovation or a number of new IT and digital products or services can be compared.

The project portfolio methods are widely used in the practice of making investment decisions and allow evaluating alternatives at various levels of the organization, considering not only the project attributes, but also critical business indicators, in some cases even the business model. Within this approach, questions are raised not only in terms of "to invest or not to invest", but also "what important business activities do we want to improve", "what processes support the most important business activities", "what IT and digital activities can support such business processes and how to improve them with a project X". These approaches include the Bedell method [13], the investment mapping method and the investment portfolio formation method [14].

The research results obtained by the authors in previous works [15] showed that the existing methods for innovative projects assessment are used for particular sectors of the economy and do not have a universal formalized algorithm that would allow quick and reliable assessment and selection of digital innovations. In each specific case, researches choose a specific set of methods and approaches for predicting project performance indicators, which also does not provide desired universality.

It is obvious that the application of the investigated approaches for assessing digital innovations is problematic because digital innovations, in addition to indicators common to any innovations, have a number of features [16]. Therefore, the existing approaches for assessing innovations require improvement. It is necessary to develop a comprehensive multi-criteria model for assessing digital innovations, which will allow choosing an adequate toolkit (set of methods, frameworks and approaches) for an objective assessment for each indicator. As a result, it will allow formalizing the process of assessing the efficiency and quality of digital innovation.

2.2 Indicator Scorecard for Digital Innovation Projects Assessment

To choose an approach to assessing digital innovations, the features of innovative IT and digital projects were taken into account: high uncertainty of the project results, ambiguity in the timing of its implementation, impact on added value as well as the necessity to assess a project from different company perspectives.

It was concluded that the group of multi-criteria approaches is of greatest interest. First, such approaches are not limited to only financial assessment, which is important when analyzing innovations, the results of which may have intangible benefits. Secondly, the multi-criteria approach can provide analysis not at the level of implementation (innovative project), but also to research to higher levels (for example, the strategic goals of the organization or influence on its product or reputation). Such methods are more flexible in terms of taking into account the uncertainty of the project deadlines. In addition, the multi-criteria approaches make it possible to create and use innovation assessment specific indicators that are relevant to a company as well as to assess a very important concept of the innovation adoption.

To develop a method for a comprehensive assessment and further selection of digital innovations, 8 groups of assessment indicators are proposed: Economic, Technological, Organizational, Consumer, Strategic, Market (external), Innovation and Digital.

Each group is formed from a sufficient number of single measurable indicators (n_i).

For each group, it is possible to calculate a complex integral indicator (Q_i), taking into account the weighting coefficients of single indicators.

$$Q_i = \sum n_i * a_i, \tag{1}$$

where a_i is the weighting factor of each n_i indicator.

The developed system of assessment indicators allows not only assessing the values of single, group or complex indicators for assessing innovations, but also comparing them with similar indicators of other innovative projects. In this case, the level of project assessment for a single criterion (n_i) or group indicator (z_i) will be determined, respectively, by the following formulas (2, 3):

$$A_i = \frac{\text{calc\_}n_i}{\text{base\_}n_i} \tag{2}$$

$$P_i = \frac{\text{calc\_}n_i}{\text{base\_}n_i} \tag{3}$$

where A_i is a project assessment for a certain criteria, P_i is a project integral assessment for a set of criteria, calc_n_i and calc_z_i are single and group indicators of the assessed project, base_n_i and base_z_i are baseline metrics for each single and group indicators. Comparison of P_i indicator of different projects can provide their rating.

2.3 Innovation Adoption Model Development

Innovations adoption models determine indicators of innovations adaptability in companies' landscape, business processes and corporate culture thus allow assessing the degree of compliance of innovations with a particular organization.

In previous works [15], the authors carried out an in-depth study of innovation adoption models. As a result, the most common of them [6, 17] have been highlighted. Table 1 presents a comparative analysis of the innovation adoption models.

Table 1. System of evaluation indicators of digital innovations.

Comparison criterion/model	Technology adoption model	Diffusion of innovation	Framework "Plan-acceptance"	Potential use model	TOE model
The approach type	Model	Framework	Framework	Model	Model
Binding to the company size	Small	Large, medium and small	Medium and small	Medium and small	Large, medium and small
The limiting stage of the life cycle of IT-innovation	Early stage of innovation	–	Early stage of innovation	–	–
The unit of assessment	Individual (job position)	Corporate	Individual and corporate	Corporate	Individual and corporate
Indicator for strategic coherence	No	No	No	No	Partially
Object of analysis of IT-innovation adoption	Internal characteristics of the company	Internal and external characteristics	Leadership skills, innovative potential of employees	Employees examination	Organization, Technology, Environment
The format of model application result	Assessment of the innovation adoption by a specific position	Assessment of the innovation adoption by a specific position	Assessment of readiness of corp. culture for the innovation implementation	Innovation use case scenarios	Evaluation of innovation adoption by the company

While researching digital innovations, the authors revealed that the market and technological properties of an innovation vary depending on its life cycle. It is important that the model can be applied to the innovation of any life cycle stage. Moreover, the first innovation adoption models considered only a specific information system or job position ignoring levels of project, department and entire organization.

Previously in this work it was justified digital innovation should support the innovation and business strategies of the company. This argument is singled out as a separate criterion in developing model (as the strategic consistency criterion).

To take into account the meaningful features of innovations innovation adoption models were compared through several significant criteria (see the results in Table 1).

It has been established that the Fleischer-Tornatzky model of technological, organizational and environmental context is of the greatest interest. Its application is not tied to the size of the company or the life cycle stage of assessed innovation, the assessment is carried out at both project and corporate levels of the organization and considers its activities from three different contexts. It is worth noting that this model has an implicit assessment of strategic coherence in the form of environmental context. That is why it was chosen for further modification for the purposes of this research.

2.4 Innovation Adoption Model Modification

As it is necessary to bypass a TOE model limitation (the absence of innovation compliance with the organization's strategy). Therefore, a strategic context has been added to the model, which makes it possible to assess the compliance of innovation with not only the organizational or technological structure, but also to take into account the impact of innovation on the achievement of the strategic goals. Figure 1 presents a modified TOE innovation adoption model.

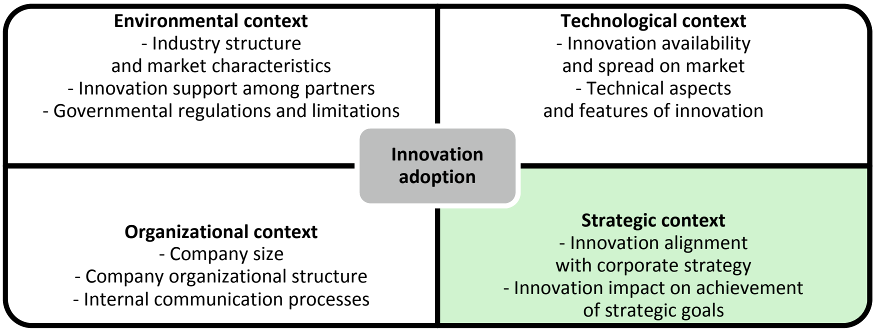

Fig. 1. A modified TOE innovation adoption model.

2.5 Procedure for Digital Innovation Assessment

The development of a procedure is one of the tools for formalizing the method of assessing innovations in the form of actions algorithm. In this work, the purpose of the procedure is to provide a comprehensive assessment of innovations for their further ranking.

Based on the recommendations for drawing up procedures for surveying the innovation activity of enterprises in the document "Oslo Guide" [12], three key stages of the procedure have been highlighted.

Stage 1 "Initiation and planning of innovation assessment activities". Preparatory work, for example, on the selection of innovative IT projects, drawing up plans and schedules, appointing the participants, responsible persons and executors, are an integral part of the effective procedure execution. It also allows to reduce the organizational risks of work in the next stages.

Stage 2 "Conduct data collection activities to assess innovative projects". At this stage, the core works of the procedure are carried out, based on the modified TOE model of the innovation adoption. These works include preparing a framework for project evaluation (selection of criteria, formation of an evaluation tool), evaluation itself and collection of data for further analysis of the results.

Stage 3 "Analysis of the results of the assessment of innovations". The final processing of the data obtained and the ranking of projects is the final stage within which the goal is achieved - obtaining a rating list of innovative projects based on their comprehensive assessment.

3 Results

Among key results of this study, a detailed procedure for innovation project evaluation is presented on Fig. 2. Its key steps are described further.

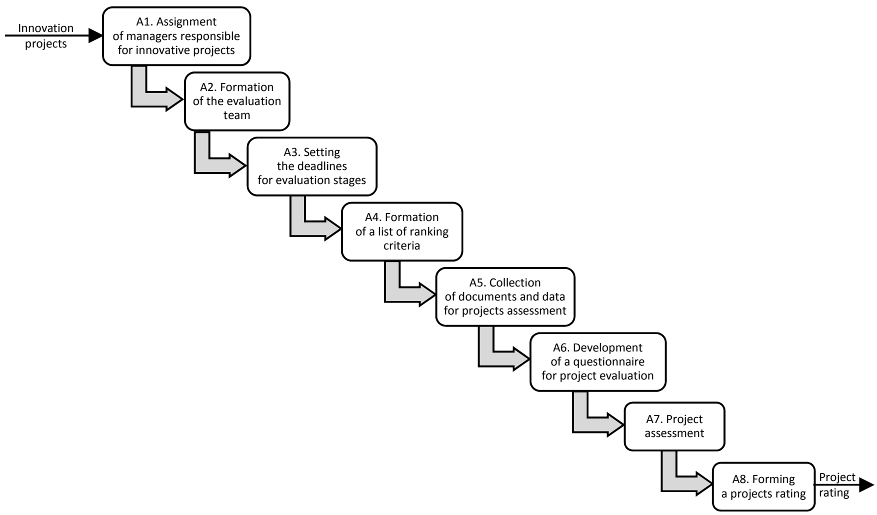

Fig. 2. A detailed procedure for innovation project assessment.

A1. Assignment of managers responsible for innovative projects. For each project that will participate in the ranking, a responsible project manager is assigned, who must take part in the ranking of projects, providing all the necessary information about the project, for example, a project passport, its content, a list of resources that will be required for its implementation, projected results, etc. In the process of preparing information, the project manager can contact other employees.

A2. Formation of the evaluation team. According to international practice, the team of assessors includes individuals whose expertise and experience will allow an adequate assessment of projects based on contextual criteria. Depending on the level of a team member, their assessment may be assigned more or less weight. The heads of departments, whose employees have sufficient expertise, experience and understanding of the company's characteristics, appoint the team of assessors.

A3. Setting the deadlines for evaluation stages. The assessment team forms an action plan for ranking projects, set deadlines, the format of communication with project managers. Changing the composition of the stages and their timing is undesirable; however, it takes place in some cases.

A4. Formation of a list of ranking criteria. The assessment team concretizes the criteria based on the modified innovation adoption model. They decompose each context (technological, environmental, organizational, and strategic) to specific indicators. For decomposing a set of models, tools and frameworks that allow identifying problem areas that require improvement can be used as well as internal policies and documents.

A5. Collection of documents and data for projects assessment. Assigned project managers prepare supporting documents. The content of the documents should provide information about the goals of the project, the resources required, the expected results, etc. In the process of preparing the documents, project managers may consult with other employees of the company. The format of the submitted documents should comply with the required templates.

A6. Development of a questionnaire for project evaluation. The team of assessors develops a questionnaire consisting of four blocks for each context of the innovation adoption model. Each block consists of statements about the impact of the results of the assessed project, the complexity of its implementation, etc., and assessment scales.

A7. Project assessment. After collecting projects documents from project managers, the assessment team evaluates them according to the criteria from step 4. Independently assessors give grades to the projects, and then a final project indicator is calculated.

A8. Forming a projects rating. Within this stage, a project rating is compiled according to the data from step 7. The results are distributed among stakeholders, so they can make a decision about project realization and prioritization.

The frequency of project ranking is determined by the company's management. It is assumed that at least once a year when setting goals for the next year and allocating project budgets, this procedure should be carried out. The frequency of the procedure may depend on:

- the emergence of new innovative projects;
- the changes in the company's business strategy;
- the changes in consumer market demand;
- the emergence of new innovations.

The members of assessment team are not fixed forever and may change with each new iteration, the team may include both other employees within the same positions as well as employees of other positions.

4 Discussion

It is clear that assessment of innovative projects is of highest interest today as it provide successful digitalization and adoption to modern economics realities. However, there is a clear lack of adequate approach for such evaluation as existing methods usually evaluate innovative project only from one perspective (financial, reputation, technological etc.).

For filling knowledge gaps, the features of digital innovations have been investigated in this study as well as a comparative analysis of methods for evaluating innovative projects has been carried out.

After that, a system of assessment indicators has been developed and a multi-criteria approach has been substantiated for an objective assessment of digital innovations projects. A ranking procedure and a graphical model for a comprehensive assessment of digital innovations have been provided for methodological support.

The prospect of this research lies in formalization of the choice of assessment tools and frameworks for each context of innovation adoption model as well as approbation of suggested model in a real company.

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Automation Marketing Strategy Choice in the Field of Internet Business Based on User Preferences

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Abstract. The article discusses the problems of automating support for choosing a marketing strategy based on user preferences. This problem arose due to a large amount of data about visitors, a variety of personalization methods and methods of developing marketing strategies. At the moment, there is a contradiction between the lack of automation and its need to increase conversion, reduce time and money costs when choosing a marketing strategy. The paper considers and compares the methods of choosing a marketing strategy and identifies patterns in user preferences, analyzes the principles of existing software analogues operation. Based on the analysis, methods and algorithms were developed to support the choice of a marketing strategy in the field of Internet business based on user preferences, an experiment was carried out on a ready-made data collection, and the software, system architecture and data architecture for a system that supports the choice of a marketing strategy were described; software implementation of the developed algorithms is being discussed. The result of the work can be used primarily by marketers and specialists in online advertising to reduce the time and money spent on advertising campaigns and increase conversion.

Keywords: Internet business · Marketing strategies · User preferences in Internet business

1 Introduction

Electronic business (Internet business) is a form of business in which all aspects of business relations, including sales, marketing, financial analysis, payments, employee search, customer and partner support, are transferred to the Internet [1, 2].

Today, the Internet is a universal business environment that connects organizations with each other and with the entire consumer audience. Any organization, regardless of its size and age, has access to e-business methods. In 2016, economic relations in the Internet sphere in the G20 countries reached a financial volume of $4,2 trillion. At the moment,

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the volume already reaches 5–9% of the total gross domestic product in developed markets, while in emerging markets the pace of Internet economy development is from 15 to 25% annually.

Many commercial organizations build sales on the Internet, for some this kind of network is considered as the main platform for doing business. Prudently selected marketing strategy will increase conversion, thereby increasing the profitabil ity of the enterprise.

The main problem can be divided into two components:

- The problem of identifying the relationship of user preferences with other data about users.

It is advisable to identify relationships using data mining software, since less time will be spent and the human factor would be eliminated. The source of the problem is the large volume of user data and its diversity [3].

- The problem of automating the choice marketing strategy

It is crucial to determine how features from a data collection influence the choice of a strategy, develop an algorithm to automate the choice of a marketing strategy. The ready-made software solution choice is not adjusted to work with features from a dataset.

The research topic is relevant, because solving the problem of automating support for choosing a marketing strategy based on user preferences will reduce the time and money spent on choosing marketing strategies and increase conversion.

The development of marketing strategies is necessary to ensure the effectiveness of ongoing marketing activities [4].

The main goals of a marketing strategy are usually the following:

- An increase in the sales volume (including an increase in customer flows or an increase in the number of orders);
- An increase in the profits volume;
- Increasing market share;
- Leadership in its segment.

The objectives of the marketing strategy are [5, 6]:

- A comprehensive study of the entire market;
- An objective assessment of demand and needs;
- Development of a marketing strategy and development of methods to implement it.

Any marketing strategy applicable to the Internet business is based on the use of appropriate marketing communications tools.

From a marketing point of view, communication is a collection of signals that come from an advertiser to different audiences. The combination of these tools constitutes a marketing strategy. The development of the Internet has created a variety of different tools, the functionality of which is to achieve marketing goals (promotion, increase sales, increase the loyalty of the target audience, form an image, etc.). Marketing communications tools can be: advertising, direct marketing, personal selling, communication with the audience and public relations.

Marketing information systems of marketing information systems (MIS) can be considered as indirect analogues. MIS provides the company with information support for modern marketing [7–9]. The main purpose is to accumulate data for analytical processing in order to make informed management decisions to improve the company's performance. However, it should be borne in mind that not every marketing information system is suitable for solving the problem: they are different in functionality. It is important to choose the one in which the ability to automate the marketing analysis of management is embedded, one should also build on the specifics of the goals set by the advertiser. The problem can be solved by using an expert decision support system in marketing [10, 11]. The experts are both marketers and consumers themselves. As part of the functioning of the system, the problem of forecasting demand is being solved. Such a marketing system is an integrated expert system that combines both the functionality of the expert system in the classical sense and the mechanism of simulation.

Also, the Yandex.Crypto technology should be considered as an analogue [12]. This technology gives advertisers the opportunity to display advertisements only to those for whom they are intended, for example, people of a certain age, income, habits, including preferences. Each user for the system is a specific set of identifiers. The crypt can assume that a user with a certain identifier might be interested in a certain offer. The technology works on the basis of the Matrixnet machine learning method [13], which is also developed at Yandex. The tools used, which are used in the Matrixnet method, are not publicly available, and one should only assume on the basis of which basic machine learning methods it works.

Choosing from the above options, it is assumed that the combination of the last two is more appropriate: they are more suitable for the specifics of the problem being solved, since the solution presented in the first has a somewhat general form. To solve this problem, it is necessary to design and develop a decision support system for choosing a marketing strategy based on assumptions about the concept and applied methods in Yandex.Crypto and Matrixnet technology, in particular.

2 Methods and Materials

As part of the work, data was processed from the "Web Visitor Interests" dataset. The data collection is a set of users' logs on the site https://www.jc-bingo.com/. The dataset includes the visitor's IP address, user agent (browser and device), user country and language, and preferences. An excerpt from the dataset is shown in Table 1.

User preferences are divided into 24 groups:

1. Communication with friends on social networks (company).
2. Online shopping (shop / online shopping website).
3. Visiting forums (forum).
4. Blogging (blog/personal homepage).
5. Using search engines (internet directory/search engine).

Table 1. "Web visitor interests" dataset.

IP	useragent	Country	Language	Interests
1.10.195.126	Mozilla/5.0 (WindowsNT 6.1; Win64; × 64)	TH	English	Other
1.1.217.211	Mozilla/5.0 (WindowsNT 10.0; Win64; × 64)	TH	Tai	Blog/personal homepage
1.121.135.213	Mozilla/5.0 (iPad; CPU OS 9_3_5 like Mac OS X)	AU	English	Company

6. Visiting automobile sites (automobile sites).
7. Visiting online editions (magazine).
8. Study of business directories.
9. Getting education online (education).
10. Installing files using torrent trackers (torrent tracker).
11. Study of materials about travel and hotels (hotel).
12. Study of materials about places of public catering (restaurant).
13. Study of materials about retail trade (retail).
14. Cooking (cooking).
15. Delivery services.
16. Entertainment and rest (entertainment).
17. Watching movies online (online cinema/movies online/cinema).
18. Art (art).
19. Sports (football / sport).
20. Listening to music and watching videos online (music/video).
21. Online games (gaming).
22. Affiliate marketing.
23. Pets (pets).
24. Other.

The solution is presented in the high-level programming language Python and the statistical programming language R and is a program code that processes data from a dataset (Appendix A and B).

The data is presented in the format of text values. To use certain data analysis tools, text values must be converted to scalar values. The solution to the problem is presented in Python (Appendix A). The data is encoded using the LabelEncoder () object. The meaning of the LabelEncoder () function is that a list of values is supplied to it, which must be encoded, and the output is a list of classes, the indices of which are the codes of the elements of the list supplied to the input.

After data re-encoding, the dataset is initially processed. The solution is presented in the statistical programming language R (Appendix B).

Functional:

(a) Preprocessing the dataset:

- Reading data from the original and recoded datasets and loading them into the dataframe;
- Determining the size of the original dataset (number of observations and features);
- Determination of missing data presence.

(b) Summary statistics for the dataset
(c) Percentages for the required parameters
(d) Diagrams for the required parameters Results:

- After defining the missing data, there were 16,716 features in the dataset.
- Most of the users are from the USA and India (4800 and 1200 respectively).
- The vast majority of users browse websites in English (12,205 views in English).
- Percentages:
  - 35.16% of users prefer chatting with friends;
  - 10.26% of users prefer to run a personal blog;
  - 8.64% of users prefer to visit forums;
  - 5.76% of users prefer to study training materials.

The relationship nature between variables is easier to identify by means of graphical tools appropriate to the situation. Therefore, when analyzing several quantitative variables, scatterplot matrices, or pair plots, are a very convenient tool.

The first stage was the one-way variance analysis. The calculation was performed using the Statistica software package for statistical data analysis. Working with the dataset required preparation: the values were presented verbally and were replaced by numbered groups. The results are presented in Tables 2, 3 and 4:

Table 2. Calculation of one-way ANOVA (based on data on countries and user interests)

Source of variation	SS	df	MS	F	P meaning	F critical
Between groups	225,650,1864	1	225,650,1864	122,8	1,687	3,841,692,196
Within groups	73,215,235,31	39,848	1837,362,862			
Total	73,440,885,49	39,849				

In fact, the P-value is the probability of error when the null hypothesis (type I errors) is rejected. In cases where the P-value is less than 0.05, Fisher's test is significant, and

Table 3. Calculation of one-way analysis of variance (based on data on the language and interests of users)

Source of variation	SS	df	MS	F	P meaning	F critical
Between groups	1,876,216,966	1	1,876,216,966	1204,18	1,68	3,841,692,196
Within groups	62,086,650,79	39,848	1558,087			
Total	63,962,867,76	39,849				

Table 4. Calculation of one-way analysis of variance (based on data about the agent and the interests of users)

Source of variation	SS	df	MS	F	P meaning	F critical
Between groups	8,449,733,403	1	8,449,733,403	10,633,55	1,68	3,841,692,196
Within groups	31,664,394,640	39,848	794,629,4579			
Total	40,114,128,043	39,849				

the factor influence under study can be considered proven. The fact that the factor effect in question turned out to be statistically significant is shown by highlight ing in red.

As stated in the previous chapter, the set of marketing communications tools constitutes a marketing strategy. For each user group (users are divided into groups by preferences). The set of marketing communications for each group can be determined by methods of expert assessment (individual assessments, collective assessments, vectors of preferences, etc.). An example of forming a set of marketing communications for each user group is shown in Fig. 1.

It should be taken into account that the set of marketing communications for each user group is determined by an expert (or a group of experts) and may vary. First of all, one needs to collect user logs from the site and process the data. Then one should apply the developed method based on Majority Voting. This method determines the belonging of each user to a certain group and predicts his interests with an accuracy of 97.14%. After that, the necessary strategy is applied to each user group, formed through a set of marketing communications.

3 Realization

This stage of system design contains additions to the database model and applications with diagrams of their placement on technical means.

The structural main components and their in terrelationships, namely:

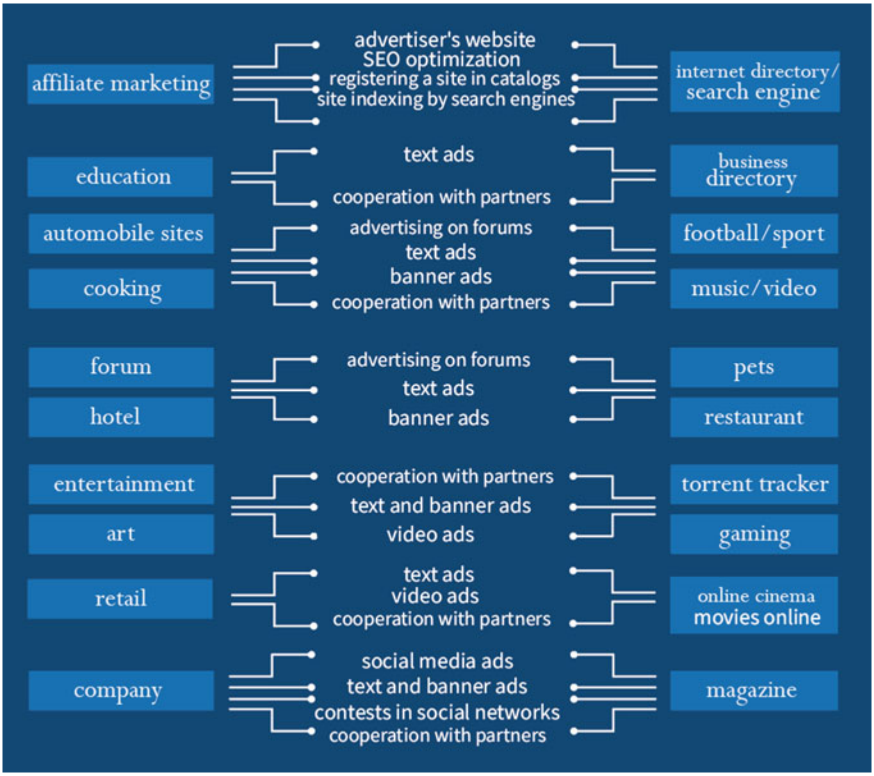

Fig. 1. Formation of a set of marketing communications.

- Database management system.
- Component for user management.
- Component Majority Voting with a subordinate component of data transcoding.
- Graphical interfaces.
- Dependencies between entities.

Deployment diagrams are used to describe the hardware configuration of in formation systems.

Deployment diagrams are used to model the physical distribution of various software, information, and hardware components of the system over a set of technical means. This diagram pays special attention to displaying which hardware components ("nodes"—database and application servers, web servers) and which software components ("artifacts"—databases, web applications) run on each of them and how parts of the complex are connected to each other.

This diagram shows the following major artifacts and their placement on hardware node components:

- Server and workstation.
- System components that were represented in the component diagram.

- "Help" document containing reference information.
- Relationships between nodes.

The use of a component diagram and a deployment diagram made it possible to describe the system architecture of the designed system that supports the choice of a marketing strategy based on user preferences.

4 Field of Application

The developed methods make it easier to choose a marketing strategy based on user preferences. The machine learning methods on which the developed method is based provide high accuracy. The software implementation of the developed methods is carried out.

The use of a system that supports the marketing strategy choice can significantly reduce the time and financial costs when choosing a marketing strategy and reduce the likelihood of an employee making mistakes.

5 Conclusions

At the present time, when the Internet and information technologies are used everywhere in all spheres of human activity, it is crucial to pay appropriate attention to the work processes automation in order to save the resources consumed.

The existing methods of choosing a marketing strategy are applied without using information about the target audience preferences. This is the fundamental difference between the methods developed in this article.

Thus, the result of the work can be used in enterprises by marketers and analysts of online advertising to increase conversion and other performance indicators.

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Optimal System for Controlling Paper Web Formation

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Abstract. This paper is devoted to creating an optimal paper web control system. The authors analyzed the requirements for modern automated control and regulation systems. The paper discusses the paper production stages and the required quality criteria on each of the stages. Issues related to the proof and use of the Pontryagin maximum principle in the theory of optimal control are considered. Pontryagin principle is used in the theory of optimal control to search for the best possible control to transfer the dynamic system from one state to another, especially if there are restrictions for state or input controls. The optimal system for controlling the weight of paper web, based on the Pontryagin principle for the minimum energy value, is presented. The result of the system using optimal control based on the Pontryagin maximum principle decays faster with less control. The application of the maximum principle allows you to achieve the optimal value.

Keywords: Optimal control · Pontryagin maximum principle · Automated process control systems · Forming a paper web

1 Introduction

The economic crisis has impacted most of the industrial enterprises. Its manifestations differ in detail, but the result is one—the actual deterioration of the financial and economic condition. The APCSs can achieve a number of goals directly related to reduced costs: an increase in the efficiency of equipment; achieving optimal indicators of loading technological objects; improving qualitative indicators of final products; saving production and energy resources, etc.

Investments in automation of technological processes makes it possible to obtain effective production control tools, thereby ensuring the achievement of optimal production indicators, the maximum economic efficiency of the enterprise, which is especially important during the crisis.

The functionality of automated control systems provides a totality and integrity of the system actions and directly affects economic indicators.

Modern APCS allows implementing innovative mechanisms and the principles of equipment control due to the greater productivity of modern hardware complexes and the use of new software algorithms [1–3].

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In the context of the crisis, the modernization of APCS becomes an urgent need because it is one of the main tools for reducing production costs. Modernization or introduction of modern automated process control systems guarantees achieving the following goals: improving the accuracy of the equipment; increasing the quality of the technological process; optimization of production cycles to obtain products with specified qualitative indicators; significant expansion of the circle of performed tasks at all levels of production in the online mode; reducing the influence of the human factor and staff errors.

Investments in automation of technological processes makes it possible to obtain effective production control tools, thereby ensuring the achievement of optimal production indicators, the maximum economic efficiency of the enterprise, which is especially important during the crisis.

Industrial automation, creation and modernization of integrated and autonomous control systems with technological lines, equipment and engineering networks at enterprises of various industries.

Automated process control systems (APCS) are a comprehensive solution to the tasks of monitoring and controlling technical processing and equipment, which is located at the production site, in the workshop, enterprise, or individual technical devices that require special attention.

Automatic systems are used in many areas of human activity—in industry, in transport, in communication devices. The use of automation in control often defines the further development of technology [4–6].

In various technological processes, the magnitude characterizing their work should meet certain requirements, for example, to control the movement of aircraft, i.e. the device should move on a predetermined trajectory, with a given speed and accuracy.

2 Paper Production

The intensive development of the printing industry, copying machines and other paper consumers sets the tasks of improving the quality of paper products. The quality of the paper is determined by a number of mechanical and printed properties, depending on its type and variety. However, regardless of the function of paper, there are quality indicators that affect most of its consumer properties. The non-uniformity of the profile of such quality indicators as the mass of 1 m^2, ash content, humidity and thickness of the paper increases the number of defects and breaks of the paper web, and an excessive high value of mass of 1 m^2 leads to the overflow of fibers, fillers and energy resources.

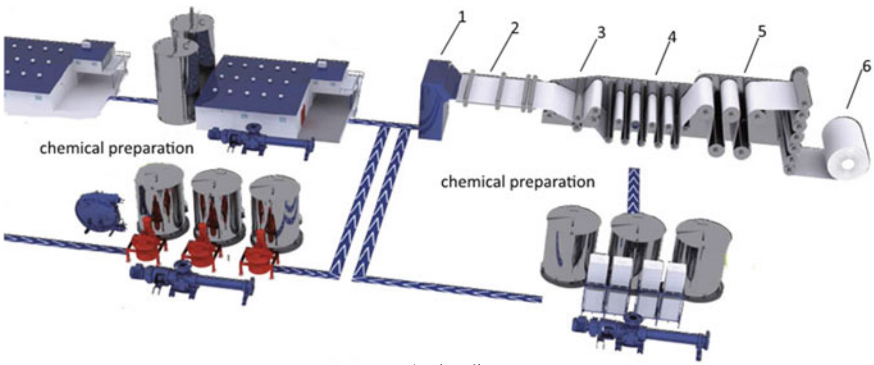
At the same time, during production, there is a tendency to increase the performance of paper machines, which is inextricably linked to the improvement of the system for controlling paper web formation. Increasing the speed of the machine over 20 m/s with a trimmed machine width of more than 8 m is not possible without accurately coordinated control of this process [7].

The functioning of the pulp and paper industry, as well as other sectors of the economy, is influenced by many factors. In a market economy, the question of the rational use of raw materials by enterprises of this industry is most acute.

The pulp and paper industry is the most difficult industry of the forest complex associated with machining and chemical processing of wood. It includes production of cellulose, paper, cardboard, and products from them.

2.1 Construction of the Paper Machine

The functional scheme of the paper machine is presented in Fig. 1. The paper machine consists of a grid, press, drying, finishing parts and drive. In addition, it includes a paper-machine feed vat for accumulating paper mass and feeding it to the machine, equipment for refining, grinding and purification of mass, water supply pumps, vacuum pumps, devices for recycling defected paper, pulp/water storage, water-exhaust ventilation system, regulating and measuring instruments [8].



1 – headbox
2 – mesh part
3 – pressing part
4 – drying part
5 – calender
6 – reel

Fig. 1. Functional diagram of a paper-making machine.

Pre-purified paper mass enters the paper machine—a complex aggregate of huge sizes (length—over 100 m, width—15 to 18 m). For one minute, the semi-finished product goes through all parts of the paper machine.

Grid part. Under pressure, this composition continuously enters the moving wire grid of the paper machine. Paper manufacturing technology is such that the fibers are located and intertwined along the grid movement, creating a machine direction, which will later play an important role when using the finished product. As the grid moves, the water gradually leaves, and the paper web is formed [9].

Press part. In the process of pressing, the web passes between several pairs of presses-shafts, compacting and loosing most of the moisture.

Drying part. In it, the base paper is dried using steam heated cylinders. But even after that, up to 8% of moisture remain in the web.

Calendar. The paper web pre-cold by drums passes calendaring—it is passed between heavy polished shafts—calendars to give it smoothness and strength. Calendared paper is rolled and cut into smaller rolls or unrolled and cut into sheets.

3 Optimal Control

Automated systems for controlling and regulating the density of paper web are intended to stabilize the specified modes of the process of paper manufacturing by controlling and regulating the technological parameters and making control impacts on the actuators.

Modern control systems have high requirements for speed and accuracy, which, in turn, is the engine of the development of the theory of optimal control. The increase in speed is achieved with the correct distribution of limited control resources. The construction of high-precision systems requires accounting in the synthesis of regulators of the mutual influence of individual parts of the system.

The regulator of an object with uncertain and changing parameters should be changed so that the performance and accuracy of the system remain unchanged.

There are many synthesis methods for optimal systems and methods for constructing an adaptive regulator operation algorithm. Methods can be presented as a statement for writing an algorithmic module. Algorithmic and software modules are included in the system of programs that implements the operation of the adaptive regulator.

3.1 Pontryagin Principle

Pontryagin principle is used in optimal control theory to search for the best possible control to transfer the dynamic system from one state to another, especially if there are restrictions for state or input controls [10–12]. It says that for any optimal control, along with the optimal state trajectory, it is necessary to solve the so-called Hamilton system, which is two-points, and the boundary value problem, plus the maximum state of the Hamiltonian [13, 14]. These required conditions become sufficient under certain conditions of convexity to the target function and the limit function [15].

Realization of the Pontryagin maximum principle for the minimally spent energy. Let's write a differential object equation:

$$0.1136\frac{d2y}{dt2} + 0.942\frac{dy}{dt} + y = 393x \tag{1}$$

Since only the first derivatives are used in the principle of a maximum formulated by Pontryagin, we introduce notation [16]:

$$y_1 = y, y_2 = \frac{dy}{dx}$$

Then Eq. (1) will take the form:

$$0.1136\frac{\mathrm{dy}^2}{\mathrm{dt}} + 0.942\mathrm{y}_2 + \mathrm{y}_1 = 393\mathrm{x} \tag{2}$$

The following can be expressed from (2)

$$\frac{d^2y}{dt^2} = \frac{dy^2}{dt}$$
$$\frac{dy^2}{dt^2} = \frac{1}{0.1136}\left(-0.942\frac{dy}{dt} - y + 393x\right)$$

Let's introduce auxiliary functions:

$$f_1 = y2; f_2 = \frac{1}{0.1136} * (-0.942y_2 - y_1 + 393x).$$

Then the optimal control will be implemented by the function:

$$H = \varphi_0 * 1 + \varphi_1 * f_1 + \varphi_2 * f_2.$$

The function φ_0 is determined by the selected optimization criterion: the minimum energy spent.

Criterion of optimality $J = (x^2 + u^2)/2$.

Then $f0 = \frac{1}{2} * (x^2 + u^2)$.

With the previous transformations we get

$$H = \varphi_0 * {}^{(x^2+u^2)}/_{2} + \varphi_1 * y_2 + \varphi_2 * {}^{1}/_{0.1136} * (-0.942y_2 - y_1 + 393x) \tag{3}$$

In order to find unknown functions φ_1 and φ_2, we use ratios:

$$\frac{d\varphi_0}{dt} = -\frac{\partial H}{\partial y_0} = 0,$$

$$\frac{d\varphi_1}{dt} = -\frac{\partial H}{\partial y_1} = 0 \text{ and } \frac{d\varphi_2}{dt} = -\frac{\partial H}{\partial y_2}.$$

Then we get

$$\frac{d\varphi_1}{dt} = \frac{\varphi_2}{0.1136}. \tag{4}$$

$$\frac{d\phi^2}{dt} = -\phi_1 + \phi_2 * \frac{0.942}{0.1136} \tag{5}$$

From (4) it is obvious that $\phi_1 = \frac{1}{0.1136} \int \phi_2 dt$. Substituting it into Eq. (5), we obtain the equation in the operator form:

$$p\phi_2(p) - p\varphi_2(p) * \frac{0.942}{0.1136} + \frac{1}{0.1136 * p} * \phi_2(p) = 0$$

We write a characteristic equation whose roots show that these are two inertial links.

$$p^2 - p\frac{0.942}{0.1136} + \frac{1}{0.1136} = 0.$$

During the schematic implementation, the structure is important, and the Simulink software is enough to implement these links:

$$\phi_1(p) = \frac{1}{0.1136} \frac{K^2}{p^2 - p\frac{0.942}{0.1136} + \frac{1}{0.1136}} * 1/p$$

It is only possible to implement ϕ_2, and ϕ_1 can be obtained by integrating output ϕ_2. Also, with the program implementation of functions f_1 and f_2, it is possible to use directly the result of differentiation of $\frac{dy}{dt}$ and $\frac{dy}{dt}$.

Optimal control in time.

$$H = -(x^2 + u^2)/2 + \varphi 1 * \frac{dy}{dt} + \varphi 2 * \frac{d^2y}{d^2t}.$$

This is the optimal energy regulator.

Implementation of Pontryagin's maximum principle in Simulink. Let's consider the application of the Pontryagin's principle in the paper web weight control system. Figure 2 shows a Simulink model of optimal paper web weight control.

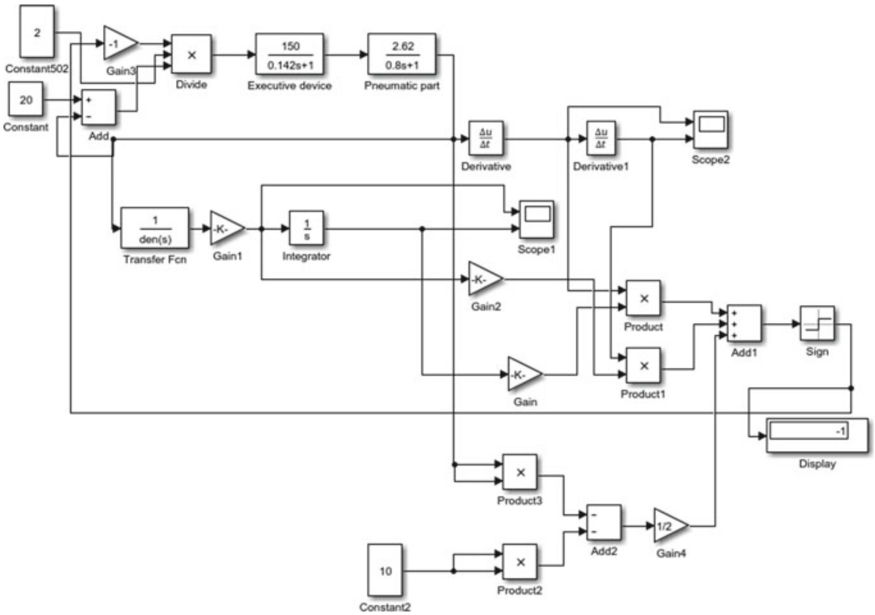


Fig. 2. Implementation of the Pontryagin's maximum principle in the paper web weight control system.

The results of modeling the optimal paper weight control system based on the Pontryagin's maximum principle are shown in Fig. 3.

The blue graph is the result of the system operation without optimal regulation. It can be seen that it has a large overcontrol. The red graph is the result of the system operation

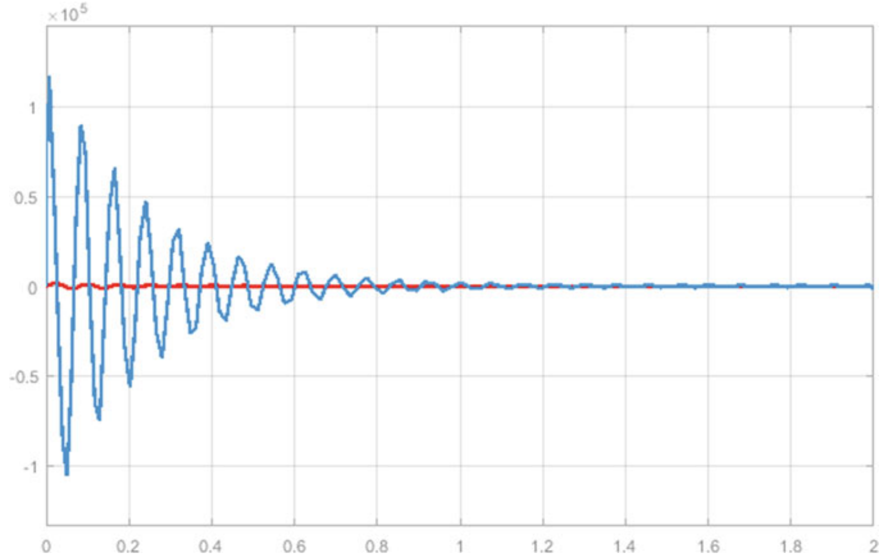


Fig. 3. Results of modeling the optimal paper weight control system based on the Pontryagin's maximum principle.

using the optimal control based on the Pontryagin's maximum principle. It can be seen from the figure that the process indicated in red decays faster with less overcontrol. Application of the maximum principle allows achieving the optimal value.

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Factor Model of Expert Opinions on Risks Assessment for Territorial Development

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Abstract. Based on the results of an expert survey, the article presents a factor model of the socio-economic challenges of rural areas in the views of heads and chief specialists of enterprises in the agrarian sector of the economy in the South of Russia. The expert survey was conducted in October–November 2020 using a questionnaire in Google Form and processed in SPSS Statistics (version 21). In the process of filling out the questionnaire, the experts assessed the significance in the list of 23 problems on a 5-point scale. The factor model makes it possible to comprehensively analyze the problem field of rural areas with the identification of possible latent factors of influence on their development. In the course of the study, 7 factors were established: a decrease in overall return (positive effects) from investments in agricultural production; financial insecurity of sustainable development of agricultural production; loss of agricultural products due to logistic inconsistencies; insufficient participation of the state in the regulation of agricultural production; limiting the development of the agricultural sector due to the specifics of production processes; human resources of the agricultural sector as a special area of responsibility of the state; lack of technologies for the production of agricultural products that do not destroy (do not worsen) the environment.

Keywords: Factor model · Risk assessment · Territorial development

1 Introduction

Rural areas and agricultural production play an important role in ensuring sustainable socio-economic development in Russia. Understanding the problem field makes it possible to correctly place accents in the strategic programs for the development of the country's territories. A theoretical analysis of the mention of the problems of rural areas and agricultural production in the last 10 years allows us to formulate a list—a catalog of socio-economic challenges of our time [1, 2]. An expert assessment of the problematic field of rural areas with the involvement of managers and chief specialists of agricultural

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enterprises in the South of Russia provides an opportunity to highlight the importance of these challenges for a specific region.

Thus, the purpose of the study can be formulated as to comprehensively analyze the problem field of rural areas with the definition of possible latent factors of influence on their development.

2 Methods

To carry out a factor analysis of the problematic field of rural areas in the South of Russia, an expert survey was conducted in October–November 2020 using a questionnaire in Google Form. The SPSS Statistics package (version 21) was used for statistical data processing. In the process of filling out the questionnaire, the experts assessed the significance of 23 problems on a 5-point scale. A total of 73 people were involved in the survey. Factor analysis was carried out by the method of separation of the main components with Varimax Rotation and Kaiser Normalization. We developed a factorial model of socio-economic challenges of rural areas in the South of Russia.

3 Results

The full explained variance for the category of experts from among the leaders and chief specialists of agricultural enterprises in the South of Russia is 83.0% and is determined by 7 components. Data are presented in Table 1.

The listed 23 socio-economic problems of rural areas of the South of Russia were grouped into 7 factors (the significance of each problem was assessed in the course of an expert survey, as a result of factor analysis performed by the Rotation Method: Varimax with Kaiser Normalization—Rotation converged in 11 iterations). Of interest is the generalized opinion of decision-makers who have a significant impact on the success of solving current problems and prospects for the socio-economic development of rural areas.

The listed 23 socio-economic problems of rural areas of the South of Russia in expert estimates (as a result of factor analysis performed by Rotation Method: Varimax with Kaiser Normalization (Rotation converged in 11 iterations) were grouped into 7 factors.

According to the content of the grouped problems, we can say that the first factor is determined by a set of variables: deterioration of the fertility of agricultural lands (load factor 0.868); limited sales channels (fload factor 0.763); inefficient use of energy resources (load factor 0.698); a high level of dependence on imports of seeds, feed, pedigree products, etc. (load factor 0.629); decreased resistance of crops to pests and diseases (load factor 0.615); low level of circulating and consistent use of water (load factor 0.580); agricultural losses due to climate change (load factor 0.553). Thus, the first factor can be interpreted as a decrease in overall return (positive effects) from investments in agricultural production (Table 2).

The second factor is determined by a set of variables: lack of funds to finance innovation (0.933); lack of funds to update the production material base (0.893); high debt load of agricultural enterprises (0.688); limited opportunities for access to borrowed financial

Table 1. Full explained variance of expert assessments of socio-economic problems of rural areas.

Component	Initial eigenvalues			Sums of squares of extraction loads			Sums of squares of rotational loads		
	Total	Discrepancy (%)	Cumulative %	Total	Discrepancy (%)	Cumulative (%)	Total	Discrepancy (%)	Cumulative (%)
1	6.493	28.229	28.229	6.493	28,229	28,229	3,726	16,202	16,202
2	3.636	15.810	44.040	3.636	15.810	44.040	3.702	16.094	32.295
3	2.408	10.469	54.509	2.408	10.469	54.509	3.133	13.623	45.918
4	2.092	9.093	63.603	2.092	9.093	63.603	2.519	10.952	56.870
5	1.727	7.507	71.110	1.727	7.507	71.110	2.123	9.231	66.101
6	1.371	5.960	77.070	1.371	5.960	77.070	1.947	8.464	74.565
7	1.367	5.943	83.012	1.367	5.943	83.012	1.943	8.447	83.012
8	0.946	4.114	87.127						
9	0.795	3.457	90.583						
10	0.553	2.405	92.988						
11	0.432	1.876	94.,865						
12	0.394	1.711	96.576						
13	0.264	1.147	97.723						
14	0.193	0.841	98.564						
15	0.112	0.486	99.051						
16	0.105	0.456	99.506						
17	0.053	0.228	99.735						
18	0.043	0.189	99.923						

(*continued*)

Table 1. (*continued*)

Component	Initial eigenvalues			Sums of squares of extraction loads			Sums of squares of rotational loads		
	Total	Discrepancy (%)	Cumulative %	Total	Discrepancy (%)	Cumulative (%)	Total	Discrepancy (%)	Cumulative (%)
19	0.018	0.077	100.000						
20	6.635E-17	2.885E-16	100.000						
21	−2.764E-16	−1.202E-15	100.000						
22	−5.294E-16	−2.302E-15	100.000						
23	−7.534E-16	−3.276E-15	100.000						

Table 2. The matrix of rotated components for experts from among the leaders and chief specialists of agricultural enterprises in the South of Russia.

Problem	Component						
	1	2	3	4	5	6	7
1. Lack of modern material base and technologies of agricultural production	0.241	0.519	−0.077	−0.086	−0.131	0.122	−0.715
2. Lack of funds to upgrade the production material base	0.107	0.893	0.091	0.165	0.082	0.205	−0.112
3. Lack of funds to finance innovation activities	0.175	0.933	0.144	−0.032	−0.069	0.155	0.144
4. Limited opportunities for access to borrowed financial resources	−0.199	0.490	0.402	−0.355	0.081	0.390	−0.052
5. High leverage of agricultural enterprises	−0.050	0.688	0.292	−0.214	0.293	−0.090	−0.261
6. Rising prices for goods and services	0.144	0.171	0.143	0.751	0.337	0.082	0.257
7. Lack of the required level of state support for agricultural enterprises	0.135	0.273	0.319	0.566	0.378	0.444	−0.223
8. Insufficient support of agricultural production from the authorities	−0.146	0.324	0.539	−0.104	0.071	0.574	−0.275
9. Limitations of logistics infrastructure	0.003	0.268	0.743	0.157	0.223	−0.085	−0.026
10. Limited sales channels	0.763	0.297	0.237	0.145	−0.196	0.294	0.119
11. High level of dependence on imports of seeds, feed, breeding products, etc	0.629	−0.280	0.175	−0.331	0.058	0.421	0.242
12. Losses of agricultural products in the process of their production, storage, processing and distribution	0.363	−0.094	0.750	0.062	0.087	0.315	0.108
13. Large amount of production waste	0.252	0.204	0.845	0.025	-0.115	0.019	0.143

(*continued*)

Table 2. (*continued*)

Problem	Component						
	1	2	3	4	5	6	7
14. Reducing the resistance of crops to pests and diseases	0.615	−0.141	0.036	0.494	0.288	−0.074	−0.374
15. Low level of recycled and consistent use of water	0.580	0.068	0.531	0.310	0.054	−0.056	0.058
16. Inefficient use of energy resources	0.698	0.558	0.198	−0.248	−0.104	−0.064	−0.058
17. Deterioration of fertility of agricultural lands	0.868	0.139	0.012	0.018	0.115	0.011	0.070
18. Non-core use of arable land and their neglect	0.051	0.233	−0.052	−0.868	0.121	−0.063	−0.063
19. Limited land resources for the development of agricultural production	0.064	0.309	−0.315	0.067	0.673	0.314	0.049
20. Deficit of young qualified personnel	0.186	0.157	−0.028	0.193	0.094	0.824	0.061
21. Seasonal employment of agricultural workers	0.004	−0.025	0.269	0.036	0.871	−0.017	0.238
22. Loss of agriculture due to climate change	0.553	−0.145	0.142	0.218	0.512	0.072	−0.070
23. Deterioration of the climate due to the influence of agricultural production	0.218	0.048	0.076	0.094	0.146	0.052	0.899

resources (0.490). Thus, the second factor can be interpreted as financial insecurity of sustainable development of agricultural production.

The third factor is determined by a set of variables: a large amount of production waste (0.845); losses of agricultural products in the process of their production, storage, processing and distribution (0.750); limitations of the logistics infrastructure (0.743). Thus, the third factor can be interpreted as the loss of agricultural products due to logistic inconsistencies.

The fourth factor is determined by a set of variables: non-core use of arable land and their neglect (-0.868); rise in prices for goods and services (0.751); lack of the required level of state support for agricultural enterprises (0.566). Thus, the fourth factor can be interpreted as insufficient participation of the state in the regulation of agricultural production.

The fifth factor is determined by a set of variables: seasonal employment of agricultural workers (0.871); limited land resources for the development of agricultural production (0.673). Thus, the fifth factor can be interpreted as limiting the development of the agricultural sector due to the specifics of production processes.

The sixth factor is determined by a set of variables: shortage of young qualified personnel (0.824); insufficient support of agricultural production from the authorities (0.574). Thus, the sixth factor can be interpreted as the personnel potential of the agricultural sector as a special area of responsibility of the state.

The seventh factor is determined by a set of variables: climate deterioration due to the influence of agricultural production (0.899); lack of modern material base and technologies of agricultural production (-0.715). Thus, the seventh factor can be interpreted as a lack of technologies for the production of agricultural products that do not destroy (do not worsen) the environment.

4 Discussion

The topic of research on the problem field of the agricultural industry and rural areas is relevant for countries with different levels of socio-economic development and is global, since it affects the issues of food security, territorial integrity, preservation of the population and traditional way of life, as well as a reasonable balance of rural and urban settlement.

Land ownership is a key issue in Leta et al. [3]. According to the authors, it is necessary to involve the farming community in the discussion of the conditions of ownership and use of agricultural land. Land law enforcement needs to focus on eliminating illegal land markets. This problem is relevant for many regions of the world. For example, Ukrainian researchers analyze the problems of agricultural land market formation in the context of environmental marketing [4].

Huynh et al. Hoang affect two important problem areas of agricultural production and rural areas—the struggle for soil conservation and the low involvement of the younger generation in agriculture [5]. In the conditions of a particular region, according to the authors, it is these two factors that significantly affect the stability of agricultural production as a whole.

The side effects of technological progress, which are also formed as a result of the operation of large livestock complexes, are considered in the study by Chew et al. [6]. The method of biomass waste processing proposed by the authors ensures the production of electricity in an environmentally friendly way. To formulate the problem field, our study identifies such socio-economic challenges as: the negative impact of agricultural production on the ecology of rural areas; problems of obtaining environmentally friendly electricity and energy saving.

Authors R. Wang, Q. Wang, L. Dong, J. Zhang speak in their study about the problem of wastewater from aquaculture, which is discharged directly into water bodies without any treatment, using the example of a number of territories in China [7]. They emphasize that large volumes of household waste and aquaculture waste are often piled up randomly, seriously polluting the surrounding groundwater and surface water and degrading water quality. Contamination of ground and surface waters is an urgent problem for Russia as well. The ecology of water resources and the need to assess the impact of agricultural production on their purity it is a significant research problem. Similar biophysical and environmental problems associated with irrigated agriculture are raised by the authors of a study conducted in Egypt [8], which once again emphasizes the topical nature of the study of the complex of socio-economic challenges of rural areas and agricultural production [9–12].

5 Conclusion

The results of the factor analysis [13] carried out using the empirical database of the expert survey make it possible to describe the key socio-economic challenges of the rural areas of the South of Russia using 7 models:

- a decrease in overall return (positive effects) from investments in agricultural production;
- financial insecurity of sustainable development of agricultural production;
- loss of agricultural products due to logistic inconsistency;
- insufficient participation of the state in the regulation of agricultural production;
- limiting the development of the agricultural sector due to the specifics of production processes;
- human resources of the agricultural sector as a special area of responsibility of the state;
- lack of technologies for the production of agricultural products that do not destroy (do not worsen) the environment.

Thus, the formulated key socio-economic challenges of the rural areas of the South of Russia show the possible vectors for the development of agricultural production and the region as a whole.

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Assessment of the Roadside Soil Pollution by Vehicles at the New Road Section

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Abstract. The paper presents the assessment of the roadside soil contamination level by aeropollutants at the new road section. The launch of the new road section is stated to reveal significant pollution level of the roadside area by harmful pollutants, in particular, by such heavy metals as Pb, Cu, Zn, Ni and metalloid As, due to the gas-air emissions from the passing-by vehicles along this area. Away from the road, heavy metals and arsenic content in the roadside area soil decreases. The accumulation indicator of heavy metals and arsenic in the roadside soil decreases in the series: Pb > Ni > Cu > As > Zn. 1 year operation of the new road section was found to increase the average indicators of hazard coefficients of lead and arsenic in the roadside soil up to 1.39 and 2.73, respectively, thus detecting significant content excess of the established threshold limit value standards. The content of such hazard metals as Zn and Cu in the studied soil almost reached the threshold limit value (TLV) established by the current hygiene standard. To prevent the current dangerous trend, it is necessary to organize sanitary and hygienic monitoring of the roadside soil, surface and ground water of the area, exposed to constant HM impact and accumulation, aimed at detecting TLV exceedings and taking preventive measures to protect these areas.

Keywords: Roadside soil · Aeropollutants · Heavy metals · Hazard coefficient · Threshold limit value · Sanitary and hygienic monitoring

1 Introduction

The most hazardous pollutants of the roadside areas are heavy metal (HM) compounds, which primarily enter the soil as a result of vehicle gas emissions. Heavy motor transport traffic causes active HM contamination of the roadside soil, frequently located in the areas of rural settlements and agricultural lands. As a result, it threatens local population and animals health, risks the grown plants by contamination [1–3].

In the Vladimir region, characterized by the extensive highway network, the lead concentration increase in the arable layer of agricultural soils was detected in comparison with the background value of the 13 administrative districts from the total 16. This circumstance is most likely associated with the anthropogenic nature of contamination, in particular, with air pollution from motor vehicles and stationary industrial enterprises [4–7].

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Most heavy metals are known to be characterized by low mobility and high storage capacity by the living organisms and depositing media [8–10]. The long-term HM impact on soil microbiocenosis, resulted in the suppression of biochemical processes occurring in them, and consequently the ecological state of these areas is worsening.

Thus, the roadside areas monitoring aimed at assessing the pollution level are very relevant.

Nowadays the new road sections of various administrative significance, are being constructed in Russia in compliance with the national project "Safe and High-Quality Highways". In this regard, it is possible to study HM accumulation dynamics and to assess their danger, to monitor the ecological state of the roadside areas, so to say "from nothing".

The research objective is to assess the roadside soil contamination level with heavy metals and arsenic at the new section of the reconstructed highway.

2 Objects and Research Methods

The research object is the roadside soil rea at the new section of the regional highway "Vladimir-Murom-Arzamas" (P72). The registration number in the Vladimir region is 17P-1.

Prior to the new construction, this highway was passing through Baraki village in the Sudogoda district of the Vladimir region. Since early 2000th, when transport bypass of the city of Murom was commissioned, the traffic flow of the passing transit vehicles through Baraki village has abruptly increased (up to 15 thousand vehicles per day). Thus, in November 2019, as part of the Vladimir—Murom—Arzamas highway reconstruction, the transport bypass of Baraki village about 10 km long was launched. It is worth noting that construction began in 2016, and the section of the reconstructed highway received the expressway status (category 1-B). There are no residential and industrial buildings, no gas stations and no large industrial enterprises nearby, and the nearest settlement—Baraki village is 2.5 km away. Therefore, the contamination level monitoring of the roadside area with HM and arsenic at this highway section, caused exclusively by gas-air emissions from the transit vehicles, allows forecasting the potential environmental hazard of the aeropollutant impact on the state of the soil cover in this area.

This study was initiated when the new highway section was launched in November 2019. The study lasted 1 year. During this period, three soil sampling trips were taken (November 2019, April 2020 and November 2020).

The road section scheme and reference sampling sites are shown in Fig. 1. The soil was sampled at the distance of 25 and 50 m away from the road from 0 to 10 cm horizon by the envelope method in three repetitions.

The soil in the studied area is characterized as sod-podzolic sandy loam with the physical clay content (<0.01 mm) $-$ 10 to 20% and humus -1.89%, the soil pH is in the range of 5.1–6.0 units, which characterizes its slight acidity.

The sandy loam soils are known to be the least resistant to heavy metal contamination due to their low buffer capacity, determined primarily by the granulometric composition and acid–base properties of this lithogeochemical soil group.

Fig. 1. Reference soil sampling sites.

HM and arsenic content (C_i) was determined by X-ray fluorescence method using spectrometer "SPECTROSCAN MAX-G" in compliance with PND F 16.1.42-04.

To assess the soil contamination level with heavy metals and arsenic, the accumulation index (A_i) and the hazard ratio (K_o) were used.

The accumulation index (A_i) of HM and arsenic was calculated using the formula:

$$A_i = \frac{C_i - C_b}{C_b}; \tag{1}$$

where C_i is HM and arsenic concentration in soil mg/kg,

C_b is background content of HM and arsenic in soil mg/kg.

Background concentrations of HM and arsenic in soil are taken from the Letter of Natural Resources Ministry of the Russian Federation dated 27.12.1993 N 04-25/61-5678.

The hazard ratio of HM and arsenic was calculated by the formula:

$$K_o = \frac{C_i}{\mathrm{MP}C_i}; \tag{2}$$

where C_i is concentration of metal and arsenic in soil mg/kg;

MPC_i is maximum permissible concentration of HM and arsenic in soil, mg/kg.

The threshold limit concentration values of HM and arsenic in the soil (MPC_i) are taken from GN 2.1.7.020-94.

Statistical data was processed in "Statistica" software.

3 Results and Discussion

Soil samples have been studied regarding the following chemical elements: As, Cu, Ni, Pb, Zn. The elements content was detected to increase in the following series: As → Ni → Pb → Cu → Zn.

The soil contamination dynamics with heavy metals and arsenic at the roadside area of the new highway section during 1 year operation is presented in Table 1.

Table 1. Soil contamination dynamics with heavy metals and arsenic at the roadside area of the new highway section during 1 year.

Sampling points	Content of TM and arsenic, mg/kg						
	Sampling season	Distance from the highway, m	Pb	As	Zn	Cu	Ni
1	November, 2019	25	36.6	4.8	48.2	37.2	16.5
		50	31.3	2.6	37.4	23.8	14.2
	April, 2020	25	38.4	5.9	57.1	48.3	24.1
		50	33.2	4.0	46.2	36.7	20.0
	November, 2020	25	44.5	7.8	64.1	61.8	58.2
		50	39.4	4.1	48.7	59.3	51.6
2	November, 2019	25	34.2	3.6	36.5	32.9	15.3
		50	31.8	3.1	33.4	21.7	13.1
	April, 2020	25	43.1	7.0	56.8	57.3	27.7
		50	37.5	6.1	39.4	31.9	23.6
	November, 2020	25	58.2	7.3	73.9	59.3	52.8
		50	50.6	6.6	68.3	42.1	41.6
3	November, 2019	25	38.7	4.5	40.1	32.4	14.3
		50	32.4	3.1	36.7	18.9	11.2
	April, 2020	25	40.7	7.8	48.8	51.1	27.8
		50	36.6	3.5	40.2	37.4	25.4
	November, 2020	25	55.8	8.5	81.2	61.9	42.2
		50	44.1	5.7	68.7	48.4	35.8
Background values, mg/kg			6	1.5	28	8	6
MPC, mg/kg			32	2	55	33	20

In compliance with GOST 17.4.1.02-83, establishing the classification of anthropogenic chemicals according to the hazard degree, the detected Pb, Zn and As refer to highly hazardous chemical elements, and Cu, and Ni refer to moderately hazardous [11–14]. Table 1 shows that more away from the road, the content of heavy metals and arsenic in the roadside soil decreases.

To identify the priority pollutants of the roadside soil, accumulation indicator (Ai) was used (Table 2).

Table 2. Accumulation indicator (*Ai*) of HM and arsenic (%) in the roadside soil at the new highway section.

Sampling season	Accumulation indicator (*Ai*) of HM and arsenic, %						
	Sampling points	Distance from the highway, m	Pb	As	Zn	Cu	Ni
November, 2019	1	25	5.1	2.2	0.72	3.65	1.75
		50	4.22	0.73	0.34	1.98	1.37
	2	25	4.70	1.40	0.30	3.11	1.55
		50	4.30	1.07	0.19	1.71	1.18
	3	25	5.45	2.00	0.43	3.05	1.38
		50	4.40	1.07	0.31	1.36	0.87
Σav *Ai*		25	5.08	1.87	0.49	3.27	1.56
		50	4.31	0.96	0.28	1.68	1.14
April, 2020	1	25	5.40	2.93	1.04	5.04	3.02
		50	4.53	1.67	0.65	3.59	2.33
	2	25	6.18	3.67	1.03	6.16	3.62
		50	5.25	3.07	0.41	2.99	2.93
	3	25	5.78	4.20	0.74	5.39	3.63
		50	5.10	1.33	0.44	3.68	3.23
Σav *Ai*		25	5.79	3.60	0.94	5.53	3.42
		50	4.96	2.02	0.50	3.42	2.83
November, 2020	1	25	6.42	4.20	1.29	6.73	8.70
		50	5.57	1.73	0.74	6.41	7.60
	2	25	8.70	3.87	1.64	6.41	7.80
		50	7.43	3.40	1.44	4.26	5.93
	3	25	8.30	4.67	1.90	6.74	6.03
		50	6.35	2.80	1.45	5.05	4.97
Σav *Ai*		25	7.81	4.24	1.61	6.63	7.51
		50	6.45	2.64	1.21	5.24	6.17

The table analysis reveals that during the observation period the accumulation of all HM and arsenic in the roadside soil occurred. The accumulation indicator of HM and arsenic in the roadside area soil decreases in the series: Pb > Ni > Cu > As > Zn.

The table proves that Pb has the highest accumulation rate in the roadside soil. It means that Pb is a priority pollutant of air-gas emissions from motor vehicles. But it cannot be unequivocally asserted that it is the most hazardous pollutant for the roadside soil, since Pb in soil is able to form strong compounds with organic ligands, complexes that become much less harmful for the living organisms than metal ions. Zn occupies the last place in this series in terms of accumulation, but its 1 year accumulation reached almost background values. Anthropogenic Zn in sandy loam soils is largely fixed with the help of iron hydroxides, phosphates, and is a part of phyllosilicates [7, 8]. Zn migration in this form is difficult, it is sedentary, it's not removed by plants or washing waters, so it accumulates in soil.

The remaining HM can be noted to increase dynamically their accumulation indicators during the year, depending on the specifics of sod-podzolic sandy loam soil, which is characterized by slightly acidic soil solution media, low buffering and sorption capacity (low content of silty particles and humus, iron hydroxides and manganese oxides) and, as a result, low self-cleaning ability.

To assess the contamination level of the roadside soil cover by individual pollutants, each hazard coefficient (K_o) was calculated (Table 3).

Table 3 shows that average Ko values in the studied roadside soil for lead and arsenic by the end of the year amount 1.39 and 2.73, respectively, thus proving their significant excess of the established standards for threshold limit values regarding these pollutants. Zn and Cu content in the soil by the end of one operation year of the new highway section of the almost reached TLV concentration. The soil pollution level below TLV and UEC standards in our environmental legislation should be noted not to be fixed and does not entail liability, but on the other hand, in the next 2–3 years, the TLV for these metals can be significantly exceeded, thus taking into account the pollution rate of these soils, will ultimately really dander the environment.

4 Conclusions

The research discovered that the new section roadside area of the reconstructed highway is contaminated with such heavy metals as Pb, Cu, Zn, Ni and As metalloid resulting from the gas-air emissions exposure of the passing vehicles.

Away from the road, heavy metals and arsenic content in the soil of the roadside area is decreasing.

The accumulation indicator of HM and arsenic in the roadside area soil decreases in the series: Pb > Ni > Cu > As > Zn.

By the end of 1 operation year of the new section at the reconstructed highway, the threshold limit value for lead and arsenic was found to exceed, and Zn and Cu content in the roadside soil was almost reaching threshold limit values.

It is required to organize sanitary and hygienic monitoring of soil, surface and ground water at the roadside areas exposed to constant HM impact and accumulation, in order to detect TLV excess for these HM.

It is vital to take measures to protect roadside areas by introducing restrictions concerning old vehicles, systematically switching vehicles to the gas-powered fuel and Euro-5 standard fuel, increasing the flow of electric and hybrid vehicles.

Table 3. Hazard coefficient (K_o) of HM and arsenic in the roadside soil of the new highway section.

Sampling season	Hazard coefficient (K_o) of HM and arsenic, %						
	Sampling points	Distance from the highway, m	Pb	As	Zn	Cu	Ni
November, 2019	1	25	1.14	2.4	0.65	0.67	0.19
		50	0.97	1.3	0.50	0.52	0.17
	2	25	1.06	1.8	0.49	0.59	0.18
		50	0.99	1.55	0.45	0.39	0.15
	3	25	1.2	2.25	0.54	0.58	0.17
		50	1.01	1.55	0.49	0.34	0.13
The average value of the *Ko* for the 3 selection points		25	1.13	2.15	0.56	0.61	0.18
		50	0.99	1.46	0.48	0.41	0.15
April, 2020	1	25	1.2	2.95	0.77	0.87	0.28
		50	1.03	2.0	0.62	0.66	0.23
	2	25	1.34	3.5	0.76	1.04	0.32
		50	1.17	3.05	0.53	0.71	0.28
	3	25	1.27	3.9	0.65	0.88	0.33
		50	1.14	1.75	0.54	0.73	0.30
The average value of the K_o for the 3 selection points		25	1.27	3.45	0.72	0.93	0.31
		50	1.11	2.26	0.56	0.70	0.27
November, 2020	1	25	1.39	3.9	0.87	1.12	0.68
		50	1.23	2.05	0.65	1.07	0.60
	2	25	1.81	3.65	0.99	1.08	0.62
		50	1.58	3.3	0.92	0.76	0.49
	3	25	1.74	4.25	1.09	1.12	0.49
		50	1.37	2.85	0.92	0.88	0.42
The average value of the K_o for the 3 selection points		25	1.64	3.93	0.98	1.10	0.59
		50	1.39	2.73	0.83	0.90	0.50

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Factors Influenced on the Connection Density in the Innovation Diffusion Process

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Abstract. In this paper, the authors touch upon a rather topical issue of the diffusion of innovations. The success of the innovation process and innovation activity depends on the speed and intensity of the diffusion of innovations. The authors considered the factors influencing the diffusion of innovations and the dissemination of information among the subjects (buyers, consumers, individuals, enterprises), namely the impact on the density of connections between the subjects of innovative activity. With their help, it is possible to manage the process of diffusion of innovations in a specific market and in a certain period of time. It is proved that the diffusion of innovations has certain distribution laws and can be modeled. The authors have considered and shown the possibility of modeling the process of diffusion of innovations using the diffusion equation, which is well known from mathematical physics (also known as the heat conduction equation). The paper proposes the diffusion of innovations in a certain spatially limited area, for example, within a separate state or their aggregate, region, city, and so on. The solution to this problem is of interest for further study of the development and modeling of innovative processes, and this will be reflected in the subsequent works of the authors.

Keywords: Innovation · Diffusion · Density of connections · Factors · Modeling · Innovation process · Logistic curve

1 Introduction

Recently, considerable interest and attention of the scientific community has been focused on the theory of innovation diffusion. Scientists in the field of mathematics, economics, innovative technologies, sociology and economics, in the field of mass communications, anthropology and even psychology are interested in this problem [1–15].

In a number of works [1–10], it was concluded, mainly on the basis of empirical data, that the diffusion of innovations is best described by a logistic function, the graph of which is an S-shaped nonlinear curve shown in Fig. 1.

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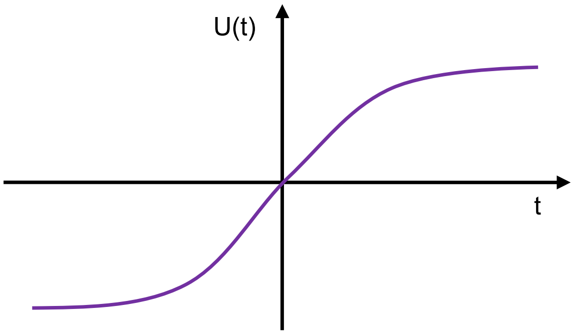

Fig. 1. The logistic function graph.

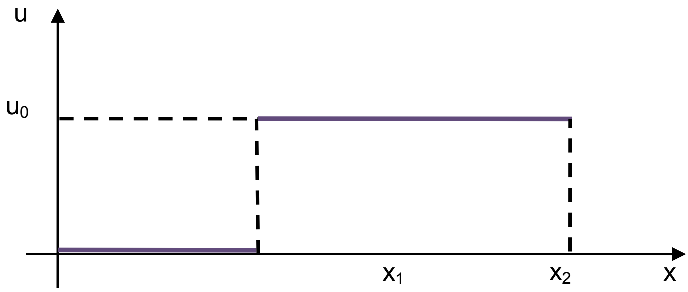

Fig. 2. Initial distribution of innovative temperature.

The forces of positive feedback act first, thereby increasing the rate of diffusion of innovation. When the diffusion rate reaches a certain critical value, negative feedback is automatically activated, which causes a slowdown in the diffusion rate, which leads to the saturation of the innovation process. The non-linear nature of the innovation process means that each diffusion trajectory reaches a saturation level within a finite period of time representing the innovation life cycle.

According to the theory of diffusion of innovations, any innovation (for example, a new idea, technique, technology) diffuses, i.e. spreads in society according to the most predictable pattern [1–17].

Diffusion (diffusion) of innovation corresponds to the phase when innovations in technology or products have already been developed by some or used by early innovators, and the firm or the administration is considering their adoption.

Depending on the direction of diffusion, innovations can be embodied in the form of external innovations (created and sold services, technologies, etc.) or in the form of internal innovations.

According to the authors, the best applicability for describing the process of diffusion of innovations, namely the so-called logistic curve, raises certain doubts. It is fair to pose the question: what are the grounds (purely mathematical, empirical, statistical) for choosing for this “privileged” role only one of the many known S-shaped curves, united by a common feature—the asymptotic tendency to ± 1 at $\pm\infty$?

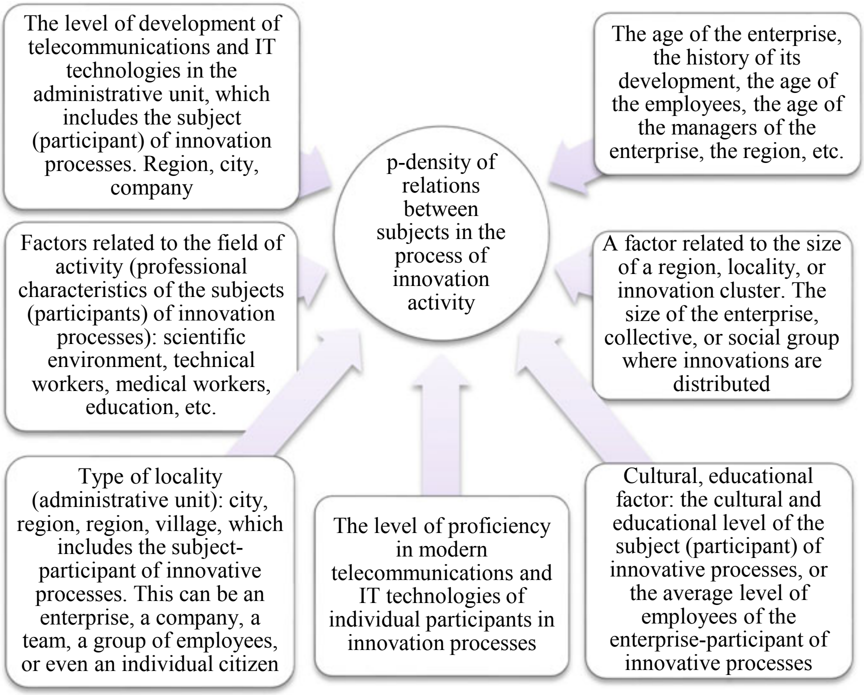

Fig. 3. Factors affecting the density of connections between the participants in the process of diffusion of innovations.

Therefore, it would be more fair to choose to describe the process of diffusion of innovations some other S-shaped curve with the above properties, for example, the well-known function erfz or the probability integral?

In the work of the authors [16], it is shown that it is the function erfz that adequately describes the process of diffusion of innovations within the framework of a mathematical model compiled by the authors using the well-known classical diffusion equation (or the heat conduction equation).

2 Materials and Methods

Thus, in [16], the possibility of modeling the process of diffusion of innovations using the diffusion equation, well-known from mathematical physics, is considered and shown (it is also the equation of heat conduction).

It should be noted that:

- In the work of the authors [16], the so-called one-dimensional case is considered, which corresponds to the diffusion (diffusion) of innovations in time and spatial space along one spatial coordinate x. In this case, a region in x was considered, which is not bounded either from the left or from the right (the so-called infinite rod).

- Equation solution $\frac{\partial u}{\partial t} = a^2 \frac{\partial^2 u}{\partial x^2}$ was sought for only one of many possible initial temperature distributions (innovative), namely for the following (Fig. 2):

$$u_{(x,t)}|_{t=0} = f(x) = \begin{cases} u_0, \text{ for } x_1 < x < x_2 \\ 0, \text{ for } x < x_1 \text{ or } x > x_2 \end{cases} \quad (1)$$

Therefore, it is very relevant and appropriate:

- Consider the case of a region bounded by x on one or both sides. The latter would correspond to the spread of innovations in some spatially limited area, for example, within an individual state or their aggregate, region, city, and so on.
- Consider the solution to the equation $\frac{\partial u}{\partial t} = a^2 \cdot \frac{\partial u}{\partial x^2}$ for some other initial temperature distributions (innovative).
- These issues will be considered below in this work of the authors, and will also be developed in their subsequent works.

3 Results

In addition to the above, we also note that in the work of the authors [16], when solving the equation describing the diffusion of innovations (the equation of diffusion or heat conduction), by analogy with those included in the classical equation of heat conduction:

U(M, t)	Temperature,
K	Coefficient of internal thermal conductivity,
ρ	Density of matter,
γ	Heat capacity of a substance is also introduced (in accordance with the closest physical analogy) such new concepts and coefficients as:
U = U(M, t)	innovative temperature—the level of innovation that changes in time and space is a certain quantitative indicator of the level of innovation activity,
K	Transfer rate of innovation K = K(ρ) (This is an analogue of the coefficient of internal thermal conductivity in the thermal conductivity equation),
γ	Coefficient of innovative susceptibility or innovative capacity (analogous to the heat capacity of a substance),
ρ	Density of connections between subjects in the process of innovation (Analogue of the density of matter).

It is from the density of connections between the subjects that the rate of diffusion of innovations is determined.

Along with a fairly natural and intuitive analogy between the well-known physical terms and the terms introduced by the authors, a more detailed consideration and explanation is needed, in particular, an indication of the totality of real, "life" economic and social factors and parameters x_i, y_i, on which, in turn, the introduced coefficients depend $k = k(x_1, \ldots, x_n)$, $\rho = \rho(y_1, \ldots, y_m)$, $\gamma = \gamma(z_1, \ldots, z_k)$.

This will be done below in this work in the form of the corresponding block diagrams.

At the same time, further, when drawing up the corresponding block diagrams, we will understand that individual citizens, large and small groups and communities, large and small enterprises and corporations, individual populated areas can act as subjects participating in innovation activities, innovation processes and processes of diffusion of innovation, points, territories and regions, and so on.

The territorial position and relations between the centers of social life, which are now megacities and regions, play a significant influence on the adoption and diffusion of innovations.

This is taken into account by the most active Asian countries in the innovation sphere, for example, China and the Republic of Korea.

However, we will not consider each time our separate scheme of interaction and dependencies k, γ, ρ on influencing factors for each level of "size" of the subject, but we will consider a single scheme.

Realizing, of course, that the main interaction takes place between subjects of exactly the same level. That is, the transfer of innovations rather comes from a citizen to a citizen, from an enterprise to an enterprise, a region to a region, and not from a citizen to a region, although this is possible.

The diffusion (diffusion) of innovations among subjects (buyers, consumers, individuals, enterprises), namely, the density of connections between the subjects of innovation, is influenced by the following factors:

1. The level of development of telecommunications and IT-technologies of an enterprise, city or region.
2. Field of activity (professional characteristics of participants in innovative processes): science, medicine, education.
3. Standard size of the information transfer area: settlement (city, village), team, group of employees.
4. Availability and timeliness of information.
5. The level of proficiency in modern telecommunications and IT-technologies of participants in innovation processes.
6. Cultural and educational factor: the cultural and educational level of the subject (participant) of the innovation process, or the average level of employees of the enterprise participating in the innovation process.
7. Size (coarseness): the size of the region, settlement, innovation cluster, as well as the size of the enterprise, team, and social group in which innovations are disseminated.
8. Age factor: the age of the enterprise, its history, the age of employees, managers, the time of foundation of the city, region.
9. Territorial factor—economic, informational and social superiority of megalopolises and regional development, which depends on the state's innovation policy.

The main provisions of the theory of modeling innovative processes and the development of diffusion of innovations in terms of economic and social geography can be summarized as follows:

- Territorial diffusion of innovations has certain distribution laws and can be modelled;
- Diffusion of innovations is a decisive factor in determining the social effect (primarily migration) for the centre-peripheral (relations between regions and centre) relations;
- The speed of diffusion does not depend on the geometric distance, but on the translational ability (speed and quality of information transfer) of individual cities through which it is carried out, on how intensive and effective contacts between people in these settlements are.

It can be argued that both γ, and especially k (which both in the classical physical case (as the coefficient of internal thermal conductivity) and in our case (as the coefficient of innovation transfer) is a function of $\rho : k = k(\rho)$ depend either directly on the factors listed above in the block diagram, or on those similar to the above.

The identification of these and other factors influencing ρ, γ, k (ρ) should be not only theoretical, but also applied—experimental, be a generalization of new and existing sociological research.

The authors are actively working in this direction at present. The expansion of the quality of the factors on which ρ, γ and k depend, as well as the clarification of the role of the already known ones, will be developed in subsequent works of the authors.

Now, having established some features of the dependence of the coefficients ρ, γ, k on real social, economic and, in general, "life" factors, let us return to the purely mathematical issues raised above under points (A) and (B) of this work.

Namely, we will consider the solution of the equation describing the diffusion of innovations (which coincides in form and natural meaning of the main coefficients with the classical equation of diffusion (heat conduction)) for some other special cases than those considered in the work of the authors [16] (Fig. 3).

So, we consider the equation:

$$\frac{\partial u}{\partial t} = a^2\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \tag{2}$$

where $U(x, y, z, t)$—time and space changing innovative temperature.

$$a^2 = \frac{k}{\rho\gamma} \tag{3}$$

where ρ is the density of communication between subjects in the process of transfer or diffusion of innovations;

γ is the coefficient of innovation susceptibility or innovation capacity;

$k = k(\rho)$—Transfer coefficient of innovations.

Since the subjects of the process of transferring innovations are either individuals or their communities of different levels, then, in contrast to the classical equation of heat conduction, it is quite enough for us to limit ourselves to the one-dimensional case without any decrease in information content. That is, to solve the equation:

$$\frac{\partial u}{\partial t} = a^2\frac{\partial^2 u}{\partial x^2} \tag{4}$$

4 Discussions

Let us explain this below, including with examples.

So, consider the solution to the problem indicated above in point A.

Consider the case of a one-dimensional innovation diffusion area (Axis Ox), bounded on one side. Equation solution $\frac{\partial u}{\partial t} = a^2 \frac{\partial^2 u}{\partial x^2}$, satisfying the initial condition $u = (x, 0) = f(x)$ и boundary condition $u(0, t) = \varphi(t)$, expressed by the formula:

$$u(x,t) = \frac{1}{2a\sqrt{\pi t}} \int_0^\infty f(\xi) \times \left[e^{-(\xi - x)^2/(4a^2 t)} \times e^{-(\xi + x)^2/(4a^2 t)} \right] d\xi + \frac{1}{2a\sqrt{\pi t}} \int_0^\infty \left(\varphi(\eta) \times e^{-x^2/(4a^2(t-\eta))} \times (t-\eta)^{-3/2} \right) d\eta \tag{5}$$

Consider the case of a one-dimensional area of innovation diffusion bounded on both sides (Axis Ox). That, as mentioned above, corresponds to the diffusion of innovations in a certain limited area, for example, within a separate region, city, team.

x = 0 и x = 1. Here the Cauchy problem is to find a solution to the equation $\frac{\partial u}{\partial t} = a^2 \frac{\partial^2 u}{\partial x^2}$, satisfying the initial condition $u_{(x,t)}|_{t=0} = f(x)$ and two boundary conditions, for example, $u|_{x=0} = u|_{x=1} = 0$ or $\frac{\partial u}{\partial x}|_{x=0} = \frac{\partial u}{\partial x}|_{x=1} = 0$.

In this case, a particular solution is sought in the form of a series $U_{(x,t)} = \sum_{k=1}^{\infty} b_k \times e^{-(k\pi a/l)^2 t} \times \sin \frac{k\pi x}{l}$

Where

$$b_k = \frac{2}{l} \int_0^1 \left(f(x) \times \sin \frac{k\pi x}{l} \right) dx \tag{6}$$

for boundary conditions $u = |_{x=0} = u|_{x=1} 0)$.

And in the form of a series

$$U_{(x,t)} = \sum_{k=1}^{\infty} a_k \times e^{-(k\pi a/l)^2 t} \times \cos \frac{k\pi x}{l} + a_0 \tag{7}$$

where

$$a_k = \frac{2}{l} \int_0^1 \left(f(x) \times \cos \frac{k\pi x}{l} \right) dx,\ a_0 = \frac{1}{l} \int_1^1 f(x) dx \tag{8}$$

(for boundary conditions $\frac{\partial u}{\partial x}|_{x=0} = \frac{\partial u}{\partial x}|_{x=1} = 0$).

5 Conclusion

The main conclusions of this work are.

Any innovation (for example, a new idea, technique, technology) diffuses, i.e. spreads in society in accordance with a certain predictable pattern. It is proved that the diffusion of innovations has certain distribution laws and can be modeled.

This paper discusses and shows the possibility of modeling the process of diffusion of innovations using the diffusion equation well-known from mathematical physics (it is also the equation of heat conduction). etc. The factors influencing the density of connections between the subjects of innovation activity, and, consequently, the speed of dissemination of innovations and information, are specifically considered.

Note that in this work, as in work [16], we consider the equation of diffusion of innovations for the non-stationary case $\frac{\partial \mathrm{u}}{\partial \mathrm{t}} \neq 0$.

Note also that it is of undoubted interest to consider the innovation diffusion equation for the so-called "stationary" case, when $\frac{\partial u}{\partial t} = 0$ (time-independent case).

Here it is of interest to find a function that describes the distribution of the level of innovation within a certain limited area, if an expression is known that describes this function on the border of the area.

The solution of such problems is of interest for further study of the development and modeling of innovative processes, and this will be developed in subsequent works of the authors.

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Algorithm for the Problem of Loading Production Capacities in Production Systems

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Abstract. This article discusses the methodology for calculating order priorities. The network planning method for loading equipment is implemented in the task algorithm using the priorities of orders and operations. The order priorities are set in the monthly plan and reflect the order's entry into the first or second group, i.e. the order is planned only for launch (ordinary orders) or for launch and release in the planned period (emergency and forced orders), and the order of execution is planned. Order priorities are the source data for calculating operation priorities for order details. The priority of an operation reflects the order of its execution for a given part, not only in relation to the details of other orders, but also in relation to other details of this order. The algorithm for calculating the priorities of the operation is designed so that for each order, a network schedule of its production is formed, which allows the technological cycle of machining for all parts included in the order to be completed simultaneously, by the time the assembly of the product begins. The network schedule for the order allows adjusting the start of the order details in production without violating the duration of the production cycle of the order production in order to reduce the work in progress.

Keywords: Workplaces · Production capacity · Network planning · Production cycle · Order making · Planning · Technological operation · Tooling

1 Introduction

Order priorities (P_o) reflect the planning strategy (the order of execution of orders for the manufacture of technological equipment), as well as in operational planning, the urgency of starting production and the need to reduce the duration of the production cycle of manufacturing orders.

To calculate order priorities, enter an order priority scale with boundaries from 0 to 20, which is divided into three intervals:

1st interval—$0 \div 1$;
2nd interval—$2 \div 10$;
The 3rd interval is 11–20.
The first stage of the calculation.

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All orders at the first stage of the calculation are divided into three groups according to the degree of urgency: emergency or super-urgent orders, forced or urgent orders, and ordinary orders.

In this case, each group is assigned its own order priority scale interval:

1 g. (emergency)—11 to 20;
2 g. (forced)—2÷10;
3 g. (ordinary)—0÷1.

The second stage of the calculation.

At the second stage, the calculation is carried out separately for each group. For the first and second groups (forced, emergency orders), the priority is calculated taking into account the following factor: Reduction factor of PCD (production cycle duration): R_{fact}.

2 Materials and Methods

This factor shows the desired reduction in PCD in percentage terms. The Rfact value is determined from Tables 1 to 2, respectively, for emergency and forced orders.

R_{fact} for emergency orders is given in Table 1.

Table 1. Reduction factor for emergency orders.

Reduction PCD	30%	40%	50%	>50%
$Rfact_1$	$1 \div 2$	$3 \div 4$	$5 \div 6$	$7 \div 9$

The order priority for emergency orders is calculated using the formula:

$$P_o = 10 + R_{fact\ 1} \tag{1}$$

here Po is the priority of orders;

Rfact 1—reduction factor;

Rfact 2—for forced orders is given in Table 2.

Table 2. Reduction factor for forced orders.

Reduction PCD	10%	20%	25%	> 25%
$Rfact_2$	$1 \div 2$	$3 \div 4$	$5 \div 6$	$7 \div 8$

The priority of orders for forced orders is calculated using the formula:

$$P_o = 10 + R_{fact\ 2} \tag{2}$$

For the third group (ordinary orders), the priority is assigned as follows: $P_o = 0$ (for orders that are put into production), $P_o = 1$ (for unfinished orders) [2, 3].

Now let's look at the methodology for calculating the priorities of operations.

The priority of operations indicates the order of loading parts to the equipment when forming a queue for the process equipment groups (PEG).

To calculate the priorities of operations, a priority scale is introduced with boundaries from 0 to 152, which is divided into five intervals:

1st interval—$0 \div 90$;
2nd interval—$91 \div 111$;
3rd interval—$112 \div 133$;
4th interval—$134 \div 142$;
5th interval—$148 \div 152$.

The first stage of the calculation.

At the first stage, the priority of operations for emergency orders is calculated ($P_o = 11 \div 20$).

For parts of this group of orders, for which the labor intensity is $L_{int} \leq 12$ n/h, the priority of the operation (P_{op}) is calculated as follows:

$$P_{op} = P_o + \Delta 1 + 111 \tag{3}$$

where

$$\Delta 1 = \begin{cases} 0,\ 0 < L_{int} \leq 1^{n}/_{h} \\ 1,\ 1^{n}/_{h} < L_{int} \leq 2^{n}/_{h} \\ \vdots \\ 10,\ 10^{n}/_{h} < L_{int} \leq 12^{n}/_{h} \end{cases}$$

In this case, the priority of the operation is in the 3rd interval ($P_{op} = 112 \div 133$).

For parts for which the labor intensity is equal to $L_{int} > 12$ n/h, the priority is calculated by the formula:

$$P_{op} = P_o + 132 \tag{4}$$

Priority operations after this calculation is stored in the 5th interval ($P_{op} = 148 \div 152$).

For operational regulation of the course of production, the following priority values have been introduced:

(a) incomplete operation—$P_{op} = 132$;
(b) user priority—$P_{op} = 133$.

The second stage of the calculation.

At the second stage, the calculation is made for forced orders ($P_o = 2 \div 10$).

For parts of this group of orders, the complexity of which is equal to $L_{int} \leq 12$ n/h, the priority of the operation is calculated as follows:

$$P_{op} = P_o + \Delta 1 + 89 \tag{5}$$

here $\Delta 1$ is the same as for emergency orders. In this case, the priority of the operation is in the 2nd interval (Pop $= 91 \div 111$).

For parts whose labor intensity is equal to $L_{int} > 12$ n/h, the priority is calculated by the formula:

$$P_{op} = P_o + 132 \tag{6}$$

And also with the aim of the possibility of operational regulation of the course of the production process, the following values of priorities have been introduced:

(a) incomplete operation-$P_{op} = 110$;
(b) user priority-$P_{op} = 111$;

The third stage of the calculation.

The third stage operation is performed to calculate the priorities of ordinary orders ($P_{op} = 0{,}1$).

The priority of the operation is calculated using the following formula [4], based on the complexity of the order (C_o) and details C_d):

$$P_o = \Delta 2 + \Delta 3 \tag{7}$$

$$\Delta 2 = \begin{cases} 0, \mathit{min} C_o (P_o = 0) \\ \vdots \\ \ddots, \mathit{max} C_o (P_o = 0) \\ \ddots, \mathit{min} C_o (P_o = 1) \\ 80, \mathit{max} C_o (P_o = 1), \end{cases}$$

$$\Delta 3 = \begin{cases} 8, C_d > 12^n/_h \\ 6, 6^n/_h < C_d \leq 12^n/_h \\ 3, 3^n/_h < C_d \leq 6^n/_h \\ 0, 0^n/_h < C_d \leq 3^n/_h \end{cases}$$

Similarly to the previous order groups, the following priorities are entered:

(a) incomplete operation-$P_{op} = 88$;
(b) user priority-$P_{op} = 90$.

The priorities of the operations of this group are in the 1st interval ($P_{op} = 0 \div 90$).

When calculating the priorities of an operation, three algorithms are used that work on the basis of grouping order details according to their labor input [5, 6]:

(1) an algorithm for parts that have a critical duration of the production cycle and are included in orders planned for launch and release in the planned period;
(2) algorithm for details included in orders planned for launch and release in the planned period;
(3) an algorithm for details entering orders planned for launch in the planned period.

In general terms, the priorities of the operations of order parts reflect the order in which the parts are loaded onto the equipment.

3 Results

To describe the operation of the problem algorithm, we introduce the following concepts:

t_{oi}^{kj}-time of release of the *j*-th workplace (WP) of the k- th PEG of the *i*-th section;

t_{1n}^{mf} -the end time of the *f*-th technological operation of the *m*-th part of the *n*-th order;

t_{2n}^{mf} -start time of the *f*-th technological operation of the *m*-th part of the *n*-th order;

$\bar{t}_{n}^{mf}$ -the duration of transport and control operations for the *f*-th technological operation of the *m*-th part of the *n*-th order [7].

where in

$$t_{2n}^{mf} = t_{1n}^{mf-1} + \bar{t}_{n}^{mf-1} \tag{8}$$

$\mathrm{F}_{\mathrm{n}}^{\mathrm{mf}}(t_{2n}^{mf})$-a function that determines the location of the *m*-th part of the *n*-th order when performing the *f*-th technological operation on the *j*-th WP of the *k*-th and PEG of the *i*-th section.

$$F_{n}^{mf}\left(t_{2n}^{mf}\right) = t_{oi}^{kj} - t_{2n}^{mf} \tag{9}$$

$\overline{\mathrm{F}}_{\mathrm{i}}^{\mathrm{kj}}(t_{0i}^{kj})$—a function that determines the downtime of the *j*-th WP of the *k*-th PEG of the *i*-th section when performing f- and technological operation of the *m*-th part of the *n*-th order.

$$\overline{F}_{i}^{kj}\left(t_{oi}^{kj}\right) = t_{2n}^{mf} - t_{oi}^{kj} \tag{10}$$

$\overline{S}_{i}^{kj}$-duration of loading the *j*-th WP of the *k*-th PEG of the *i*-th section;
in turn

$$\overline{S}_{i}^{kj} = \overline{T}_{i}^{kj} + \overline{\prod}_{i}^{kj} \tag{11}$$

here $\overline{T}_{i}^{kj}$ is the labor intensity of technological operations performed on the *j*-th WP of the *k*-th PEG of the *i*-th section;

$\prod_{i}^{kj}$-the duration of downtime for the *j*-th WP of the *k*-th PEG of the *i*-th section;

as well as

$$\overline{\prod}_i^{kj} = \sum_{h=1}^{\overline{\alpha}} \overline{Q}_{hi}^{kj} \quad (12)$$

here $\overline{Q}_{hi}^{kj}$ is the duration of the h-th downtime for the j-th WP of the k-th PEG of the i-th section.

The choice of WP when planning the loading of technological operations on equipment is determined by one of the following conditions [8]:

$$\alpha_i^{kj} = \min F_n^{mf}(t_{2n}^{mf}) \quad (13)$$

(fulfillment of the loading criterion according to the formula (9).

Or

$$\beta_i^{kj} = \min \overline{F}_i^{kj}(t_{0i}^{kj}) \quad (14)$$

(fulfillment of the loading criterion according to the formula (10).

4 Discussion

Let's consider the operation of the problem algorithm.

At the first step of the algorithm, the queues for the PEG are normalized.

The queues are formed in two stages.

In the first stage processing operations based on the group-feasting on priority operations are divided into three groups:

(1) $a_1 \leq q_n^{mf} \leq b_1$
here q_n^{mf}—is the priority of the f-th technological operation of the m-th part of the n-th order;
$[a_1, b_1]$—the boundaries in which the priorities of the operations of parts that have a critical duration of the production cycle and are manufactured according to a reduced cycle change [9];

(2) $a_2 \leq q_n^{mf} \leq b_2$
here are the $[a_2, b_2]$ boundaries in which the priorities of the operations of the parts produced according to the reduced cycle change;

(3) $a_3 \leq q_n^{mf} \leq b_3$
here $[a_3, b_3]$ are the boundaries within which the priorities of the operations of the parts produced by the ordinary cycle change [10, 11].

At the second stage, the download queue is summarized for each group of priority operations.

For the first group ($a_1 \leq q_n^{mf} \leq b_1$), the queue is built from details according to the magnitude of the priorities of the operations.

The download queue for the second group ($a_2 \leq q_n^{mf} \leq b_2$) is built in a similar way.

For the third group ($a_3 \leq q_n^{mf} \leq b_3$), a queue is built for each PEG from technological operations based on grouping by technological process. Thus, queues for the PEG are formed for the first outstanding operations.

In the future, the blocks of the algorithm, in which the operations are loaded onto the equipment, work only with the queues for which they are configured.

At the second step, it is planned to load technological operations onto the equipment, the priorities of which are equal:

$$a_1 \leq q_n^{mf} \leq b_1$$

Loading planning is carried out for each part in accordance with its technological process [12].

After reading the record for the part from the queue, a check is made whether the technological operation is thermal or locksmith's. If the operation is thermal, then a mark is made about the load and the transition to the next record is carried out. In the case of a locksmith operation, the start time of the operation is calculated [13]:

$$t_{2n}^{mf} = t_{1n}^{mf-1} + \bar{t}_n^{mf-1} \tag{15}$$

and the end time of the operation:

$$t_{1n}^{mf} = t_{2n}^{mf} + T_n^{mf} \tag{16}$$

Then the end time of the technological operation is checked and, if it does not go beyond the available time on the WP for the shift, then a note is made about the load and the transition to the next technological operation on the part is carried out. Otherwise (the end time of the operation is greater than the total available time), the next entry from the parts queue is read. [14].

After that, it is determined for the next technological operation (if it is not thermal and not locksmith's) PEG (turning, milling, etc.), on which the technological operation should be performed, and the available fund of available time for it.

The loading of technological operations on the equipment is calculated in two stages.

At the first stage of loading, the possibility of performing a technological operation during equipment downtime is checked (equipment loading time consists of the complexity of technological operations performed on the equipment and equipment downtime caused by inter-operational time linking) [15].

If the technological operation is the first one that is not completed, then the transition to checking the WP indication for performing the operation is performed. Otherwise, the start time of the technological operation is calculated, which should not exceed the maximum available time for the WP per shift.

When the RM is used to perform a technological operation, it is checked whether the qualification of the worker corresponds to the category of work for this technological operation and whether the WP is specialized. In the case when the specified WP is specialized, its equipment is compared with the equipment of the technological operation [16].

In the future, when the WP is not specified, all the WP of this PEG are viewed for loading the technological operation for idle equipment. For this purpose, a check is made for the compliance of the qualification of the worker with the category of work on the technological operation, and, if the WP is specialized, the tooling, as well as the time for changing the equipment is deducted from the complexity of the technological operation.

For the selected WP, if there are equipment downtime, the start time of the downtime and the start time of the technological operation are compared, and if there is no part lying down, the duration of the downtime and the complexity of the technological operation. Then the duration of downtime after loading on the WP of this technological operation, the time of the beginning of the downtime and the time of the end of the operation are calculated, and a note is made about the loading.

If it is impossible to load the technological operation on the WP due to equipment downtime, we proceed to the second stage of loading [17].

In the second stage, the load is calculated based on the available free time (i.e., the equipment's available time fund minus the WP load time).

In the case when the WP is not specified, the WP is selected, according to which the lying of the part will be the least (condition α_i^{kj}), and a check is made for its specialization, and, if necessary, for the conformity of the equipment, and the time for the changeover of the equipment is subtracted from the labor intensity of the technological operation.

Then, the complexity of the technological operation is added to the loading time of the equipment, and the resulting loading time of the equipment should not exceed the fund of the available time for the WP.

After that, the time of equipment release and the end of the technological operation is calculated and a note is made about the load.

And, finally, the presence of downtime and the fund of available time for equipment at this production site, unloaded technological operations for the part is checked.

At the third step, it is planned to load technological operations on the equipment, the priorities of which are equal:

$$a_2 \leq q_n^{mf} \leq b_2$$

Load planning is performed in the same way as in the second step.

At the fourth step, it is planned to load technological operations on the equipment, the priorities of which are equal:

$$a_3 \leq q_n^{mf} \leq b_3$$

Load planning is carried out for each PEG separately (i.e. turning, milling, etc.) and is carried out in two stages.

For the thermal and locksmith PEG, the planned task for the shift will be the queues to the corresponding groups.

At the first stage of loading, it is calculated based on downtime caused by inter-operational linking in time.

When specifying the WP for processing, the compliance of the worker's qualification with the category of work for this technological operation is checked and whether the WP is specialized. In the case when the specified WP is specialized, its equipment is compared with the equipment of the technological operation.

If the WP is not specified, all the WP of this PEG are "viewed" for loading the technological operation according to the idle time of the equipment. For this purpose, a check is made for the compliance of the qualification of the worker with the category of work on the technological operation, and, if necessary, the equipment.

In the future, when the WP is specialized, then the time for equipment changeover is deducted from the complexity of the technological operation.

For the selected WP, if there are equipment downtime, the duration of the downtime and the complexity of the technological operation are compared. Then the idle time is calculated after loading on the WP of this technological operation and a note is made about the loading.

If the process operation failed to load on the equipment at the first stage, proceed to the second stage of loading.

At the second stage, the load is calculated based on the downtime of the equipment caused by the underutilization of the WP (i.e., the availability of a free fund of available time).

5 Conclusions

In a situation where the WP is not specified, the least loaded WP is selected (condition β_i^{kj}) if the qualification of the worker and the category of work for the technological operation coincide, and then all checks and calculations are carried out for the specialized WP, in the case of its specialization.

Then, the complexity of the technical operation is added to the time of loading the WP, and the resulting loading time should not exceed the maximum available time for the WP, and a note is made about the loading.

After that, the presence of downtime and the fund of available time for the RM of this PEG production site and technological operations in the queue for loading is checked.

The result of solving the problems of managing the organization of production is such an organizational structure of production sites that corresponds to the implementation of the "busy" production program in the planned period.

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Stock Trading Indices: A Mechanism for Attracting Speculative Capital

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Abstract. The article is devoted to the study of stock exchange trading in stock indices as a tool for attracting speculative capital to the market in Ukraine. Reasonably, the investment process takes place through the purchase of an ordinary index share issued by an investment fund. Investors who buy this share receive a profit not only from the exchange rate difference of the share, but also on the payment of dividends by the fund. The stock market of Ukraine is at the stage of formation and development, so it has many problems and shortcomings. One of these disadvantages is the lack of opportunities to trade exchange-traded stock indices. The authors draw conclusions based on the fact that in order to implement the proposal of legislative regulation, the government needs to adopt a law on futures trading, which should contain a definition of the contract market, a definition of the futures exchange. Also create an administration for stock futures contracts within the Department of the Stock Market and Securities of Ukraine, which today exists as the National Securities and Stock Market Commission. The authors have proved that trading stock indices can be very attractive for a trader due to the fact that the index, in its essence, is a widely diversified financial instrument.

Keywords: Forward · Futures · Commodity derivatives · Hedging instruments · Risks · Speculation

1 Introduction

At the present stage of development of the stock market of Ukraine, there is a need for a systematic study of the state of its conjuncture. This is not possible without the use of large amounts of statistical information, which serves as the basis for calculating generalizing indicators. A special place among them is occupied by indicators of business activity of the securities market-stock indices. Indices are the most widely used tools for financial analysis of the stock market in the world. Since they adequately reflect the nature of all forms of fluctuations in the proportions of supply and demand for securities and are used by investors as a source of information for forming an effective investment strategy,

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adjusting financial policy, and making economically sound decisions. The intensive development of the global stock market has updated the issues of using stock indices as a tool for financial analysis of its market conditions in order to provide information to market participants to optimize investment priorities. But due to the fact that the stock market of Ukraine is currently in its infancy, the existing stock indices are not able to fully adequately reflect the price trends of the national securities market. There is a need to clarify and justify new approaches to the formation and application of stock indices in Ukraine, which will expand and diversify the modern system of indicators and more fully meet the information needs of market participants.

2 Methodological Foundations

The study of the functioning of stock indices, since their appearance, has been of interest to foreign scientists. The issues of the use of stock indices in the stock market were covered by scientists in their works. Among the foreign scientists whose works are devoted to the study of the use of stock indices, we should single out P. Abbondante, G. Abuselidze, H. Bessembinder, K. Chan, T. Evans, D. McMillan, H. Fung, G. Sierra, T. Kilgallen, M. Leung, M. Madaleno, T. Mills, B. Pant, J. Ricketts, R. Roll, A. Sharkasi, P. Shu, G. Smith, F. Zhou, Q. Zhang, D. Sornette, L. Jiang and etc. [1–18].

The purpose of this article is to study and analyze the theoretical and methodological approaches and provisions of the features of stock index trading and their impact on the mechanism of attracting speculative capital to Ukraine.

3 Results and Discussion

To create competitiveness in the speculative capital market in Ukraine, it becomes necessary to attract the foreign experience of those countries that already have a developed capital market and have passed all the stages of its development from ordinary trading in financial instruments, to complex instruments such as stock indices and derivatives. Stock index trading originates from the US stock market, where historically they were created and calculated, so using the US experience is the most correct solution. This is logical, because the stock market of Ukraine was built on the American model. Also, the United States stock market today is the benchmark market, because of its development and largest capitalization.

First of all, analyzing foreign experience, it is necessary to pay attention to the number of stock index trading tools that have personal tasks [19, 20]:

- Index futures—a tool created for the purpose of low-risk investments in stock indices, as well as for the purpose of hedging price risks in the stock market;
- Index options are a multi-level instrument used for the purpose of speculation, as well as hedging price risks;
- ETFs are a tool used by institutional and private investors to generate profits.

For the existence of each of these instruments, the US government needed to create laws regulating the existence of these financial instruments, as well as to create a place for their turnover in the form of exchanges on which these securities are listed. For example, three categories of exchanges operate in the United States: stock exchanges, futures exchanges, option exchanges.

Stock exchange is a place where financial assets are traded. These assets are mainly stocks, bonds, and ETFs. That is, the set of instruments that are traded in this market are instruments, the main focus of which is investing.

Almost all stock exchanges have futures and options divisions, and in some cases they create related specialized exchanges. Accordingly, after the introduction of the regulatory framework and the creation of a place for the turnover of stock index trading instruments, investors and hedgers have intensified their activities in the direction of using stock indices. But depending on the purpose of using the indices, professional stock market participants have developed different methods that have different personal characteristics and different approaches to use: investing in stock indexes and hedging through stock indexes.

In the United States, investing in stock indexes occurs, as noted earlier, from futures trading, as well as through the purchase of stock ETFs. The most striking example of such an index is an ETF, which repeats the S & P 500 price chart. The ticker of such an ETF is SPY. This index is considered the most liquid index in the world. Its price per share ranges from $270 to 300.

Thus, the investment process takes place through the purchase of an ordinary index share issued by an investment fund. Investors who buy this share receive a profit not only from the exchange rate difference of the share, but also on the payment of dividends by the fund. Of course, for large investment investors, this is not a promising investment tool, so they use futures with a ticker/ES, also need a fully correlated chart (see Fig. 1).

Investors use the index as an insurance policy that ensures the purchase of the index at a predetermined price. Professional market participants who perform such operations are called hedgers. To hedge risks, they use instruments such as options and futures, which give the right or obligation to buy or sell a security at a predetermined price [26–32].

Consider an example of hedging price risks by buying an option contract on a stock index. It is also important to understand the essence of the option contract. Index options are a derivative of a derivative instrument [33–35]. This means that an option contract, issued on a futures contract, is issued on an index. It can also be an ETF, and this is another level of the instrument, that is, an option is issued on an ETF created on the basis of the futures that are issued on the index (see Fig. 2).

For example, a hedger decides to protect himself from a fall in the price of a stock index by buying one "call" option, which gives the right to buy an asset at a set price. For example, at 266 USD, as of October 2019, for which he paid $3. This means that a hedger can buy an ETF on the index at a price of $266.

Depending on where the price will go in the hedger can occur in two possible scenarios of development of events: The price rose to 272, the hedger fulfills the terms of the option contract and bought the ETF. He made a profit and lost the price risks. His income was 272 (current price)—266 (price, contract)—3 (premium, paid by the hedger) = $3 profit.

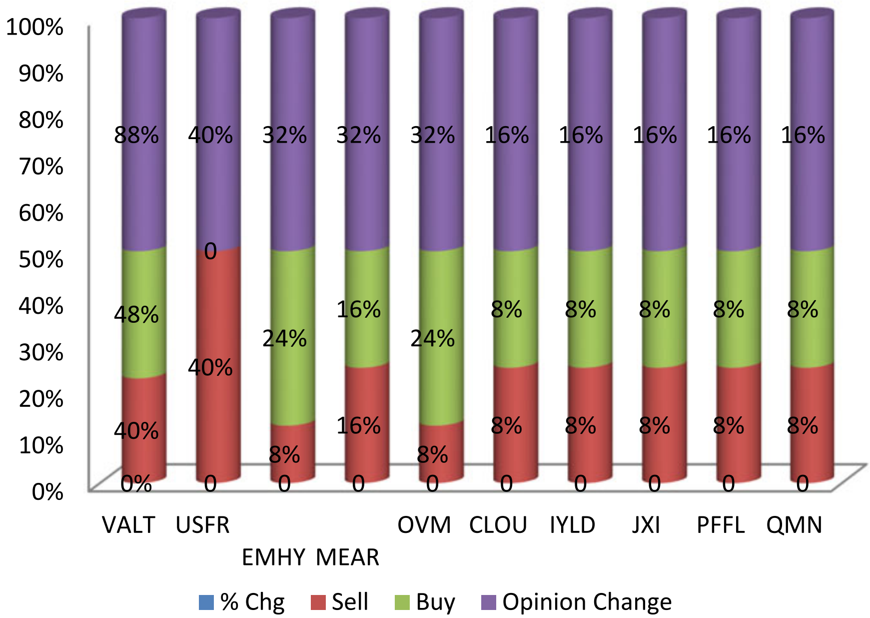

Fig. 1. The price chart of the SPY ETF, repeating the price of the S&P500 index. *Source* Developed by the author on the basis of [21–25].

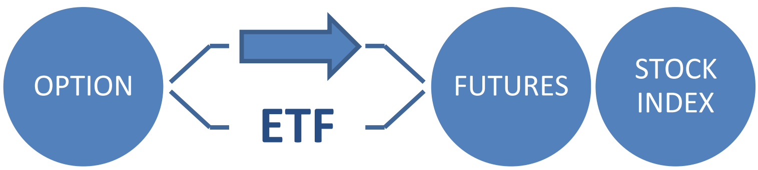

Fig. 2. Superstructure of stock instruments based on stock indices. *Source* Developed by the authors.

The price of the stock index fell to 260, the hedger does not fulfill the terms of the option contract. He loses the premium paid, but the price risks are limited only by the premium that was paid and is deprived of the price risks.

Hence, this is how stock indices are traded in the United States of America. This market not only has a place to trade the index in the form of exchanges, but also a full range of derivative financial instruments, introduced at the legislative level. Also, the US stock market has professional participants who understand the market tools and know how to use them, unlike the Ukrainian ones.

The stock market of Ukraine is at the stage of formation and development, so it has many problems and shortcomings. One of these disadvantages is the lack of opportunities to trade exchange-traded stock indices. This problem is based on the lack of a normal futures trading infrastructure. Therefore, we have developed proposals for the introduction of futures contracts for stock indices, which should be present on any developed stock market.

As noted earlier, the process of trading stock indices should go through several stages. According to these stages, proposals were developed. Therefore, to form a futures trading system, we proposed:

1. The introduction of the system of state regulation, which regulates futures trading
   Analyzing foreign experience, we made conclusions based on the fact that in order to implement the legislative regulation proposal, the government needs to adopt a law on futures trading, which should contain a definition of the contract market, a definition of the futures exchange, as well as create an administration for stock markets and futures contracts within the Department of the Stock Market and Securities of Ukraine, which today exists as the National Securities and Stock Market Commission. This law should regulate trading on the futures exchange and the other five market organizers that are functioning today. This means that the National Securities and Exchange Commission gets the right to monitor trading, collect information about the activity of the futures market, and check the accounts of exchange members. The law provides for the creation of a register of brokers, the obligation of all market participants to obtain the status of professional participants, to register each professional participant, and by default to register a new futures contract. The next stage in the state regulation of futures trading is the approval of the law "On the Creation of a Futures Exchange"—the law regulating the activities of the exchange fully describes its purpose, approves the supervisory board, members of the exchange, as well as its charter. This means the appearance of a futures contract on the Ukrainian stock market as an investment tool. Today, only two futures can be such: Futures on the PFTS index and Futures on the UX (CME/NYMEX) index.
2. Creation of an investment fund
   The proposal is based on the creation of a contract, regardless of the state capital, or with the involvement of institutional investors who can create such a fund. This proposal provides for the creation of an investment institution that makes direct investments in the stock market in a futures contract for stock indices. That is, in this way, an investment pool is formed, which has a large number of contracts, which makes up almost all of the fund's balance sheet assets. The next step of the fund is to attract additional funds for further investment. To do this, the fund issues shares, the size of which is equal to the balance sheet assets of the enterprise. This will allow the private investor to carry out investment operations not only in the stock market, but also in the market of futures contracts, although not in the form of a standardized contract, but in the form of buying shares of ETFs. But this also requires the introduction of laws that regulate this security and allow for speculative and investment operations with this financial instrument.
3. Attracting software manufacturers are versed in stock trading
   This stage involves the creation of software on the exchange itself, allow you to perform operations on the futures market, as well as a platform that is aimed at trading futures in real time, at prices that have formed at the moment. This will provide the market with constant liquidity, and therefore investment attractiveness.

The application of these proposals for the introduction of a futures contract on the real market conditions of the domestic stock market provides opportunities to obtain a competitive stock market and will receive the following elements inherent in developed markets:

- The use of stock index futures will make the stock market of Ukraine, the market that uses leverage, and accordingly it will increase the interest and attract the attention of traders with foreign capital, to buy not only government bonds, but also indices;
- The contract provides opportunities to hedge price risks;
- Low commission compared to other investment instruments;
- The ability to create and use robots in trading;
- Increasing the stock market assortment in the form of futures and ETFs is a medium- and long-term investment tool in the long term;
- Thanks to the low commission and high diversification, these funds will bring great profits to investors;
- Ukrainian indices will take on the function of diversifiers and accordingly this will smooth out any sharp jumps in the stock price;
- The emergence of investment opportunities in the market, both large and small investors.

Trading in exchange—traded indices can be very attractive for a trader due to the fact that the index is, at its core, a widely diversified financial instrument. That is, it shows the state of things in the industry as a whole and does not depend much on the share price of individual companies included in it. When investing in a stock index, you can completely abandon such concepts as analyzing the financial performance of an individual company, completely focusing on the state of affairs in the industry as a whole.

4 Conclusions

The dynamics of trading in the indices of the world stock market has been studied, and it has shown that although each stock market has its own structure and the principle of its development depends on a separate state, there is still a dependence of one stock market on another. This is reflected through correlatable markets, as in the space of a particular region or on a shared world. One of the markets studied was the US market, which over the past ten years has shown the best dynamics among all, expressed in the constantly growing stock indices of the country. Special attention should be paid to the stock indices of the domestic stock market. The main difference between stock indices in Ukraine and world indices is that they are not investment indices at all, but are used only as a weighted indicator for all stocks. This is a big disadvantage of the Ukrainian securities market. But the prerequisites for the lack of opportunities for trading stock indices in Ukraine:

- There are no regulatory frameworks governing the introduction of new trading instruments in the stock market;
- There are no systems of control over the activities of new financial instruments;
- There are no futures trading on the stock market;
- There are no new investment funds;
- There are no systems of taxation of futures trading;
- Low level of education of the government, as well as domestic investors;
- Low level of qualification of professional market participants.

Only if all of the above problems are solved in Ukraine, it is possible to successfully trade stock indices. Most of the problems that have arisen are primarily related to the government's lack of confidence in the need to develop this direction. Therefore, most of the laws adopted are ill-considered, and today they are also outdates.

So, for the development of the stock market in Ukraine, it is necessary to solve all the problems that have developed on it. This gives not only the opportunity to develop companies, but also the development of the country as a whole. In particular, it becomes necessary to create conditions for trading stock indices, because this will help the country to attract foreign capital, extract excess money from circulation and become a competitive country that has its own developed stock market.

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Application of Hedge Technologies to Minimize Price Risks by Agricultural Producers

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Abstract. The article is devoted to substantiation of methodological aspects of application of hedge technologies of minimization of price risks of agricultural commodity producers. It is substantiated that the inelastic supply of agricultural products in relation to changes in market prices leads to fairly high price risks for farmers. The authors emphasize that thanks to hedging tools already during the sowing campaign, the agricultural producer can set a price at which he will be able to sell his harvest in the future. It has been proven that the advantages of hedging include the confidence of the agricultural producer that he will receive some pre-established income and intermediaries are protected from possible market fluctuations. It is stated that a forward contract is the cheapest and easiest way to hedge (protect) price risks as the supply of agricultural products is inelastic in relation to changes in market prices, which leads to fairly high price risks of agricultural producers. Within the limits of development of recommendations, the authors' research of separate strategies caused allocation of the basic indicators and terms of their application on the exchange market by different categories of traders, therefore the proposed method of developing costs and revenues from the use of exchange rate strategies demonstrates the feasibility of using hedging in any direction of change in the price environment.

Keywords: Hedging instruments · Commodity exchange market · Price risks · Commodity derivatives · Manufacturers of agricultural products

1 Introduction

In current conditions, the agricultural manufacturers face risks which can cause substantial losses for them. High level of uncertainty at market as well as unpredictable climate and weather situation influence the process of agrarian production and the results of it. Seasonality, fluctuations in production volumes, and natural and climatic conditions have a great influence on the formation of prices for agricultural products. The combined effect of these factors increases the risks of agribusiness. Overcoming their negative impact on entrepreneurial activity in the entire economy requires the establishment of progressive elements of market-trading. That is why there are concrete tools which can

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be used to fulfill the task of lessening the risk or avoiding it. It should be said that hedge technologies possess an important place in the overall system of risk management.

2 Methodological Foundations

2.1 Literature Review

Many works of world scientists are devoted to the issues related to exchange trade and commodity derivatives. In particular, the following foreign economists study the instruments of exchange derivatives markets and develop new strategies for their application: R. McDonald, J. Marshall, J. Hull, M. J. Bohmann, D. Michayluk, V. Patel, G. Abuselidze, A. Slobodianyk, M. J. Carrer, L. Shao, J. Shao, Z. Sun, H. Xu, G. Smith, etc. [1–16].

In Ukraine a significant contribution to the study of problems associated with the development of the commodity exchange market is made by the following scientists: However, the functioning of the market of commodity derivatives for agricultural products in Ukraine and the use of appropriate technologies to minimize the price risks of agricultural producers, its organization and regulation remain insufficiently studied and require further studying. The aim of the research is to investigate the ways of using exchange instruments to minimize price risks of participants in the agricultural market of Ukraine.

2.2 Research Instruments

To achieve the formulated aim of the research a set of well-known scientific methods and techniques have been used. The method of logic synthesis has been applied in order to well-ground theoretically the importance of studying the hedge technologies as an effective tool of lessening and avoiding risks in agriculture. Using the methods of analysis and synthesis allowed showing the importance using the technologies of risk management in the agrarian sector. The method of finding logical connections was used to demonstrate the necessity of practical implementation of the hedge technologies and the advantages of it. Method of building diagrams was used for visual demonstration of Understanding the concept of risk hedging by agricultural producers in Ukraine. Mathematical method was used to show the formulas considering the price fluctuations at market and basic risks for the agricultural producers in the given conditions.

3 Results and Discussion

Agricultural production has always been characterized by a high degree of risk. This is primarily due to the conduct of activities in space and accordingly its high dependence on weather conditions. The process of agricultural production itself depends significantly on climate change, often unpredictable behavior of suppliers and customers, partners in the implementation of various contracts. Also inelastic is the supply of agricultural products in relation to changes in market prices, which leads to fairly high price risks for farmers. In addition, risks in agriculture differ in areas within the industry itself, i.e. risks in crop production are different from risks in livestock or aquaculture. For example, in animal husbandry, the main risks arise due to the indefinite start and end of the grazing period which may lead to the need to increase feed. Moreover, normal power outages can lead to untimely milking of cows if the process is electrified at a particular farm. To prevent such situations and reduce risks farmers often install stand-alone power sources. In crop production, risks arise in particular due to breakdowns of worn-out agricultural machinery, untimely supply of spare parts or fuel and, consequently, delays in harvesting.

In current conditions, in the process of carrying out activities in risk management, agricultural enterprises are usually guided by the desire to reduce these risks to a certain acceptable level in accordance with the principle of economic feasibility. In Ukraine about 56% of agricultural producers are concerned about the risks of price changes in the agrarian market. This fact also worries about 23% of processors and 37% of traders of such products. As a matter of fact, important risk posed by the Ukrainian farmers is the risk of crop failures due to unpredictable weather changes. It should also be noted that in Ukraine, external risks have a significant impact on the development of business in the agrarian sector including changes in state regulation of the agrarian sector, military conflict, various restrictions in trade of agrarian products, which change from year to year, and lack of transparent logistics schemes for transportation of raw materials and finished products, cases of theft [5, 17–20].

In addition to these risks, agrarian producers, like all entrepreneurs, face risks associated with the functional areas of production and sale of agricultural products (operational activities of the enterprise) as well as management and financing of the enterprise itself.

Since July 2000, in accordance with the Decree of the President of Ukraine “On Urgent Measures to Stimulate Production and Development of the Grain Market” of June 29, 2000, associated stock exchanges have been granted the right to enter into and register trade agreements for agrarian products.

Since the agrarian production is seasonal, there is a real need of crediting it. There is a traditional way to use bank loans which provides interest on the loan. However, the financial condition of medium and small agrarian enterprises and private farms is difficult and banks frequently refuse to provide loans [21–23].

In market conditions, advances for agrarian producers are performed by such form of contracting as forward contracts. However, forward contracts have not been properly developed in Ukraine, despite the fact that the Law of Ukraine “On State Support of Agriculture of Ukraine” stipulates that the system of state forward grain procurement should be introduced to replace the regime of public mortgage procurement.

In the process of financial and economic activities, there is always a market risk, i.e. the risk associated with the sale of goods and services produced by the entrepreneur, and financial risk associated with the placement and use of financial resources and investment activities. There is also a management risk due to the presence or absence of a sufficient number of suitably qualified employees in the enterprise. In short, the activities of agricultural enterprises take place in conditions of uncertainty and insufficient information, and this fact causes risks of their activities. It is impossible to completely eliminate the risk in conducting agrarian activities, as well as other business activities. That is why there is a need to develop specific schemes and tools to reduce the degree of risk [24, 25].

Strategies of management of agrarian risks are grouped into three blocks—strategies aimed at minimizing risks, transferring risks, and mitigating the impact of risks in the final result. In Ukraine the most common strategy is to minimize yield risks but Ukrainian farmers remain virtually unprotected from external risks and risks of changes in market prices. It should be noted that in order to minimize risks, agronomic approaches are most often used to increase yields. With regard to transferring risks, it is done in particular through insurance or risk hedging (through the use of forwards, futures or options). This practice is not common in Ukraine leading to significant effects of market price fluctuations on the performance of farmers. Due to the imperfection of the process of implementing programs to support agricultural producers at the national level through various agricultural funds, insurance programs and debt restructuring, risk mitigation tools in the agricultural sector are also underused [5, 17].

Typically, when entrepreneurs use hedging, they try to protect their business from the negative event. This does not prevent the event from happening, but it certainly reduces its impact. Not only individual investors, but also large corporations use hedging techniques to manage their investment portfolios to minimize the impact of different types of risks and reduce the negative impact on them (Fig. 1).

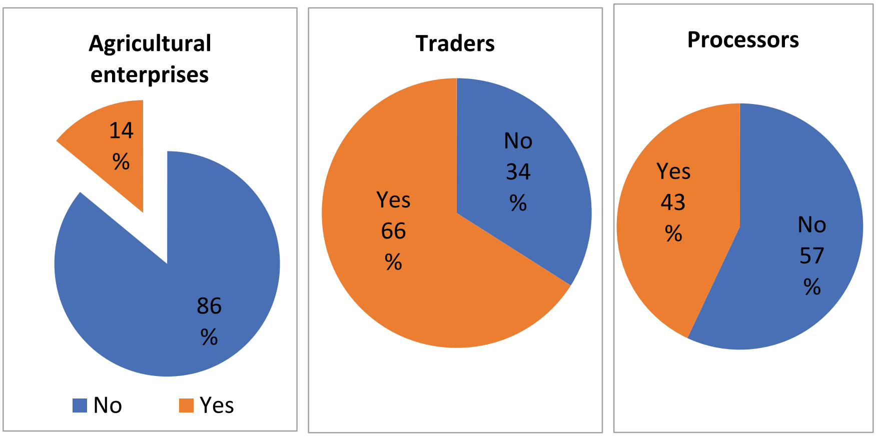

Fig. 1. Understanding the concept of risk hedging by agricultural producers in Ukraine. *Source* Own elaboration on data from [17].

Thanks to hedging tools during the sowing campaign, the agricultural producer can set a price at which he will be able to sell his harvest in the future. Although the farmer may lose potentially higher income, he insures himself against potentially large costs that may arise in conditions of uncertainty [20].

The advantages of hedging include the confidence of the farmer that he will receive some pre-established income and intermediaries are protected from possible market fluctuations. As for investors, they get the opportunity to invest their free funds in several areas which greatly increases the liquidity of their investment portfolios. Hedging saves a lot of time as long-term transactions eliminate the need for constant monitoring and adjustment of the asset portfolio in the face of daily market volatility. Using hedging with options the parties are protected from losses due to changes in commodity prices, inflation, changes in exchange rates, changes in interest rates.

Farmers use the hedging tools in different situations. In particular, there is the concept of "storage hedging" when farmers protect themselves from lowering the price of goods stored in storage by "short" hedging. To do these futures contracts are sold as soon as the harvest reaches the warehouses, so the value of the goods is maintained in accordance with the expectations of the producer. "Hedging of production" is also used in a similar way. In any case, the loss of possible higher profits (in case if the market prices increase) is compensated by possible losses when market prices fall. Long-term hedging is used when livestock farmers wait for the purchase of corn or other feed to protect themselves from price increases through the sale of futures at pre-determined prices and volumes.

To better understand the importance of basic risk in hedging, consider the example of a corn grower thinking about setting prices for its future harvest. Suppose such an agricultural producer is engaged in soil irrigation and anticipates possible natural risks. At the same time, he is more or less aware of the volume of his future harvest. In this case the main concern of the farmer is the risks associated with price fluctuations. If the farmer does not hedge his risk is related exclusively to the monetary price of the harvest (P_2), which can be calculated as the price of futures for the harvest (F_2) plus the basic price of the harvest (B_2). Thus, the net profit of the farmer in the situation of sale on the market (R_u) can be calculated as the price of the futures and the base price of the harvest ($F_2 + B_2$) multiplied by the actual production (Y_2), minus production costs (C):

$$R_u = [(F_2 + B_2) * Y_2] - C$$

Assume that a farmer uses short hedging (for example, to sell a futures contract) to reduce the risk of lower prices for his future harvest. The expected final net profit on the Rh crop will be based on the basic price for the crop ($F_2 + B_2$) and the profit or loss that will be derived from the futures ($F_1 - F_2$) depending on the market situation. The actual level of production of the farmer is denoted as Y_2 in the following equation, and the volume that is hedged—h * Y_1, where h is the hedging factor and Y1 is the expected volume of production

$$R_h = [(F_2 + B_2) * Y_2)] + [(F_1 - F_2) * (h * Y_1)] - C$$

Assuming that the amount of harvest is known, a hedge contract is concluded in which the volume of production is equal to the amount of hedging (for example, $Y_2 =$ h * Y_1). Then

$$R_h = [(F_2 + B_2) * Y_2)] + [(F_1 - F_2) * Y_2] - C$$

Or

$$R_h = [Y_2 * (F_1 + B_2)] - C$$

The last equation shows that the price component of a farmer's net profit depends on the futures price at the time of hedging with the addition of the basic price for the harvest. Due to the fact that the futures price is known, the only risk left for the farmer is the risk associated with the crop itself. The risk associated with price fluctuations is compensated by a hedging instrument.

A forward contract is the cheapest and easiest way to hedge (protect) price risks. Having signed such agreement with the buyer of corn, the farmer fixes the sale price and is no longer afraid of market prices' falling. The only question is the reliability of the buyer and his desire to fulfill the forward agreement in the event that prices fall significantly during the delivery period. The forward contract is not standardized, it can be concluded for different volumes and quality of corn, with different terms and conditions of delivery. This is definitely the advantage of a forward contract. But it is not always possible to sign a forward contract. For example, it is very difficult to find a buyer for corn in the physical market under a forward contract long before delivery time and even when the price is to fall according to the market analysts' forecast. This is how the situation on the corn market may develop (pessimistic option), i.e. prices will fall and for the delivery period (October–November) the price will be $145–160/t on FOB deep-water ports of the Black Sea. But this price does not suit the producers in terms of planned profitability. Therefore, we decide to hedge part of our corn production (10%) from the fall in prices via the sale of non-physical goods under a forward contract (we do not have such an opportunity), but the sale of ten corn futures on the Chicago Board of Trade (CBOT).

Corn futures are almost the only commodity futures in the agro-industrial sector, represented in the TOP-10 the most liquid futures in the world (Fig. 2). It is followed by futures on soybeans, soybean oil, wheat and soybean flour. The average daily trading volume of corn contracts on the CBOT stock exchange amounted to 288,459 in the 3rd quarter of 2019. Electronic trading covers 93% of total asset trading [21]. The amount of open interest is 1,324,250.

Futures are presented under the ticker ZC:

- Contract trading is carried out from Monday to Friday 2:00 21:15.
- The stock exchange of this asset breaks from 15:15 to 17:30.
- The contract months include March, May, July, September and December.
- The expiration date is on the last business day before the 15th calendar day of the month of delivery.
- The size of a corn futures contract is 5,000 bushels, and the price is indicated for 1 bushel of raw materials in the center.
- The minimum price change is 0.25 ($12.5 when buying a full contract).

On average, the Chicago Board of Trade carries out about two hundred thousand transactions per day with the nearest corn futures contract, which causes price changes tens of times per one second and makes this market very liquid [20, 21].

It should be noted that the largest number of corn futures contracts are with the Chicago Board of Trade. For this reason, the Chicago Board of Trade (CBOT) is more often used to hedge price risks.

As a matter of fact, CBOT trades corn futures of only American origin with the possibility of physical delivery to American elevators, so it is very important for the Ukrainian producers to have information about the price difference between the physical

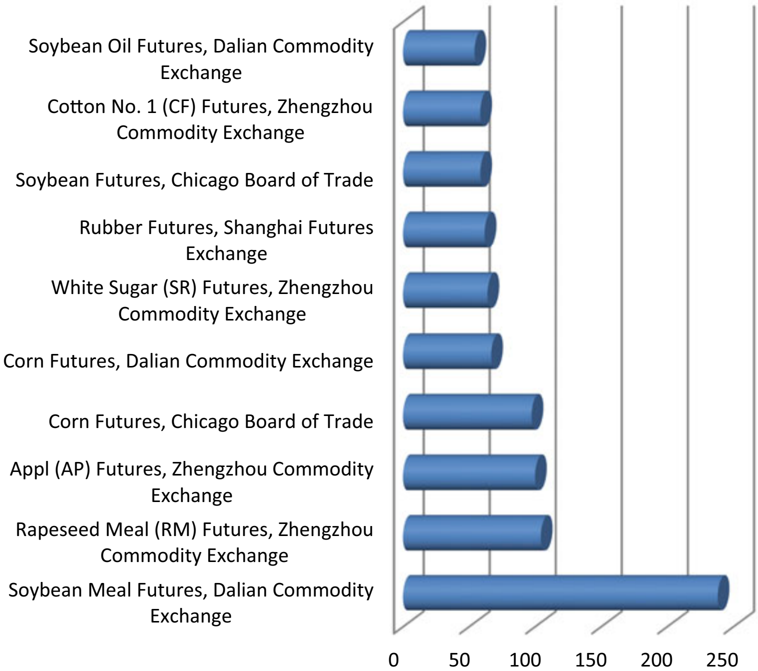

Fig. 2. Leading agricultural futures and options contracts traded globally, by volume (in millions). *Source* Own elaboration on data from Statista [26].

corn market in Ukraine and the CBOT corn futures market. This difference is called the basis.

If we buy a corn futures contract and corn prices rise, so does the price of our futures contract, because the two phenomena are interrelated. In this case, we receive a profit from the ownership of the futures contract and can record this profit by selling the futures contract. Conversely, when the price of corn falls, we will bear losses from owning a futures contract and will have to replenish the deposit. In addition, we will have to pay our broker a commission for the purchase or sale of a futures contract. Such payment is not provided by forward contracts.

We plan to sow corn in spring and to have harvest in autumn. The price of corn is $ 240 per ton on CPT terms with delivery in March, and it suits us in terms of yield per hectare. But we cannot fix this price for next year's harvest because there are no physical buyers who would like to buy corn for the new harvest today. That is, the physical market is not working yet.

But in addition to the physical market, there is also a corn futures market, such as the Chicago Board of Trade (CBOT). If a futures contract is liquid enough, we can use it to hedge our price risks.

For the futures markets to function properly, the cash price for corn and the price for corn futures at the time the corn is delivered must match. If prices do not match, then hedging as the economic reason for the existence of any futures markets becomes impossible.

The price risk of agricultural goods can arise due to a number of reasons, including drought, which affects production volumes, changes in demand, changes in the state of international markets and international production. Commodity futures markets are tools for spreading risk between those who produce their own commodities by becoming hedgers and those who speculate in the market.

Futures stocks of exchange exist and are successful on the principle that hedgers can give up part of the profits in exchange for the opportunity to reduce their risks. Futures contracts are potential price risk management tools for farmers.

In exchange practice, there are more than 20 strategies for using stock contracts to manage the level of price risk, which are purchases, sales, or combinations of purchases and sales.

The study of certain strategies, within the limits of the development of recommendations, led to the selection of the main indicators and the timing of their application on the exchange market by different categories of traders. The offered method of developing costs and revenues from the use of exchange rate strategies demonstrates the feasibility of using hedging in any direction of change in the price environment.

The expansion of the sphere of the stock exchange services is an important condition for the agricultural producers because in current conditions it easier to share the harvest to the intermediaries than to enter a stock exchange by themselves having used an elevator beforehand. Very often the agricultural producers are forced to share their production with the creditors, suppliers of sowing material and fertilizers.

Therefore, there is a need to move to civilized methods of selling the agricultural products. First of all, it is beneficial for the producers, as they will no longer benefit from the additional financial resources that can be used for the development of the enterprise.

4 Conclusions

So that, using hedge technologies in agrarian sector by the agricultural manufacturers plays a very important role in current conditions in Ukraine as well as in other countries of the world. This is due to the fact that the agricultural manufacturers act mainly in conditions of uncertainty and there are risks which are difficult to avoid or lessen. There are concrete tools to protect the agricultural production against the risks. It is important for them to provide more or less stable harvest results and sell it at optimal costs, as well as to produce high-quality, but at the same time cheap products. And the hedge technology plays a key role in this. Thanks to hedging the agricultural manufacturers provide themselves with some stable results of their work and become able to overcome the climate risks and other risks. Today we can witness a lot of examples of effective using of the hedge technologies and it is very important because it demonstrates rising of the addicting of the agricultural producers to move to civilized methods of selling the agricultural products.

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Improving the Competitiveness of Transport Enterprises Through the Implementation of a Quality System

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Abstract. In the article suggests measures to increase the economic interests of enterprises by developing service-oriented and customer-oriented personnel. The rating analysis of the leading countries in personnel management is presented, based on the qualitative indicator "customer orientation" from the well-known worldwide methodology of Klaus Schwab. Tools are offered to increase staff motivation and loyalty to customers. Based on the use of the process approach, the authors propose a solution for optimizing business processes for JSC "Post". The authors propose to develop an operational plan of necessary measures to improve production processes in the framework of increasing competitiveness based on the introduction of the Japanese lean manufacturing method. Consider the basic concepts to improve the competitiveness of the enterprise. We study competitiveness as an economic category for the micro-level and note that—this is not only the ability of an enterprise to produce and sell goods or services, but also withstand competition with significant income. This concept is the most profound and requires a detailed theoretical study. The content of the understanding of effective personnel management and the practical application of categories such as "business activity of the personnel" and "satisfaction with the work of the personnel" is usually disclosed in the institutional environment in modern conditions. Therefore, to ensure the competitiveness of an industrial enterprise, it is necessary to maintain a balance of national interests, including those related to the development of a scenario for the transition of the Russian economy to an institutional innovation environment.

1 Introduction

The purpose of the study is to identify internal reserves and determine the degree of satisfaction with labor and business activity of staff, as tools to enhance the competitiveness of Russian enterprises. The methodological base of the study is represented by theories

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of economic growth and enterprise competitiveness. Given the significant contribution of scientists to the solution of theoretical and methodological problems in the formation and development of enterprise competitiveness, the creation of stable positions, it should be noted that in modern conditions, updating, improving the methodological apparatus for developing managerial decisions on the development of technological innovations is required, which will serve as the basis for choosing a scientific problem many countries. The research methodological base is represented by theories of economic growth and enterprise competitiveness. Given the significant contribution of scientists to the solution of theoretical and methodological problems in the formation and development of enterprise competitiveness, the creation of stable positions, it should be noted that in modern conditions, updating, improving the methodological apparatus for developing managerial decisions on the development of technological innovations is required, which will serve as the basis for choosing a scientific problem many countries. The study is also based on the ideas of a number of modern Western researchers such as, Alcian et al. [1–5].

So foreign scientists of the subject area M. Porter, M. Armstorng, K. Isikawa, A. Morita J. Robinson, G. Hemel and K. Prahad believe that the competitiveness of the enterprise depends on meeting the needs of both its own targeted audience and external Wednesday. We believe this condition should be considered the main thing in a market economy and determine the impact on this term "quality" [1–4].

Scientist D. Ivakhnik discloses this term as follows: "Competitiveness of an enterprise is a complex characteristic of a business entity for a specific period of time in a specific market, reflecting an advantage over competitors in a number of characterizing indicators: financial, economic, marketing, industrial, technological, human and environmental, as well as the subject's ability to function without crisis and operational adaptation to the changing circumstances of the environment" [1–5].

N. Yashin: "The competitiveness of the enterprise, in his opinion, is associated with the possibility and dynamics of adaptation to market conditions. Consider the basic concepts to improve the competitiveness of the enterprise. So the term "competitiveness" is the ability of objects to compare one with another in a similar industry.

We study competitiveness as an economic category for the micro-level and note that this is not only the ability of an enterprise to produce and sell goods or services, but also withstand competition with significant income. This concept is the most profound and requires a detailed theoretical study [1–3].

So, foreign scientists of the subject area M. Porter, M. Armstorng, K. Isikawa, A. Morita J. Robinson, G. Hemel and K. Prahad believe that the competitiveness of the enterprise depends on meeting the needs of both its own targeted audience and external Wednesday. We believe this condition should be considered the main thing in a market economy and determine the impact on this term "quality" [1].

2 Materials and Methods

For the analysis of this problem, theoretical and empirical methods, quantitative and qualitative analysis methods, data aggregation methods, expert evaluation method, classification and structuring of information method, comparison method, reference and statistical data.

We determined earlier that a competitive and sustainable development of a enterprise depends on a number of indicators that determine competitiveness, such as innovative opportunities, competitive advantages, investment attractiveness, etc. This is first of all an assessment of the competitiveness of the internal environment and, accordingly, identification of factors that can be conditionally divided into external and internal factors.

External factors include socio-economic relations, allowing the company to form certain advantages regardless of the influence of state policy, development strategies of the territory where it is located. And as a tool for effective employee policies and relationships in order to increase productivity.

Thus, the nature of specific measures to improve the organization of production is to a certain extent determined by the characteristics of the enterprise and the current situation. At the same time, it is possible to formulate the general direction of work on rationalization and the sequence of their implementation in the association and at the enterprise.

The largest and most united measures to improve the organization of production are introduced into the relevant forms of the current plan. To develop the future and current plans of the enterprise or association, a work plan of activities is being developed, which is a detailed document. Without fail, we will determine the composition of the working group and assign those responsible for monitoring the implementation of these measures.

We will divide all improvement measures into organizational and implementation measures. In Table 1 we define the plan of necessary measures to improve production processes.

We will analyze the process of transporting finished products to the consumer.

In order to get an effective result from the implementation of lean manufacturing tools, you must first try to see the whole process of creating products in terms of processes that create value, and processes that do not create value, that is, losses. By loss we mean useless repetitive actions that should be immediately ruled out.

3 Results

Based on the study of methodology "The Global Competitiveness Report" by K. Schwab the points of the decrease in the social and economic indices of Russia were revealed [6]. In our opinion, they have a negative impact on many branches of the Russian economy: goods market efficiency (intensity of local competition; extent of market dominance; effectiveness of anti-monopoly policy; effect of taxation on incentives to invest; total tax rate % profits no of procedures to start a business; time to start a business days; agricultural policy costs; pevalence of non-tariff barriers; trade tariffs % duty; prevalence of foreign ownership; business impact of rules; burden of customs procedures; degree of customer orientation; buyer sophistication including the potential for innovations, the quality of research institutions, expenses of companies on research and technological development, public purchases of high-technology production, patent certification applications for 2017–2018 (Fig. 1).

According to picture 1, the degree of customer orientation in Russia is characterized by rather low results during the period of 2017–2018 in spite of its leading position in the world rate of natural resources.

Table 1 Proposed Corrective Actions

Problem solver, type of problem	Quality improvement activities	Required resources
1. Lack of production personnel; lack of choice of retraining programs (managerial problem)	1.1 review of personnel policy 1.2 Review of the quantitative ratio of administrative and production personnel 1.3 Elimination of duplication of managerial functions and workplace automation (AWP) 1.4 Development and approval of the matrix project responsibility	The cost of one training program for employees is 8 thousand rubles The approximate cost of one set of AWS in leasing is 45 thousand rubles (system unit, monitor, multifunction devices, uninterruptible power supplies and a barcode scanner)
2. Lack of staff motivation (management problem)	2.1. Payment of bonuses in the absence of complaints and an increase in the speed of customer service 2.2 Changing the corporate identity of all staff 2.2 Regulation of modified business processes, development of pilot programs	The maximum increase in bonuses when fulfilling all quality indicators of work performed by employees is 30% of salary
3. The lack of implementation of internal control and the degree of responsibility (management problem)	3.1 Improving internal control and creating a department for monitoring logistics services 3.2 Development of regulations for audits and audits 3.3 Implementation of all types of control of business processes	Head of the department of internal control with a salary of 30 thousand rubles. in month Analyst of the internal control department with a salary of 20 thousand rubles. in month
4. Lack of staff assessment (management problem)	4.1 Testing and assessment of staff competencies	Included in the duties of the personnel officer, additional resources are not required

(*continued*)

Table 1 (*continued*)

Problem solver, type of problem	Quality improvement activities	Required resources
5. Lack of constructive dialogue with regulatory authorities in matters of law enforcement practice, increase in legal costs in case of cargo loss (management and legal issue)	5.1 Timely response to changes in legislation	Director Responsibilities
6. An insufficiently formed image of the organization (managerial and marketing problem)	6.1 Marketing research of the quality of logistics services, calculation of the effectiveness of each route	The cost of research in the market of marketing services ~70 thousand rubles

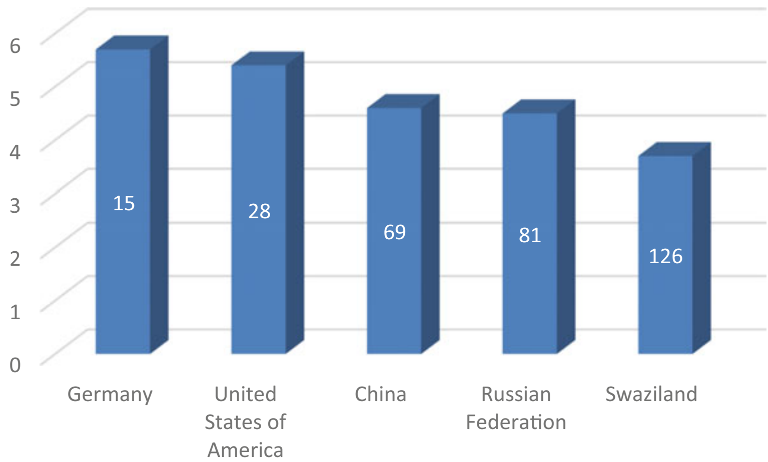

Fig. 1. The rating of countries according to the development of enterprises taking into account the use of degree of customer orientation of the transport company.

For these purposes we have developed a scheme to increase the competitiveness of the transport and service company and its criteria in Fig. 2.

According to Fig. 2, an integrated scheme to improve the competitiveness of the transport company and the criteria for its evaluation it follows that:

1. At the MIDDLE (operational level) of enterprise competitiveness management, the solution to the problems of competitive services is taken into account, which includes the characteristics of financial stability. The solution to these problems must be implemented through the implementation of marketing measures to ensure rolling stock in order to meet the demand for transport services and analyze the market for transport services. The criterion is an aggregate indicator of the competitiveness of auto transport services;
2. At the ENTRY (tactical level) of the transport company, it seeks to provide a stable financial and economic status and other indicators. The main task of this level is the problem of ensuring economic and managerial transparency, financial accounting and reporting. The criteria for this level are the ratio of supply and demand, quality of services, resources;
3. At the TOP (strategic level) of the competitiveness of the transport company, the valuation of the transport company are the main tools to ensure competitiveness, as the methods offer accurate and interconnected evaluation criteria, on the basis of which it is possible to control the competitiveness of the transport company. At a strategic level of competitiveness management of a transport company, it is necessary to give preference to a system of criteria and the use of expert approaches, which are in the form of a real mechanism for implementing the strategic level.

A relatively recent increase in competitiveness has been determined by the fact that this term is interpreted as follows: to which object (subject) does it refer? In its

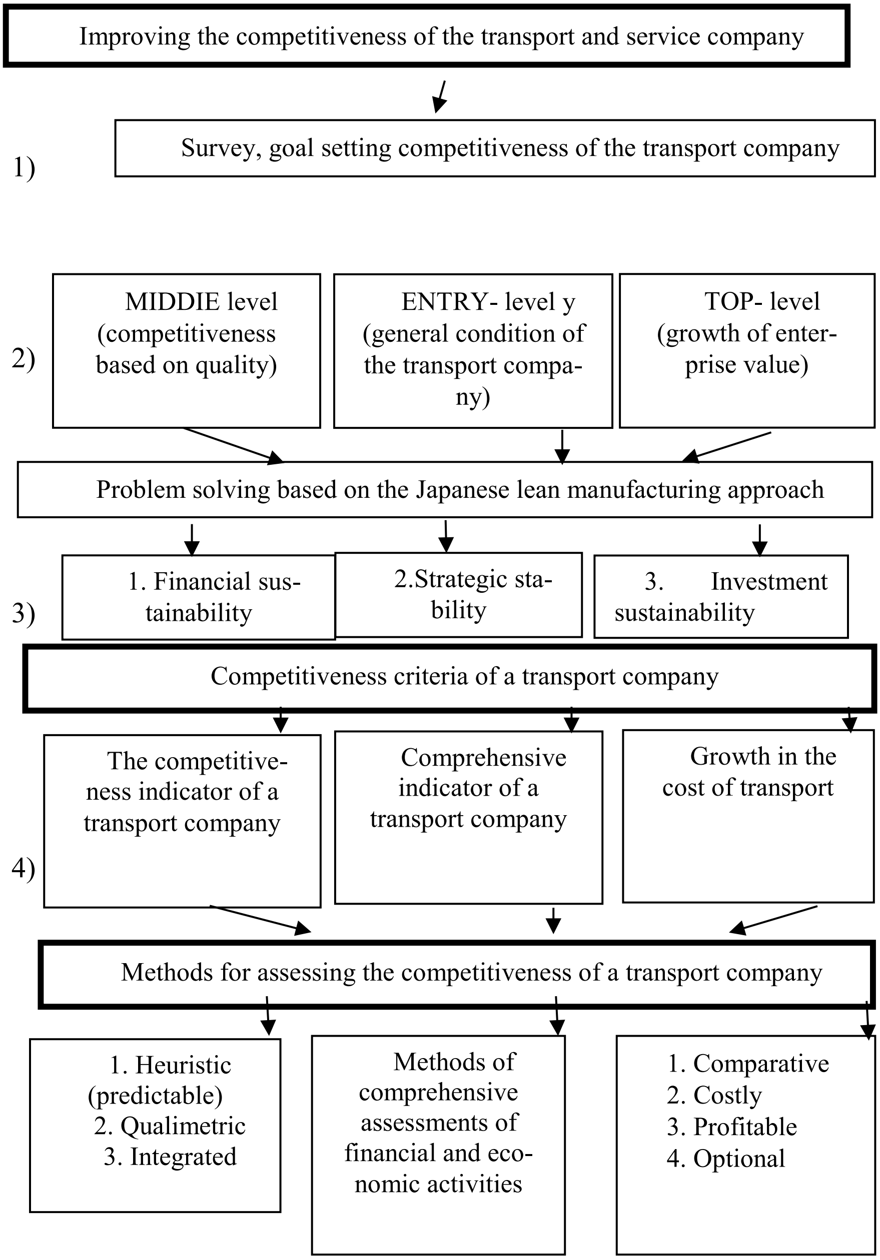

Fig. 2. The competitiveness of the transport and service company and its criteria.

most general form, competitiveness in economic science is understood as the ability to compete with similar objects in a particular market, using competitive advantages to achieve its goals. Competitiveness is not a simple economic category, considered at four levels, they are presented in Table 1.

Identify all losses allows the construction of a map of the stream of creating value. This is the graphic representation of the entire product transportation process. Mapping the flow of values will start from the last section of the logistics, and carried out in the opposite direction until the start of the distribution cycle. We'll draw up a map of the value stream and analyze in detail the processes that occur at each section of the transformation of the proposed service.

The table shows that in addition to identifying managerial problems, we offer measures to improve the quality of logistics services through the revision and recalculation of transportation of products and the required resources for changing business processes.

We propose to study the production problems that we have identified that affect the performance of the enterprise (Table 2).

Table 2 Overpriced transportation of products, recalculation of transportation routes (production problem)

Problem solver, type of problem	Activities to improve the quality of customer service	Optimization must go into a changed business process
1. Damage to client cargo during transportation (production problem)	1.1 Optimization of business processes for the uninterrupted supply of transport and logistics services	Included in management responsibilities, no additional resources required
2. Overpriced transportation of products recalculation of transportation routes (production problem)	2.1 Development of a flexible pricing strategy for tariffs	Development and organization of work should go into a changed business process for the development of new services
3. Transformation of the process of providing additional services (production and service problem)	3.1 Development of basic logistics services	Corrective action

The table shows that in addition to identifying production problems, we offer measures by optimizing the production functions that should be included in the modified business processes for personnel management.

Quality improvement is proposed through the optimization of seven business processes:

1. Process: Documentation, records management.
2. Process: HR and customer management.
3. Process: Printing QR codes.
4. Process: Commitment to leadership.

5. Process: Corrective and preventive actions.
6. Process: New product development.
7. Process: Customer focus.

Summarizing the foregoing, we came to the conclusion that it is necessary to control all business processes:

- Development and implementation of quality policy;
- Resource management;
- Creation in the documented procedure “Personnel management of the creation of a subprocess: evaluation by the “540 method”;
- Feedback from consumers;
- Development of new services taking into account the requirements of consumers.

Optimization of business processes for the uninterrupted supply of transport and logistics services and other activities we have proposed will increase the growth rates of enterprises, creating a competitive advantage in comparison with competing logistics companies.

4 Conclusion

Based on the data of the study, the following conclusions can be drawn:

1. There is a need on the part of the management to strengthen the work on managing the enterprise’s competitiveness by constantly monitoring and monitoring the internal and external environment.
2. Once a quarter, conduct a rating analysis and evaluate the competitive environment of the enterprise.
3. Conduct surveys of employees in order to increase productivity.
4. Introduce a quality management system in the business processes of the enterprise.
5. To increase innovative activity and innovative activity in accordance with the social interests of consumers and customers.
6. The proposed set of tools, including personnel, investment optimization of the enterprise’s business processes, will complement the sustainable development tools in accordance with state priorities and the hierarchy of goals. It is this approach that will give the most high-quality, oriented to the future.
7. To ensure the sustainability of the internal environment of enterprises (mission, tasks, technologies and workers) it is necessary to solve problems and problems, including those related to maintaining the functioning of the Russian economy in innovative conditions, transforming property relations, interacting with other enterprises, while maintaining a balance of regional and national interests.
8. Ensuring the strategic sustainability of the transport industry can become one of the most important areas of modernization of enterprises and their access to an innovative and sustainable development path, contribute to identifying the most effective “fields of management decisions” to increase business and innovation activity of employees and enterprises in general, which ultimately As a result, it will give an impetus to technological innovation.

Scientific works by Russian scientists Kolbachev, E., Kolbacheva, T., Cherkesova, E., Breusova, E., Savchishkina, E., Demidova, N. are devoted to the research of the analytic aspects of enterprise management and to the issues of the assessment of the level of a business activity of enterprises in particular, where the complex approach is the approach in which the number of phenomena i.e. economic behavior of the subjects of the local market in the region is considered [7–9].

We should particularly distinguish such scientists as Tatuev, A., Abanokova, E., Ovcharova, N., Rakotyanskaya, V., Usanov, A., Tkacheva, O., Popova, E., Sukhova, A., Grevtseva, E., Karashchenko, V., Goloshchapova, L., Dovlatova, G., Zatsarinnaya, E., Tkacheva, O., Chistyakov, A., Agafonov, A., who try to find the responses to modern transport and production challenges coming from structural reproductive processes [10–12].

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