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OPTIMIZATION OF PRODUCTION RESOURCES IN SCIENCE-BASED COMPANIES: A MATHEMATICAL MODEL INCLUDING A FIXED SHARE OF IMPORTS

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Abstract. The Russian economy is highly import-dependent, which is also relevant for the enterprises of the science-intensive industry. The later is based on the emerging realities, and strives to develop and introduce a strategy that would allow for the most efficient implementation of the planned import substitution program. In this research the authors have developed a comprehensive mathematical model that takes into account the peculiarities of the local labour and technical capital market, as well as their impact on the production costs of the science-based enterprise. The practical application of indicators that can define the current state and the level of dependence of science-based production on foreign raw materials will provide grounds for a revision of the existing development strategy. What is more, it will be possible to take into due consideration the mission of import substitution, based on the available resources of the enterprise and the maximum permissible share of imports in production.

Keywords: mathematical model, production estimation, production efficiency, science-based industry, import, import substitution

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ОПТИМИЗАЦИЯ ПРОИЗВОДСТВЕННЫХ РЕСУРСОВ НАУКОЕМКИХ ПРЕДПРИЯТИЙ: МАТЕМАТИЧЕСКАЯ МОДЕЛЬ С УЧЕТОМ ФИКСИРОВАННОЙ ДОЛИ ИМПОРТА

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Аннотация. Российская экономика, безусловно, зависит от импорта, в том числе и от предприятий наукоемкой отрасли, что, в свою очередь, исходя из складывающихся реалий, ставит перед ними задачу разработки и внедрения стратегии, позволяющей наиболее эффективно реализовывать запланированную программу импортозамещения. В данном исследовании авторами была разработана математическая модель, которая позволяет учитывать особенности местного рынка рабочей силы и технического капитала, а также их влияние на стоимость производственного процесса наукоемкого предприятия. Применение на практике показателей, способных охарактеризовать текущее состояние и уровень зависимости наукоемкого производства от зарубежного сырья, позволит пересмотреть текущую стратегию развития предприятия с учетом задачи импортозамещения, исходя из имеющихся ресурсов предприятия и максимально допустимой доли импорта.

Ключевые слова: математическая модель, оценка производства, эффективность производства, наукоемкая отрасль, импорт, импортозамещение

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Introduction

Since science-based enterprises make the engine of economic growth in our country, effective assessment of production provides grounds for timely process optimization, identification of new development paths, and implementation of innovations. Production evaluation in science-intensive industries is important and requires modern approaches for their analysis, including the development of architectural solutions for IT support of R&D, thus contributing to the integration of enterprise systems, process automation, and data security. The benefit that are brought in via the implementation of standards (e.g. TOGAF) and conceptual architectures improve performance, reduce costs, and help enterprises adapt to changing conditions. These approaches are especially important for modelling resource optimization processes of science-based enterprises. The problem with evaluating the impact of imported components on production derives from the lack of developed tools for assessment and adaptation of production processes with due consideration of the ongoing changes that result in import substitution in all sectors of the economy, including science-intensive industries.

The main measure aimed at the development of science-intensive production is the refusal of imports, which, in turn, is likely to put excessive burden on the available resources of the

Russian production. With the resource shortage, chances are that the price for local resources of Russian production will grow; their appreciation will become a consequence of demand growth, thus leading to higher prices for the final product and increased cost of the production process. Therefore, the shift to domestic resources should be well planned and, ultimately, should increase the efficiency of science-intensive production, thereby reducing dependence on imported resources and increasing the sustainability of the economy as a whole.

Materials and Methods

The present day economy invites various mathematical multi-factor models for assessing import dependence in terms of the impact of foreign trade on domestic production, including in the science-intensive industry, employment, and other economic parameters. Such models allow determining the changes in import conditions that affect the economic sustainability of the country (Batkovskiy, Fomina, Semenova, Khrustalev, Khrustalev, 2016). The study by Urrutia et al., 2015, articulated a mathematical model of imports and exports in the Philippines. Paired tests show that there is no significant difference between the predicted and actual value of both import and export (Urrutia et al., 2015; Drath, Horch, 2014).

For many years, scholars have been studying the short-run adjustment of the economy to sustained increases in the prices of imported goods. On the other hand, they have paid attention to the impact of imported inflation on the terms of trade (Shinkai, 1973). The foreign sector in conventional macroeconomic models has not been properly integrated with behavioural relationships in the rest of the economy. The aggregate-producing sector is usually depicted as employing primary factors, capital and labour, to produce a single output that simultaneously meets the demands of consumers, producers, governments, and foreigners. In this one-sector model, imports are implicitly assumed to be either final goods that enter the utility functions of consumers, or intermediate goods that are separable from primary factors in production (Fayoumi, Williams, 2021). The first assumption conflicts with empirical evidence that the bulk of international trade occurs in intermediate goods, while the second assumption involves a substantive restriction on the form of the technology that ought to be examined and justified empirically rather than assumed (Burgess, 1974).

For a comprehensive consideration of the issues raised in this research, the authors also studied works related to the development of an economic mechanism for optimizing the innovation and investment program in the development of agro-industrial production (Brockova, Rossokha, Chaban, Zos-Kior, Hnatenko & Rubezhanska, 2021; Kalugin, 2013), as well as issues of adaptation of high-tech science-intensive enterprises to the challenges of Industry 4.0 (Poloskov, Zheltenkov, Braga & Kuznetsova, 2020). It is worth noting that Industry 4.0, in a broad sense, characterizes the current trend of automation and data exchange. It includes cyber-physical systems, the Internet of Things, cloud computing, and represents a new level of production organization and value chain management throughout the entire life cycle of manufactured products (Rossini et al., 2021). At the same time, estimation of production in science-intensive industries involves certain difficulties (Guevara-Rosero, Carriyn-Cauja, Simbaca-Landeta, and Camino-Mogro, 2023). For instance, assessment of production in science-intensive industries is important and requires the use of modern approaches for their analysis, including the development of architectural solutions for IT support of R&D (Chemeris, Dubgorn & Tick, 2022), which allows for the integration of enterprise systems, process automation, and data security.

In order to achieve the aim of this research, the authors employ the following methods: observation, system analysis, economic, mathematical and experimental modelling, abstract-logical and graphical methods.

Results and Discussion

Since the existing mathematical assessment models do not take into account a fixed share of imports, there is an urgent need for development of a mathematical model aimed at estimation of production at Russian science-based enterprises with due consideration of imports. Thereby, it is essential to:

– reflect the impact of international economic and political changes on the development of production in a modern way;

– analyze the impact of foreign goods on competition and demand for Russian products;

– improve the accuracy of productivity and efficiency assessment of Russian industrial companies;

– determine the dependence of science-intensive enterprises on import supplies;

– develop new technologies to promote economic independence from foreign raw materials and, as a consequence, increase the resistance to change in the foreign market.

In order to find the optimal parameters of production in science-intensive industries a mathematical model should be built. Let the production function of a science-based enterprise be defined as follows:

$$Q = f(L,K), \tag{1}$$

where:

Q is a volume of output;

L is labor resources;

K is a volume of used technical capital.

Technical capital is a set of tangible and intangible resources that are necessary for the production of science-intensive enterprises. It includes equipment, components, materials and semi-finished products, software, licenses and patents for the use of technical solutions and other resources that implemented in production.

Let us assume that technical capital includes local (national) and external (imported) components:

$$K = K_{out} + K_{local} \tag{2}$$

where:

K_{out} is external (imported) technical capital;

K_{local} is local (national) technical capital.

The share of external capital in total capital K is given as:

$$K_{out} = \theta * K, \ K_{local} = (1-\theta) * K \tag{3}$$

where:

K is total technical capital;

θ is a share of external (imported) capital ($0 \le \theta \le 1$).

The share of external (imported) technical capital (parameter θ) is of practical importance because the enterprise sometimes faces the need to use external technical capital with a not more than a pre-approved and strictly regulated share of the total value of technical capital.

Taking into account the introduced parameter θ, the production function takes the form:

$$Q = f(L,K,\theta) \tag{4}$$

Total labor costs, local capital K_{local} and external capital K_{out} should not exceed the C budget:

$$C_L(L) + C_{local}(K,\theta) + C_{out}(K,\theta) \le C \tag{5}$$

where:

C is total production budget (a given constant);

$C_L(L)$ is labor costs (cost of labor);

$C_{local}(K,\theta)$ is expenditures on local (national) technical capital, a function of the technical capital K involved in production and the share of the external (imported) component in it θ;

$C_{out}(K,\theta)$ is the cost of external (imported) technical capital, a function of the technical capital K involved in production and the share of the external (imported) component in it θ.

The problem of finding the optimal production parameters L^*, K^* *and* θ^* is an issue of maximizing the production function (4) under the budget constraint (5). To solve the problem using the Lagrangian method, the Lagrangian function is introduced (Cranmer, Greydanus, Hoyer, Battaglia, Spergel & Ho, 2020):

$$\mathcal{L}(L,K,\theta,\lambda) = f(L,K,\theta) - \lambda(C_L(L) + C_{local}(K,\theta) + C_{out}(K,\theta) - C) \tag{6}$$

where:

λ is Lagrange multiplier, reflecting the growth of the production function $f(L,K,\theta)$ when the budget constraint is changed by one.

In order to find the optimal production parameters L^*, K^* *and* θ^* it is necessary to calculate partial derivatives of the Lagrangian function on the variables.

In the considered mathematical model it is assumed that the increase in production volumes by a science-based enterprise located in a certain closed system (region, country, group of countries) has a significant impact on the local labor market and resource market. At the same time, the impact of this enterprise on the international (external, in relation to the closed system) resource market is considered insignificant and can be ignored.

The matter is that in the real economy, as the demand for labor increases, the cost of hiring additional workers begins to grow faster than linearly. The first reason is the limited labor resource, since in the local labor market the qualified workers are scarce. In order to attract additional resources, the enterprise is forced to offer higher wages. Another reason for the rising cost of labor is the incentive to overwork. When already hired workers are forced to do overtime, their labor is paid at higher rates, leading to a growth of labour costs with increasing volume.

Based on the specifics mentioned above, it is possible to assume that the labor cost W(L) has the following dependence on the volume of labor:

$$W(L) = w_0 + k * L^2 \tag{7}$$

where:

w_0 is base labor cost;

k > 0 is a coefficient of labor cost growth depending on the volume L.

Considering (7), the following dependence of labor costs is obtained:

$$C_L(L) = W(L) * L = w_0 * L = k * L^3 \tag{8}$$

In the local market, the supply of technical capital is limited. As demand increases, enterprises begin to compete for limited resources, which leads to higher prices. Let us assume that as demand grows, local producers start to raise prices linearly to compensate for the growth of their costs and take advantage of market conditions. Then, the dependence of the cost of local technical capital, as follows $R_{local}(K_{local})$, will have the form of:

$$R_{local}(K_{local}) = r_0 + m * K_{local} \tag{9}$$

where:

r_0 is base (initial) cost of a unit of local technical capital;

m is a coefficient of price growth of technical capital depending on its consumed volume.

Considering (9), the dependence of costs on local technical potential goes as follows:

$$C_{local}(K,\theta) = R_{local}(K,\theta) * K_{local} = (r_0 + m * K_{local})K_{local} \tag{10}$$

Given (3), it turns out that:

$$C_{local}(K,\theta) = (r_0 + m * (1-\theta) * K) * (1-\theta) \tag{11}$$

Let us assume that the change in the consumption volume of technological capital at the local enterprise is not able to have a significant impact on pricing in the international market.

Thus, the cost of external technical capital will be considered unchanged:

$$R_{out}(K,\theta)=p_{out} \tag{12}$$

Considering (12), the dependence of expenditures on external (imported) technical potential is obtained:

$$C_{out}(K,\theta)=R_{out}(K,\theta)*K_{out}=p_{out}*K_{out} \tag{13}$$

Taking into account (3), we obtain:

$$C_{out}(K,\theta)=p_{out}*\theta*K \tag{14}$$

In order to model the production process of a science-based enterprise, we will employ the Cobb-Douglas production function. This function is universal and reflects the key aspects of production in high-tech industries, including labor, capital and their interaction (Douglas, 1928):

$$Q(L,K)=A*L^{\alpha}*K^{\beta} \tag{15}$$

where:

Q is the output volume;

L is labor resources;

K is the amount of technical capital utilized;

A is a coefficient reflecting the level of technology;

α,β is elasticity of output by labor and capital.

Substituting (15), (14), (11), (8) into (6) we obtain the Lagrangian function in the following form:

$$\begin{aligned}\mathcal{L}(L,K,\theta,\lambda)&=A*L^{\alpha}*K^{\beta}-\lambda((w_0*L+k*L^3)+\\&+(r_0+m*(1-\theta)*K)*(1-\theta)+p_{out}*\theta*K-C)\end{aligned} \tag{16}$$

To find the optimal values of L^*,K^*,θ^* we will take partial derivatives of the obtained function (16) on the variables L,K,θ,λ and equate them to zero.

The derivative of L (labor) will be as follows:

$$\frac{\partial\mathcal{L}}{\partial L}=A*\alpha*L^{\alpha-1}*K^{\beta}-\lambda*(w_0+3k*L^2) \tag{17}$$

The derivative of K (technical capital):

$$\frac{\partial\mathcal{L}}{\partial K}=A*\beta*L^{\alpha}*K^{\beta-1}-\lambda*(m*(1-\theta)^2+p_{out}*\theta) \tag{18}$$

The derivative of θ (the share of imported technical capital):

$$\frac{\partial\mathcal{L}}{\partial\theta}=\lambda*(r_0+2m*(1-\theta)*K-p_{out}*K) \tag{19}$$

The derivative of λ (budget constraint):

$$\frac{\partial\mathcal{L}}{\partial\lambda}=(w_0*L+k*L^3)+(r_0+m*(1-\theta)*K)*(1-\theta)+p_{out}*\theta*K-C \tag{20}$$

To find the values of $L^*,K^*,\theta^*,\lambda^*$ it is necessary to solve the resulting system of equations, which consists of 4 equations (17), (18), (19), (20) with respect to the variables L,K,θ,λ:

$$\begin{cases}A*\alpha*L^{\alpha-1}*K^{\beta}-\lambda*(w_0+3k*L^2)=0\\A*\beta*L^{\alpha}*K^{\beta-1}-\lambda*(m*(1-\theta)^2+p_{out}*\theta)=0\\\lambda*(r_0+2m*(1-\theta)*K-p_{out}*K)=0\\(w_0*L+k*L^3)+(r_0+m*(1-\theta)*K)*(1-\theta)+p_{out}*\theta*K-C=0\end{cases} \tag{21}$$

The resulting system of 4 equations is nonlinear and has no analytical solution for the general case. For specific values of parameters ($A,\alpha,\beta,w_0,k,r_0,m,C,p_{out}$) the solution can be found only numerically using optimization methods.

If the variable θ is considered as a predetermined parameter, for example, the enterprise has a task to use imported capital by no more than 30% (θ_c = 0,3), then the system of equations (21) will take the following form:

$$\begin{cases} A*\alpha*L^{\alpha-1}*K^{\beta}=\lambda*(w_0+3k*L^2) \\ A*\beta*L^{\alpha}*K^{\beta-1}=\lambda*(m*(1-\theta_c)^2+p_{out}*\theta_c) \\ w_0*L+k*L^3+(r_0+m*(1-\theta_c)*K)*(1-\theta_c)+p_{out}*\theta_c*K=C \end{cases} \quad (22)$$

The resulting system of 3 equations is also nonlinear and has no analytical solution for the general case. For specific values of parameters ($A,\alpha,\beta,w_0,k,r_0,m,C,p_{out},\theta_c$) the solution can be found only numerically using optimization methods.

The economic essence of the developed model is to apply a mathematical model that takes into account a fixed share of imports θ to optimize the production resources of knowledge-intensive enterprises. Fig. 1 schematically depicts the optimization directions of import substitution strategies using the proposed mathematical model.

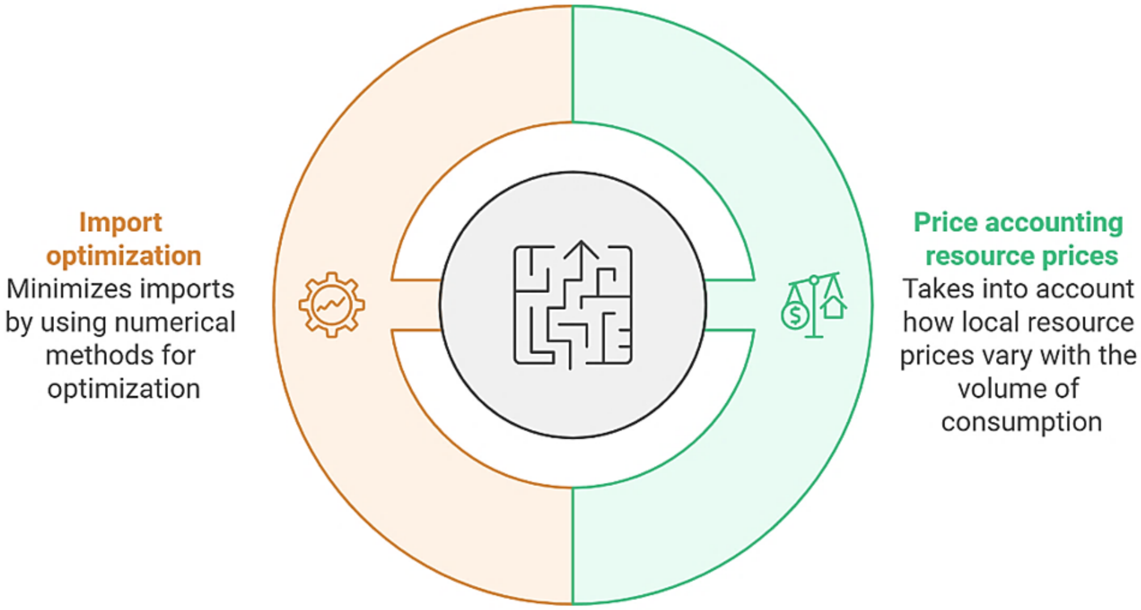

Fig. 1. Optimization directions of import substitution strategies using the proposed mathematical model (designed by the authors)

Overall, the mathematical model suggested in this research allows to:

– Take into account the dependence of prices of local resources on their planned consumed volume when generating the import substitution strategy;

– Determine the optimal strategy to reduce the share of imports involved in production using numerical methods.

This model makes a tool for resource optimization, improvement of management decisions, and strategic planning in the science-intensive industry as a whole. As the analysis shows, the cost of labour and local technical capital nonlinearly depend on the volume of their use, which is explained by the resource scarcity, competition in local markets, and rising costs. Taking into account these factors, the enterprises can plan costs more accurately and avoid price fluctuations.

Conclusion

The model developed in this research provides enterprises with a tool for strategic planning, allows them to respond quickly and adapt production processes to changes in the external environment, allocate resources more efficiently, reduce costs, and increase productivity. Its application contributes to the overall development of strategies aimed at reduction of dependence on imports and higher resilience to external economic challenges. In the further research it is planned to make the model more accurate via expanding and including additional criteria, such as the impact of technological innovation, and the dependence of prices for technical capital and labour resources on time (inflationary component). To sum up, the suggested model proves to be very promising in terms of its potential use in various branches of science-intensive production to ensure efficiency and competitiveness.

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FORECASTING USING COMPLEX-VALUED AUTOREGRESSION WITH ERROR

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Abstract. This article discusses the possibility of predicting the values of a series using complex-valued autoregression with an error for short-term forecasting. The authors consider the basic concepts of the function of a complex-valued variable and the model of complex-valued autoregression, together with the results of applying first- and second-order models of complex-valued autoregression with the CARE(p) error to describe and predict the initial series. The results obtained are compared with the first- and second-order autoregression in real numbers. A complex-valued autoregression model with an error showed a more accurate result for short-term forecasting, unlike the autoregression model in real numbers. The authors also conclude that complex-valued autoregression with an error is subject to further investigation in order to find out the prospects of using its imaginary part.

Keywords: complex-valued autoregression with error, complex numbers, short-term forecasting, autoregressive model, standard deviation, function of complex-valued variable

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ПРОГНОЗИРОВАНИЕ С ИСПОЛЬЗОВАНИЕМ КОМПЛЕКСНОЗНАЧНОЙ АВТОРЕГРЕССИИ С ОШИБКОЙ

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Аннотация. В данной статье рассматривается возможность прогнозирования значений ряда с использованием комплекснозначной авторегрессии с ошибкой для краткосрочного прогнозирования. Рассматриваются основные понятия теории функции комплекснозначного переменного и модели комплекснозначной авторегрессии, приводятся результаты применения моделей первого и второго порядка комплекснозначной авторегрессии с ошибкой CARE(p) для описания и прогнозирования исходного ряда, сравниваются полученные результаты с результатами авторегрессии первого и второго порядков в действительных числах. В результате исследования, авторами был сделан вывод о возможности применения модели комплекснозначной авторегресии с ошибкой, так как она показала более точный результат для краткосрочного прогнозирования, в отличие от модели авторегрессии в действительных числах. Так же делается вывод, что комплекснозначная авторегрессия с ошибкой подлежит дальнейшему исследованию, чтобы выяснить возможность применения её мнимой части.

Ключевые слова: комплекснозначная авторегрессия с ошибкой, комплексные числа, краткосрочное прогнозирование, модель авторегрессии, среднеквадратичное отклонение, функция комплекснозначного переменного

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Introduction

Nowadays, humans often ask themselves the question, “What’s coming?”. We tend to find specific interest in the events that are coming even if it is impossible to look into the future. Many forecasters try to make their prognosis as close to reality as possible. Unfortunately, a forecast can never be one hundred percent correct, since numbers and formulas fail to describe our complex and constantly changing world. Still, everyone is trying to find a model that will be able to capture the trends of change.

As the volume of data in today's information society grows, forecasting plays an important role in various fields, from economics and finance to data science and marketing. Forecasting is an integral part of our lives. Every day we attempt to predict the outcome of various events and calculate our chances for all possible options. We even check out the weather forecast before going outside.

There are many different models that are capable of “predicting” the future to varied degrees. This research focuses on modelling stationary reversible processes that can be predicted using autoregressive models. Today, autoregressive models are the most frequently used ones in short-term economic forecasting (Svetunkov, 2021). For some reason, most forecasters use real numbers for their forecasts, considering complex numbers to be the prerogative of physicists and mathematicians (Doronin, 2023; Andrei, 2021). It does make sense, since complex numbers consist of two parts: real and imaginary. However, what is the imaginary part in the real world? Most forecasters probably stumble at this question and get back to the well familiar real numbers. For example, when modelling production processes, production functions of complex variables describe these processes in more detail and, in a number of cases, demonstrate greater accuracy than production functions of real variables (Svetunkov, 2019).

In this paper the authors briefly review the theory of complex-valued variables and examine the application of complex-valued autoregressive models such as CARE.

Materials and Methods

A complex number is a pair of numbers consisting of two parts – real and imaginary:

$$Z = x + iy$$

where,

x is the real part of a complex number;

iy is the imaginary part of a complex number;

x and y are real numbers;

i is the imaginary unit, which satisfies the equality: $i = \sqrt{-1}$

Complex numbers are quite an interesting tool that gives more possibilities, unlike real numbers. At the same time, it is possible to carry out all the same operations with real numbers as with complex numbers (Vasilyeva, 2019). Why then, is this tool not as popular among forecasters? It happens to be all about the imaginary part. Many do not understand its meaning in the real world, which is clear, because there is nothing imaginary in our world, only real. In fact, complex numbers are simply a tool for reflecting reality, like any procedure in mathematics, so almost any characteristic of a process can become imaginary.

A complex number consists of a pair of numbers. Thus, in order to reflect it on a plane, two numerical axes must be used. The real part of the number is plotted along the abscissa axis, and the imaginary part along the ordinate axis. Figure 1 shows a complex number in a Cartesian coordinate system.

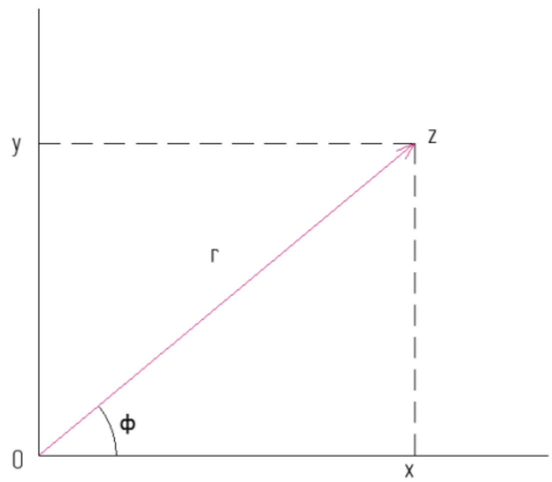

Fig. 1. Complex number in Cartesian coordinate system.

A complex number can be represented as a vector that starts at the origin and ends at point Z. Then any complex number can be represented in polar coordinates:

$$z = x + iy = r(\cos\varphi + i\sin\varphi) \quad (2)$$

where,

φ is the polar angle;

r is the polar radius (vector length), which is called the modulus of a complex number (Zvereva, 2021).

The modulus of a complex number is equal to:

$$r = \sqrt{x^2 + y^2} \quad (3)$$

The polar angle can also be easily found:

$$\varphi = arctg\frac{y}{x} + 2\pi k \quad (4)$$

where,

k is an integer. Sometimes the polar angle is called the argument of a complex number. In most cases, the condition k = 0 is accepted.

The fact that complex numbers can be considered simultaneously in both Cartesian and polar coordinates is their advantage over real numbers. Another important property of complex numbers, which will be useful to us for further research, is that two complex numbers are equal to each other if and only if their real and imaginary parts are equal to each other:

$$y_r + iy_i = F(y_r + iy_i) = f_r(x_r) + if_i(x_i) \quad (5)$$

We will consider the following form as a more compact:

$$\begin{cases} y_r = f_r(x_r) \\ y_i = f_i(x_i) \end{cases} \quad (6)$$

It is important to note that in this form of notation we have gotten rid of the imaginary unit, and for those who are not familiar with the theory of functions of a complex-valued variable, it will be easier to perceive this equality (the imaginary unit remains only in the indices to distinguish between variables). Modern researchers who use random variables in their work always believe that their parts (real and imaginary) are independent of each other (Tavares, 2006; 2007; Kennedy, 2008). Some scientists also consider the dependence of these parts, although they add the prefix "pseudo" – pseudo covariance or pseudo dispersion (Kammeyer, 2002; Picinbono, 2009). S.G. Svetunkov in his works (Svetunkov, 1999; 2019) demonstrated the conditions for the dependence of these two parts.

More information on the theory of functions of a complex-valued variable can be obtained from the manual "Complex numbers and functions of a complex variable" (Gamova, 2022; Peca, 2011). For further research in the framework of this paper, the presented information is more than sufficient.

Results and Discussion

Complex-valued autogression model

Let us examine models of complex-valued autoregressions for short-term forecasting (Svetunkov, 2021).

In general, the complex autoregressive model can go as follows:

$$y_{1t} + iy_{2t} = \sum_{\tau=1}^{p} F(y_{1(t-\tau)} + iy_{2(t-\tau)}) + (\varepsilon_{1t} + i\varepsilon_{2t}) \quad (7)$$

where,

y_{1t} and iy_{2t} are the real variables predicted at time t;

i is the imaginary unit, $i = \sqrt{-1}$;

F is some complex-valued function;

τ is the autoregressive lag;

p is the autoregressive order;

ε_{1t} and ε_{2t} are the approximation errors of the first and second variables at time t.

Depending on the type of function F, complex autoregressions can be linear and nonlinear. Nonlinear autoregressive models of real variables are not often encountered in either practical applications or theoretical studies. Therefore, we will use linear autoregressions and denote them as CAR(p). Thus, the considered complex-valued autoregressive models CAR(p) in general will be presented in the following form:

$$y_{1t} + iy_{2t} = (b_0 + ib_1) + \sum_{\tau=1}^{p} (a_{0\tau} + ia_{1\tau})(y_{1(t-\tau)} + iy_{2(t-\tau)}) + (\varepsilon_{1t} + i\varepsilon_{2t}) \tag{8}$$

where,

b_0 and b_1 are coefficients (free terms) reflecting the initial value of the complex series;

$a_{0\tau}$ and $a_{1\tau}$ are proportionality coefficients.

If we center the variables relative to the arithmetic mean, we can get rid of the free terms.

Then, the first-order complex autoregression CAR(1) can be represented as:

$$\hat{y}_{1t} + \hat{y}_{2t} = (a_{01} + ia_{11})(y_{1(t-1)} + iy_{2(t-1)}) \tag{9}$$

In this model, two variables are predicted. We transform this model to predict one variable, taking the second variable equal to the error ε_t, because it can serve as a characteristic of the process. Our model will take the following form:

$$\hat{y}_t + \hat{\varepsilon}_t = \sum_{\tau=1}^{p} (a_{0\tau} + ia_{1\tau})(y_{t-\tau} + i\varepsilon_{t-\tau}) \tag{10}$$

This model is usually refered to as a complex-valued autoregression with error and is denoted by CARE(p).

The idea of such a complex model was put forward first by I.S. Svetunkov back in 2011, when the complex-valued form of the exponential smoothing model was presented (Svetunkov, 2012; Racine, 2019). Research has shown that the complex-valued exponential smoothing model provides more accurate economic forecasts compared to exponential smoothing models of real variables (Svetunkov, 2015).

The CARE(p) model, as discussed earlier, can be represented as a system of two real variables:

$$\begin{cases} \hat{y}_t = \sum_{\tau=1}^{p} (a_{0\tau} y_{t-\tau}) - \sum_{\tau=1}^{p} (a_{1\tau} \varepsilon_{t-\tau}) \\ \hat{\varepsilon}_t = \sum_{\tau=1}^{p} (a_{0\tau} \varepsilon_{t-\tau}) + \sum_{\tau=1}^{p} (a_{1\tau} y_{t-\tau}) \end{cases} \tag{11}$$

Then for the real part of the complex-valued model we get:

$$\text{ReCARE:}\ \hat{y}_t = \sum_{\tau=1}^{p} (a_{0\tau} y_{t-\tau}) - \sum_{\tau=1}^{p} (a_{1\tau} \varepsilon_{t-\tau}) \tag{12}$$

And for the imaginary part of this model:

$$\text{ImCARE:}\ \hat{\varepsilon}_t = \sum_{\tau=1}^{p} (a_{0\tau} \varepsilon_{t-\tau}) + \sum_{\tau=1}^{p} (a_{1\tau} y_{t-\tau}) \tag{13}$$

Thus, in economic forecasting, in addition to the general CARE(p) model, two other independent models can be used: ReCARE(p) and ImCARE(p) (Svetunkov, 2020).

Using the CARE(p) model and comparing the CARE(1) and CARE(2) models

As mentioned earlier, the CARE(p) model can be used as a system of two equalities:

$$\text{ReCARE: } \hat{y}_t = \sum_{\tau=1}^{p}(a_{0\tau} y_{t-\tau}) - \sum_{\tau=1}^{p}(a_{1\tau}\varepsilon_{t-\tau}) \quad (14)$$

$$\text{ImCARE: } \hat{\varepsilon}_t = \sum_{\tau=1}^{p}(a_{0\tau}\varepsilon_{t-\tau}) + \sum_{\tau=1}^{p}(a_{1\tau} y_{t-\tau}) \quad (15)$$

These models describe a series with some error, and the problem of estimating the coefficients $a_{0\tau}$ and $a_{1\tau}$ is reduced to minimizing the sum of the squares of this error. For models (14) and (15), these errors are respectively equal to:

$$\text{Re: } \varepsilon = y_t - \hat{y}_t \quad (16)$$

$$\text{Im: } \mu = \varepsilon_t - \hat{\varepsilon}_t \quad (17)$$

Moreover, if we minimize the sum of squares (16), then the errors (17) will be very large, and vice versa.

For the study, series No. 2810 was taken from the International Institute of Forecasters database. For this series, forecast values ($\hat{y}_t$) and forecast deviations ($\hat{\varepsilon}_t$) were calculated using the CARE(1) and CARE(2) models.

The results obtained are presented in Figure 2.

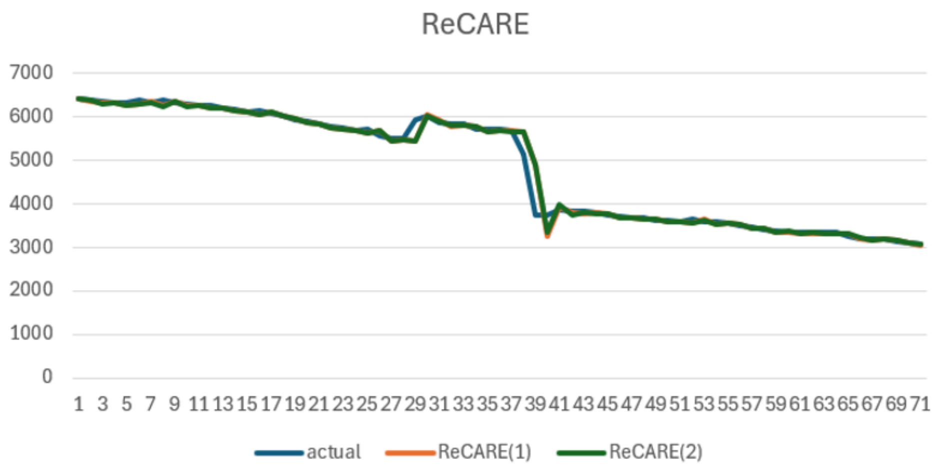

Fig. 2. Initial series y_t and calculated values of the model ReCARE(p).

The model, as can be seen from the figure, described the series well and was able to capture the trends of change. There is no particular difference between the models ReCARE(1) and ReCARE (2).

The results obtained for the model ImCARE(p) are presented in Figure 3.

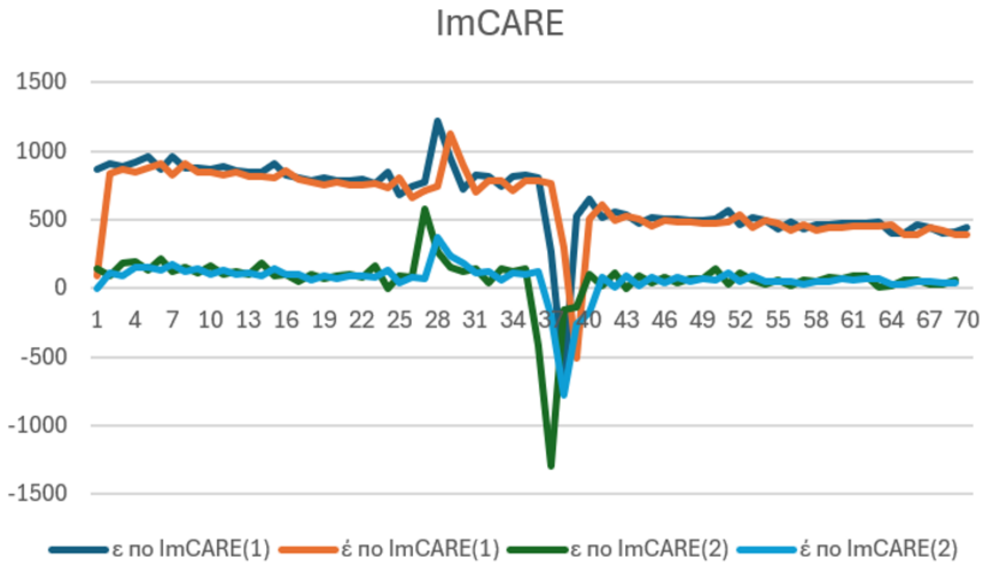

Fig. 3. Deviations ε_t and calculated values of model deviations ImCARE(p).

Models ImCARE(1) and ImCARE(2) also coped well with the task. They adequately described the deviations of their own models. However, these models described errors ε_t, with absolutely different coefficients $a_{0\tau}$ and $a_{1\tau}$ from models ReCARE(1) and ReCARE(2). Here, the question does arise: "How did the calculated values y_t deal with the coefficients $a_{0\tau}$ and $a_{1\tau}$ of models ReCARE(1) and ReCARE(2)?" In order to respond, it is necessary to minimize the sum of the squares of the approximation error μ (17) in models ReCARE(1) and ReCARE(2). Figure 4 depicts the obtained results.

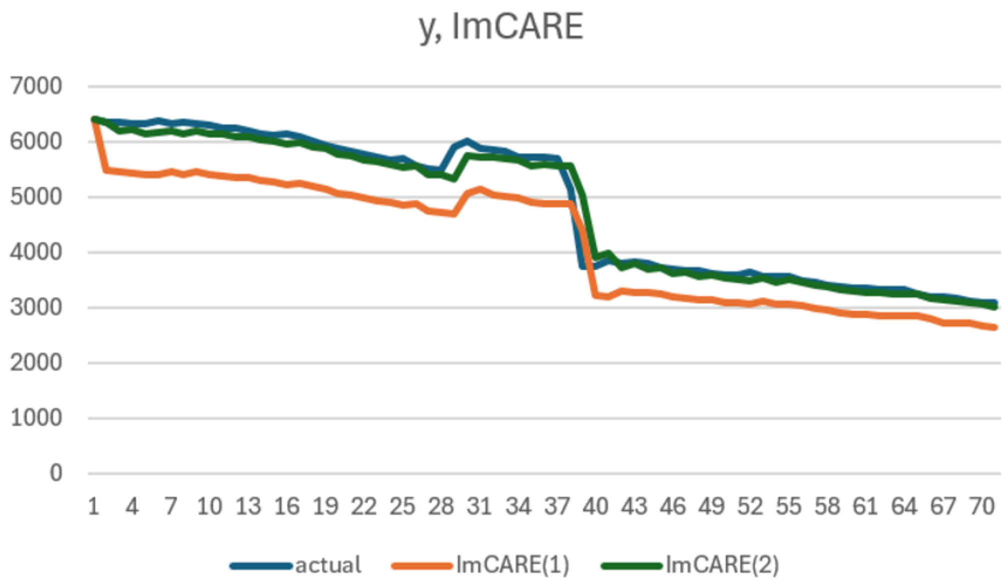

Fig. 4. Initial series y_t and calculated values for the model coefficients ImCARE(1) and ImCARE(2).

These models also capture the trend of change, but it is as if the model with ImCARE(1) coefficients is shifted along the ordinate axis below the actual values by some fixed value. The model with ImCARE(2) coefficients described the original values y_t way better.

The only remaining thing to do is to find out what calculated values of deviations ε_t will be obtained when using the coefficients of the ReCARE(1) and ReCARE(2) models. In order to do so, the ImCARE(1) and ImCARE(2) models will be used, but the sums of the squares of the error ε (16) will be minimized. Figure 5 demonstrates the results.

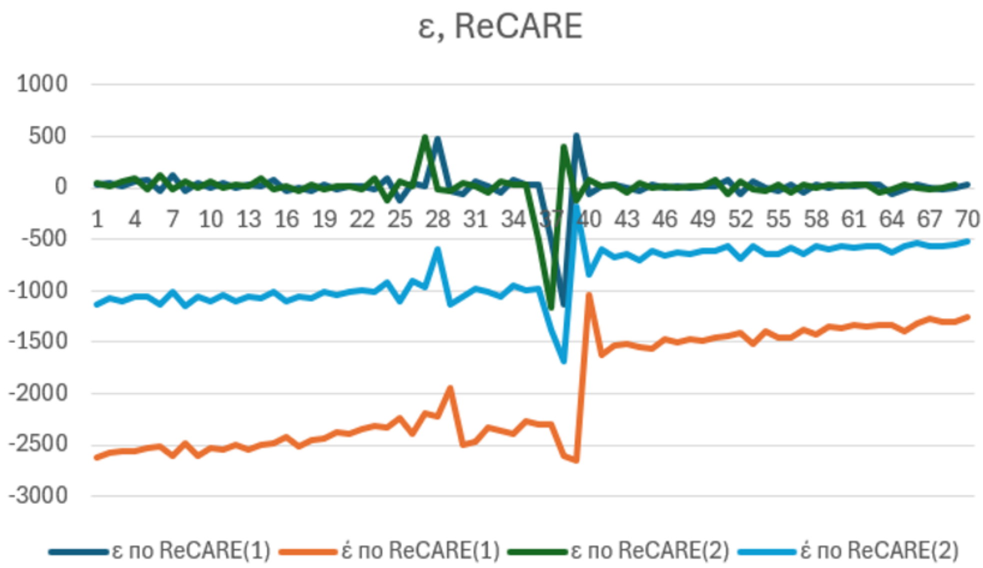

Fig. 5. Deviations ε_t and calculated values of deviations for the coefficients of models ReCARE(1) and ReCARE(2).

It is no surprise that the deviations of the two models are very close, since their calculated values are also close (Fig. 2). What is more interesting is that the calculated values of the deviations ε_t capture the trend of change, but again there is a shift along the ordinate axis lower by some value.

It is difficult to describe the scope of application of the ImCARE (p) model, since it does not predict the values of y_t, but the characteristics it calculates can probably serve as an additional characteristic of the process under study, which remains unclear.

For further research, we took the same series №2810 from the International Institute of Forecasters database. This series consists of 71 observations. This time we will split it into two parts – training and testing. The first 67 observations will be training, and the coefficients of the ReCARE(1) and ReCARE(2) models will be calculated on them. The last 4 observations will serve as testing for these models. The later will be compared by calculating the relative error. Table 1 summarizes the results.

Table 1. Comparison of ReCARE(1) and ReCARE(2) models

Observation No.	y	1 order		2 order	
		$\hat{y}_t$ Re	Error, %	$\hat{y}_t$ Re	Error, %
68	3181.4	3179.938	0.045955939	3202.492	0.66299386
69	3129.1	3135.165	0.193818401	3146.096	0.543160288
70	3086.6	3107.248	0.668957055	3116.743	0.976576857
71	3081.5	3077.714	0.122854666	3084.117	0.084934346

The table shows that both models coped with the task and were able to predict the next values with an accuracy of over 99%. The ReCARE(1) model did a better job, although the ReCARE(2) model also performed well.

Now, using the same principle, we will compare the ImCARE(1) and ImCARE(2) models, only the calculated values will be compared with the deviation ε, each model will have its own deviations, since the calculated values y_t differ. The results are given in Table 2.

Table 2. Comparison of ImCARE(1) and ImCARE(2) models

Observation No.	1 order			2 order		
	ε Im	$\hat{\varepsilon}$ Im	Error, %	ε Im	$\hat{\varepsilon}$ Im	Error, %
68	264.7697	278.7766	5.290202952	45.54745	33.06735	27.40020701
69	3296.899	3294.786	0.059053573	216.462	217.8235	0.628957094
70	3359.584	3358.786	0.023741284	1703.596	1755.585	3.051706806
71	3457.8	3417.41	1.168089727	3466.573	3411.657	1.584169878

The ImCARE(1) model showed a more accurate result. The ImCARE(2) model also showed a good result, except for the 68th observation. It should also be noted that both models showed absolutely different results on the same observations, with the difference reaching the order of thousands. Moreover, ε increases in both cases from 68 to 71 observations. The deviations of ε itself are smaller when using the second-order model.

In this regard, the behavior y_t of the coefficients of the ImCARE(1) and ImCARE(2) models became interesting. The comparison was carried out according to the same principle. Table 3 presents the obtained results.

Table 3. Comparison y_t of the coefficients of the ImCARE(1) and ImCARE(2) models

Observation No.	y	1 order		2 order	
		$\hat{y}_t$ Im	Error, %	$\hat{y}_t$ Im	Error, %
68	3181.4	2916.63	8.322427811	3135.853	1.431679331
69	3129.1	-167.799	105.3625424	2912.638	6.917709369
70	3086.6	-272.984	108.8441611	1383.004	55.19328402
71	3081.5	-376.3	112.2115983	-385.073	112.4962837

Surprisingly enough, 68 and 69 observations of the 2nd order model can be considered quite good. For a more detailed analysis, graphs are presented below (Fig. 6).

Fig. 6. Initial series y_t and calculated forecast values for model coefficients ImCARE(1) and ImCARE(2).

As can be seen from the figure, these models described the training set quite well up to the 68th observation (although the ReCARE(p) model did better). Starting from the 69th observation, the model with the ImCARE(1) coefficients went into disarray. The model with the ImCARE(2) did so starting from the 71st observation, although it started showing poor results already at the 70th observation.

Comparing the deviations and their error using the coefficients of the ReCARE(1) and ReCARE(2) models does not make any sense, since when using these models they did a poor job in describing the original series (Fig. 5).

Comparison of AR(p) and CARE(p) models

The general form of the autoregressive model AR(p) is:

$$\hat{y}_t = \sum_{\tau=1}^{p} a_\tau y_{t-\tau} \quad (18)$$

With its help, stationary processes are modeled, each current value of y_t which is determined by previously accumulated values y_{t-1}, y_{t-2}, etc.

In order to construct this model, and namely to determine the values of the coefficients a_τ, as for the ReCARE model, it is necessary to minimize the sum of the squares of the deviations ε:

$$\varepsilon = y_t - \hat{y}_t \quad (19)$$

As can be seen from the model, it is not oriented towards taking into account the approximation errors ε.

To begin with, let's construct a first-order model, which will take the form:

$$\hat{y}_t = a_1 y_{t-1} \quad (20)$$

For the analysis we will use the same series #2810 from the International Institute of Forecasters database.

Figure 7 presents the obtained results.

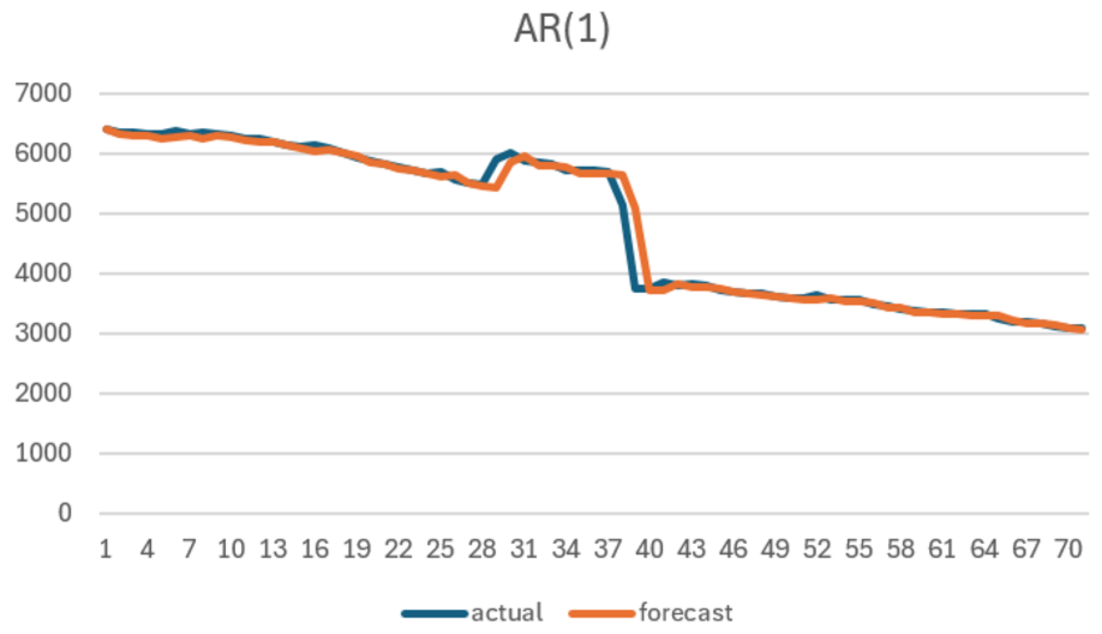

Fig. 7. Initial series y_t and calculated values of the model AR(1).

Overall, the model did a good job. It described the series perfectly well and captured the trend of changes. However, the ReCARE model will be able to compete with it, since Figure 7 and Figure 1 are quite similar.

Next, we will build a second-order autoregressive model, it will take the form:

$$\hat{y}_t = a_1 y_{t-1} + a_2 y_{t-2} \tag{21}$$

Figure 8 presents the obtained results.

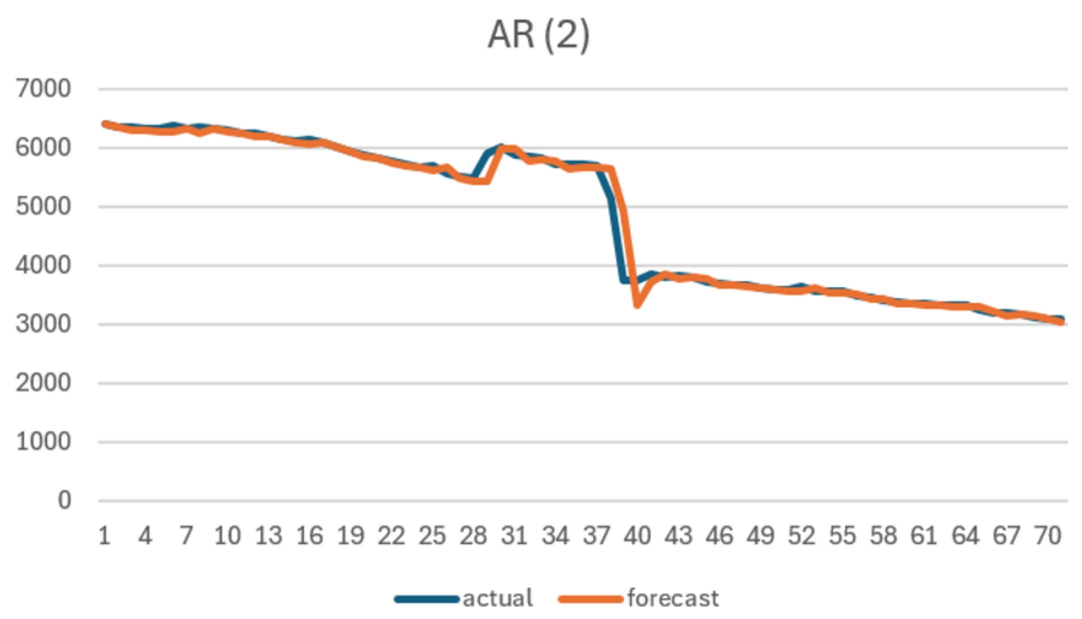

Fig. 8. Initial series y_t and calculated values of the model AR(2).

No significant changes are observed. The model performed well, as did the models in Figures 1 and 7.

The ReCARE model performed no worse or better than the well-known AR model, meaning that the ReCARE model is competitive. Now, let's compare the ReCARE(p) and AR(p) models in numerical values.

In order to compare two different models, we need a more precise criterion than just a single-strength error. Deviations from the test set are not always the best indicator for choosing a model, since only the last values are compared, not the entire series.

In order to compare the results, three most commonly used approximation accuracy characteristics were calculated:

1. Root mean square deviation of the approximation error (RMSD);
2. Akaike information criterion (AIC);
3. Bayesian information criterion (BIC).

The standard deviation of the error shows how large or, on the contrary, insignificant the errors of approximation of the entire series were. The smaller RMSD – the better. The last two criteria show the "clutter" of the model; by comparison, they can be used to determine a simpler model that retains the accuracy results.

First, as with the ReCARE(1) and ReCARE(2) models, we will split the data into training and testing data, and then check how the AR(1) and AR(2) models performed and compare them with other models based on the specified criteria. Table 4 summarizes the obtained data.

Table 4. Comparison of approximation accuracies of the ReCARE(p) and AR(p) models

AR						
Observation	**RMS (1st order)**	AIC (1)	BIC (1)	**RMS (2nd order)**	AIC (2)	BIC (2)
68	**192.1437**	10.54589868	10.5785385	**185.3886**	10.50373156	10.5690112
69	**304.6962**	11.46761622	11.49999457	**305.2839**	11.50045567	11.56521238
70	**371.4359**	11.86332406	11.89544542	**373.6194**	11.90361787	11.96786059
71	**420.8575**	12.11275749	12.14462622	**423.5752**	12.15380011	12.21753758
ReCARE						
Observation	**RMS (1st order)**	AIC (1)	BIC (1)	**RMS (2nd order)**	AIC (2)	BIC (2)
68	**180.18735**	10.4468178	10.51209748	**172.05523**	10.4132781	10.54383738
69	**304.6941**	11.4965877	11.56134439	**301.72071**	11.5349456	11.66445901
70	**375.75992**	11.9150437	11.97928646	**372.20506**	11.9531756	12.08166102
71	**420.75671**	12.1404476	12.20418503	**422.58824**	12.2054726	12.33294752

All models showed the best result on the first observation, which is understandable, because the problem is short-term forecasting. In fact, all models coped with forecasting specific observations with approximately equal accuracy. The ReCARE(2) model showed the best results in forecasting the 68th (although the ReCARE(1) model also coped better than the models of ordinary autoregression). This indicates the accuracy of the ReCARE model.

Conclusion

In this research, the theory of complex-valued variable functions was considered, and the model of complex-valued autoregression of the CARE(p) was studied. Autoregression of this type consists of two parts: ReCARE(p) and ImCARE(p).

The ReCARE(p) model is excellent at learning from the given data, picking up on trends, and being able to "predict" the data with excellent accuracy.

The ImCARE(p) model is well-oriented to predict approximation errors, but with completely different coefficients from the ReCARE(p) model. The model is well trained to predict the values themselves but is only capable of producing good results for one step, while the ReCARE(p) model with its coefficients produces a result much more accurately. This model needs to be studied in more detail to recognize its practical application.

When comparing the ReCARE(p) model with the standard autoregressive (AR) model, the ReCARE(p) model showed a more accurate result when forecasting for one step; the standard deviation was 180.187 (first order) and 172.055 (second order) against 192.144 and 185.389, respectively. This indicates the advantage of the complex-valued autoregressive model. These two models are short-term forecasting models, so when forecasting for more steps than one, they showed slightly worse results. Nevertheless, the accuracy of these results is quite high; the models coped with the task at about the same level.

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ARTIFICIAL INTELLIGENCE AND ARTIFICIAL NEURAL NETWORKS IN HEALTHCARE

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Abstract. The healthcare industry makes one of the main components of the productive forces of the state. Therefore, the well-being and welfare of the entire society in the future depend on its thriving development. Despite significant accumulated knowledge in medicine, there are still some white spots that are difficult to analyze and predict. The use of artificial intelligence and neural networks in healthcare can significantly expand the analytical apparatus and radically change the existing approaches to scientific research. This article discusses the results of the practical application of artificial intelligence and artificial neural networks in healthcare. The research aims to demonstrate the prospects and advantages of using these information technologies in medicine; identify problems in the implementation of AI technologies in medical practice and offer possible solutions to some of them. The authors provide a comprehensive literature review on the issues of artificial intelligence and neural networks, consider successful examples of the AI use in pharmacology, forecasting, and research of various types of diseases, including cardiovascular system, dermatology, and oncology. A significant part of the research is devoted to ethical and legal concerns, as well as problems associated with the practical use of artificial intelligence. As a result of the research, the authors suggest the models of the IT architecture of a medical information system and data flows, based on the TOGAF standard.

Keywords: healthcare, artificial intelligence, artificial neural networks, diagnosis and prediction, TOGAF standard, medical information system

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ИСКУССТВЕННЫЙ ИНТЕЛЛЕКТ И ИСКУССТВЕННЫЕ НЕЙРОННЫЕ СЕТИ В СФЕРЕ ЗДРАВООХРАНЕНИЯ

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Аннотация. Отрасль здравоохранения является одной из главных составных частей производительных сил государства, поэтому от её развития зависит благополучие и благосостояние всего общества в будущем. Несмотря на значительный пласт накопленных знаний в области медицины, существуют трудно анализируемые и трудно прогнозируемые области. Применение искусственного интеллекта и нейронных сетей в здравоохранении способно существенно расширить аналитический аппарат и коренным образом изменить существующие подходы к научным исследованиям. В статье рассматриваются результаты практического применения искусственного интеллекта и искусственных нейронных сетей в сфере здравоохранения. Цель исследования – показать перспективы и преимущества использования данных информационных технологий в медицине, выявить проблемы при внедрении технологий искусственного интеллекта в медицинскую практику и предложить возможные варианты решения части этих проблем. В статье приведен обзор литературы по проблематике искусственного интеллекта и нейронных сетей, рассматрены примеры успешного применения искусственного интеллекта и нейронных сетей в фармакологии, прогнозировании и исследовании разных типов заболеваний: сердечно-сосудистой системы, дерматологии, онкологии. Вторая часть исследования посвящена этико-правовым аспектам и проблемам практического использования искусственного интеллекта. В качестве основных результатов исследования представлены разработанные в соответствии со стандартом TOGAF модели IT-архитектуры медицинской информационной системы и потоков данных.

Ключевые слова: здравоохранение, искусственный интеллект, искусственные нейронные сети, диагностика и прогнозирование заболеваний, стандарт TOGAF, медицинская информационная система

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Introduction

The healthcare industry is actively developing thanks to the introduction of modern IT solutions. For instance, telemedicine has made it possible to receive high-quality medical counselling in remote regions; modern computer screening techniques now allow detecting and treating rare and severe diseases at early stages. The application of computer technologies facilitates creation of medication with unique pharmacological properties and significantly reduces the cost of their development. Accordingly, these developments make drugs more available for the population.

Currently, many positive trends can be specified: higher life expectancy, better quality of health care, and medical services provided to the population. At the same time, new challenges that require up-to-date approaches arise. A possible response to this demand is the introduction of artificial intelligence (AI) and artificial neural networks (ANN) as basic tools of the support system and medical decision-making. The AI and ANN are expected to transform information according to the emerging requirements. In order to do so, the neural network is trained using a special algorithm, which shapes connections of individual neurons and modifies them, so that the final output signal corresponded to the desired command. Thus, the task of these technologies is reduced to finding solutions to certain problems, especially when the user is not fully aware of the internal processes involved.

This article reviews the results of a wide range of studies on the application of AI and ANN in several areas of healthcare and highlights the associated challenges faced by healthcare professionals in the use of these technologies. Recognizing these challenges can enable the community to direct intended effort in the attempt to overcome prospective obstacles. When considered from such an ambitious perspective, artificial intelligence and neural networks can make a win-win tool for the medical and scientific community to use.

Materials and Methods

The main method used in this research is literature review and analysis of scientific studies published in Web of Science, ResearchGate, and PubMed. Most of the examined papers were written in the period from 2013 to 2023 by foreign specialists from Spain and Turkey. Domestic studies on the IT technologies in healthcare were also analyzed.

Based on the literature review and assessment, the authors identified the main implementation prospects of neural networks and artificial intelligence. The graph by Nature in 2020 depicts an increase in the overall interest in these types of digital technologies in the medical industry. According to the results, the 2014-2019 period has seen an almost eightfold increase in the number of publications in the electronic medical library PubMed on the application of artificial intelligence and neural networks in medicine.

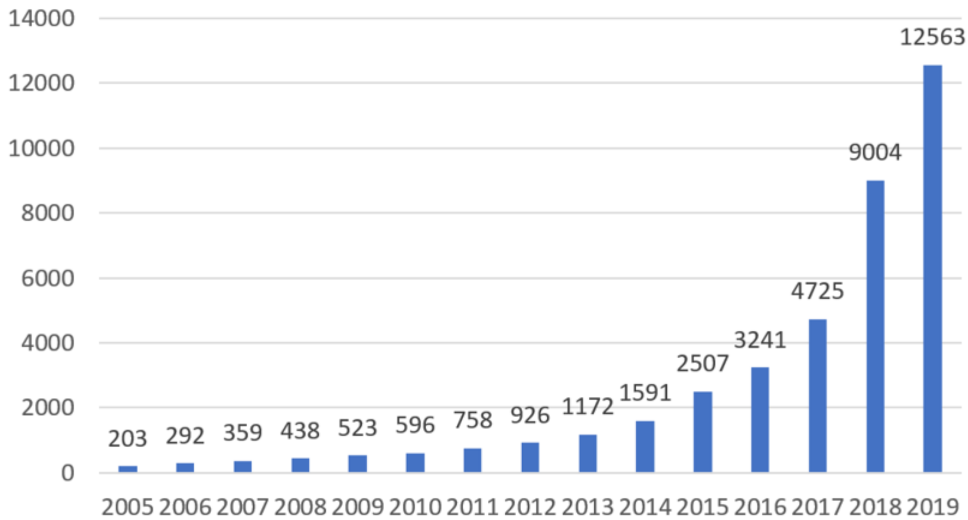

Fig. 1. Number of published AI studies.

This exponential growth in the number of studies is usually associated with the gradual mastering of technologies and, accordingly, with the expansion of the overall agenda. However, what is the reason for such excitement around artificial intelligence and its derivative tools? For many non-professional users, artificial intelligence is just a toy that can generate text of varied reliability, process images, and answer questions. Such a superficial attitude provokes a number of questions. Should AI and ANN technologies be taken seriously? Are AI and ANN the cutting-edge technologies of the future that will shape the basis of many business processes? Should companies reorganize themselves now to apply AI and ANN? This research aims to answer these questions based on the specifics of the medical industry.

A widespread expansion of artificial intelligence originates from a number of reasons:

1. The development of computer technology, in particular computer GPUs, has made it possible to obtain relatively cheap computing power, which AI and ANN calculations are based on.

2. AI is an effective tool for big data processing. Every day a large amount of both structured and unstructured data is generated and used for further analysis and management decision-making. AI makes it possible to process data at high speed, identify hidden patterns, and draw predictions.

3. AI and ANN automate many business processes that used to require direct human participation. For example, speech or image recognition.

4. AI and ANN are actively used in fundamental scientific research. ANN as an analytical tool is already showing significant results in many scientific fields. Medicine and biology make no exception.

5. The models and principles involved in the performance of AI and ANN are multifunctional and can be applied in many areas.

In the medical industry, AI's ability to analyze a large stream of data and draw logical conclusions is particularly relevant. AI can be used as a system to support medical decision-making when deciding on difficult diagnoses or predicting the course of chronic diseases. When considering the healthcare, it is impossible to neglect other related scientific areas of fundamental knowledge. AI is actively used in the development of new medications, including ones for different types of cancer; electronic histology; cytology; genetics.

In the domestic studies, one of the most fundamental research on neural networks in medicine was carried out by N.V. Ivanov (Ivanov, 2018). The author describes the basic structure of neural networks, their principles, and existing training algorithms. What is more, N.V. Ivanov specifies the advantages and disadvantages of using neural networks. Here is the range of the emphasized advantages:

1. The possibility of solving problems with implicit or unknown regularities. Traditional mathematical and analytical methods are unsuitable for analyzing this type of data.

2. Resistance of algorithms to noise in the input data – the ability to work with uninformative noisy incoming signals by screening them automatically in the course of the algorithm.

3. Adaptability of models to changes in the external environment. Neural network algorithms can be sufficiently adaptive to changes in the analyzed signals in time. In addition, neural networks are retrained on the go in real time.

4. Potential fast performance and fault tolerance.

N.V. Ivanov also groups many factors as disadvantages:

1. Neural networks require a significant dataset for successful training and operation.

2. Creating neural networks is a labour-intensive and time-consuming process.

3. Possible mathematical errors in the model, including inaccurate definition of local extrema, excessive growth of weight coefficients at the sigmoidal character of the transfer function of the neuron, unsuccessful choice of the input variables.

4. Neural network problem solving is not explicit for the user, as transformations inside the hidden layers of the network occur covertly.

5. The data should be similar to those that the network was originally trained on. Otherwise, the predicted values may be inaccurate.

The research by Filippo A. and co-authors (Filippo, 2013) is dedicated to the application of ANN in diagnostics. The researchers consider the main directions of diagnostics of various diseases, where ANNs show highly reliable results.

In the cardiovascular diagnosis, the best results were shown with the ANN for non-invasive detection of coronary heart disease. Based on cholesterol, patient's age, and arterial hypertension, the neural algorithm produced a diagnosis with the 91.2% accuracy.

At the same time, the neural network was able to recognize the most frequent risk factors for the disease (Karabulut, 2013). In addition to coronary heart disease, neural networks can detect heart rhythm disorders. In his work, H. Uguz (Uguz, 2013), describes the application of neural networks in analysis of audio recordings of heartbeats. The results obtained show 99% accuracy in recognizing sounds, which is significantly higher than standard stethoscopy.

The application of neural networks in the diagnostics of oncological diseases has shown significant efficiency as well. Every year more than 300 000 people die of cancer in Russia, so the speed of analysis and its accuracy play a vital role in diagnosing cancer at early stages. The first neural networks capable of determining the type of cancer appeared in the late 1990s. Since then, approaches to cancer cell screening have been significantly improved. One of the promising methods of cancer detection is microwave radiothermometry, which allows detecting temperature deviations in the affected areas. The most important disadvantage of the method is the imperfections of human interpretation of the obtained results.

The work of A.G. Losev and D.A. Medvedev (Losev, 2019) focuses on the application of ANN as an analytical tool and decision support method for diagnosing breast cancer by radiothermometry. According to the results, the neural network developed by the authors gives a correct, and most importantly, fast result with a probability of more than 84%.

Similar results were shown in the work by A. Tate. The neural network was trained to recognize different types of ovarian cancer by analyzing the results obtained from a mass spectrometer. The accuracy of 96% significantly outperforms classical statistical methods of cancer typing, such as Student's t-test. D. Brougham (Brougham, 2011) and the team of researchers applied the neural network developed by A. Tate to process the results of lung MRI. The achieved accuracy of 100% in classifying lung adenocarcinomas indicates a high degree of applicability of the A. Tate's neural network. Thus, the joint efforts of several research groups have proved that the same neural network can be used to analyze different forms of tumours.

The next important area of diagnosis is diabetes. According to statistics, by the end of 2021, more than 5 million people suffering from various types of diabetes had been recorded in Russia. The type 2 diabetes is the most common. In this type the response of cells to insulin is disturbed, leading to impaired tissue homeostasis and hyperglycemia. At the moment it is not so difficult to recognize diabetes. It is detected by the level of glucose in the blood and the test can be taken in an ordinary district clinic or with a simple glucometer. Nevertheless, since diabetes is accompanied by many associated complications, it is necessary to anticipate patients' conditions based on their medical records and regularly updated blood tests.

In their study, A.G. Trofimov et al. consider the application of self-learning neural networks in determining the dosage of glucose in patients with type 1 diabetes mellitus. Continuous glucose measurement systems were used, as well as insulin pumps that administer subcutaneous insulin automatically when necessary. The models of the glucose control system are based on the mechanism of glucose processing by body cells under the action of insulin. Since analyzing this mechanism is rather complex, parameters are normally estimated individually for each patient, which significantly reduces the accuracy of predictions. The neural network developed by the authors allows for a mathematical evaluation of glucose processing. The results obtained show high accuracy of the predicted values. Similar studies were conducted by other authors, including Klimonotov V. (Klimonov, 2021).

ANN algorithms are also employed in prediction of diseases associated with diabetes mellitus. S. Safarova (Safarova, 2023) described an ANN predicting bone metabolism in diabetes. As input data for the neural network she used sex, age, and duration of the condition. The output data were represented by variables reflecting the state of bone metabolism: bone mineral density and markers of bone remodeling. The developed system predicted the correct development of reparative osteogenesis with a probability of 92.86%. In his turn, E. Dobrov (Dobrov, 2022) describes the use of ANN for the diagnosis of diabetic retinopathy.

In addition to the conditions described above, ANNs are used in the diagnostics of many other diseases:

1. Ophthalmologic diseases;
2. Skin autoimmune diseases. The TzanckNet neural network developed by American scientists diagnoses diseases based on smear images with 94.3% accuracy;
3. Skin cancer. A neural network developed by American researchers from Stanford University is able to predict skin cancer with 72% probability based on images, which is 6% higher than the conclusion of dermatologists based on empirical data.
4. Skin rash. The AI Skin mobile app uses a neural network to analyze skin rashes from a photograph, followed by a preliminary diagnosis.
5. Respiratory diseases. The mobile application "AI Resp" can analyze a person's breathing patterns and detect respiratory diseases.

Many studies are devoted to the specific practical application of artificial neural networks in medicine. The work by Y.A. Sergeev, E.A. Sterleva, and D.A. Niazian (Sergeev, 2021) provides a description of a three-layer recurrent neural network capable of predicting pathologies of therapeutic profile.

Diagnostics of diseases is not the only medical area for AI and ANNs to be actively used. ANNs make a serious contribution to pharmacology in the development of new medication. The main methods for searching for pharmacologically active compounds today are virtual screening methods and classification and regression algorithms. The application of artificial neural networks is a fundamentally new but no less effective method. Since 2021, many approaches have been developed to produce new drugs and repurpose existing ones using artificial intelligence methods. Artificial neural networks are used to guide the search for new compounds with the desired type of pharmacological activity while achieving significantly higher accuracy.

There are three main areas in pharmacology for the neural networks to be applied:

1. Predicting which medication has better qualities to reverse the negative effects of a disease;
2. Creation of new molecules;
3. Predicting the chemical properties of compounds: absorption, distribution, metabolism.

One of the brightest examples of an already finished product used in practical pharmaceutics is the "AlphaFold2" system. An aggregate of various neural networks, "AlphaFold2," predicts the three-dimensional structure of a protein based on the primary sequence of amino acids. The Skolkovo Institute project "BiteNet" uses deep learning and machine vision algorithms to analyze proteins and identify potential drug targets.

The most striking result was achieved by Insilico Medicine, a Chinese pharmaceutical company, which developed a compound to treat idiopathic pulmonary fibrosis using AI. The main tool was a platform of three digital systems with AI tools: PandaOmics for data analysis, Chemistry42 for molecular design, and InClinico's clinical trial prediction engine. The system based on AI tools reduced the drug development period to 18 months and reduced costs by 170 times.

At the moment, the Russian Federation is a leader in the development and implementation of artificial intelligence systems in healthcare, with about 16% of medical institutions using AI.

Unfortunately, it is still difficult to talk about a full-fledged transition of healthcare. The largest test region is Moscow, where the following technologies are used: artificial vision to analyze medical images (CT, MRI, X-rays, mammograms); a support system for medical decision-making and selection of a diagnosis in accordance with anamnesis (SPPVR); a chatbot to collect complaints before a doctor's examination; and AI analysis of echocardiogram results.

Based on the results of the implementation of AI tools in medicine, the significant benefits that AI tools provide can not be neglected. Artificial intelligence helps to reduce the burden on medical staff and expand opportunities of basic medical research. Nevertheless, at the current stage of development, a number of serious barriers arises. In this paper we will try to touch upon a part of them. First of all, the application of AI in medicine raises ethical issues. Who will be held responsible in case of misleading forecasts that harm a patient? According to Federal Law No. 2129-p from 19.08.2020, by 2024 a program should be developed to define ethical rules for the development, implementation, and use of AI in healthcare in accordance with the human-centred approach. Now, however, more attention is paid to the material side of the technology.

An equally important problem is the issue of trust in neural networks, both on the part of doctors/patients and private investors, who are reluctant to invest in their design and development due to the lack of substantial evidence of clinical efficacy.

The third challenge is the quality and quantity of data. Quality training of neural networks requires data with a high degree of purification from noise, so before training networks, it is necessary to first collect a dataset, which is not always fast.

The next barriers are related to the challenges of the architecture layer of healthcare provider applications. Most medical institutions have already automated their business processes, so integrating AI without the ability to scale to the entire healthcare system will be very difficult, especially if the architecture of medical information systems is designed as a monolith rather than a set of microservices.

The final challenge is the computing power required to run artificial intelligence. Most of the computing equipment used in medical institutions does not meet the minimum requirements for even the simplest computations.

Structurally, a neural network consists of an input layer, which receives primary signals (in disease diagnosis – the parameters under study), one or more hidden layers, and an output layer (results). Figure 2 schematically depicts an example of a neural network in the form of a black box with hidden layers, taking into account the inputs and outputs of medical information.

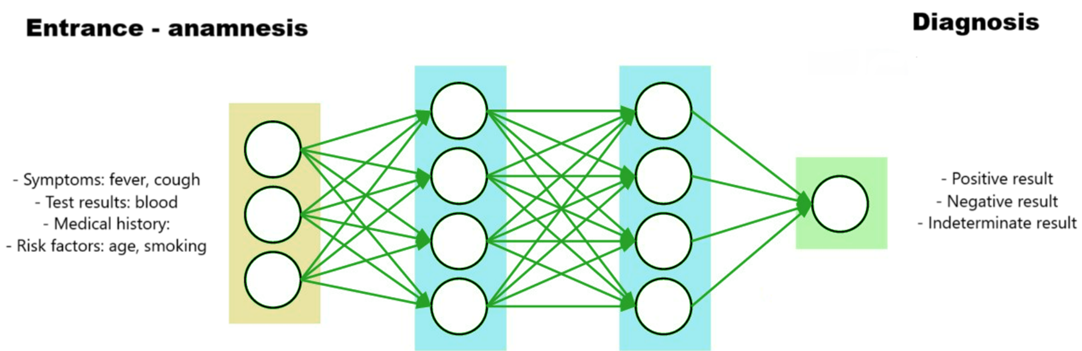

Fig. 2. Inputs and outputs of a medical ANN.

In order to ensure training and further work in the neural network, it is necessary to create a database. The classical format of the database is the relational form, which allows the neural network to unload data in the form of a matrix. However, for a number of ANNs it is more preferable to use document-oriented databases. If a single-table database is used, normality violations are possible, but otherwise the issue of data demoralization or the use of additional DBMS functions may arise, increasing the ANN's running time and efficiency. For more complex ANNs, the database may have a different structural form, such as a classical snowflake. Figure 3 shows the data table for one of the simplest forms of neural networks—perceptron, capable of determining the presence of coronary heart disease. This neural network outputs only 2 values as a result: positive and negative.

coronary heart disease	
Patient ID	*Int4*
Age	*Int4*
Cholesterol levels	*Int4*
Arterial hypertension	*Bool*
Maximum blood pressure	*Int4*
Minimum blood pressure	*Int4*

Fig. 3. Database for perceptron neural network operation.

In practice, all data come from different sources. Inorder to collect the necessary information about a patient, it is necessary to perform a complex query combining data from several databases and tables. In practice, the process of combining data from different databases can be complicated by many factors: data incompatibility (differences in syntax), data inconsistency, lack of access to a particular database, database dependencies, etc. Thus, when applying neural networks in medical organizations, it is important to consider the current architecture, database compatibility, and so on.

The architecture of a medical organization has a complex structure and can vary greatly depending on the type of medical institution (hospital/state clinic/private clinic). In this regard the creation of a typical architecture of a medical organization is possible using the TOGAF design standard. The Content Framework component of the TOGAF standard acts as the basis for representing the architecture of a medical organization. According to the framework, the representation consists of five related architectures or perspectives. The business perspective includes three types of business processes: core, supporting, and management processes. The information layer also includes the information flow diagram, reflecting the information architecture. The technology layer combines data architecture and process architecture, reflecting the flows between different databases.

In their nature, neural networks are information systems, so it is reasonable to consider their design within the framework of IS and data architecture, paying attention to the technological architecture. As mentioned earlier, a medical organization has a complex architecture due to its purpose, but the medical information system (MIS) is used as the basis of the information system. Thus, most of the information infrastructure and service architecture is built around it. Figure 4 shows the recommended structure of the future mMIS developed by the specialists of the Pirogov National Medical and Surgical Centre.

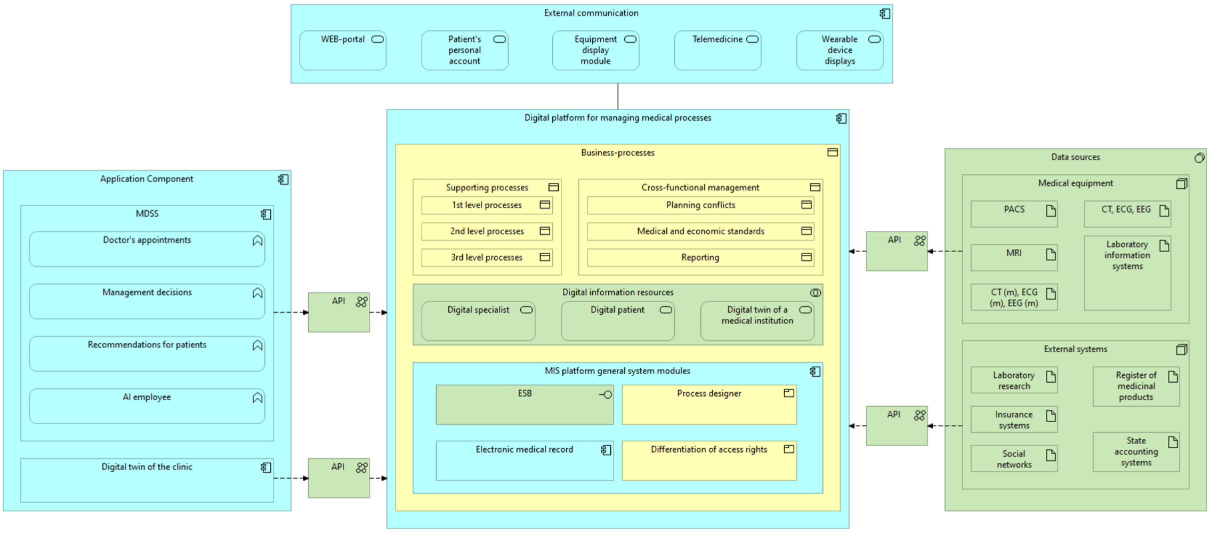

Fig. 4. Recommended MIS architecture.

The considered model of the future MIS structure is still imperfect at the moment, but it largely explains the architecture of MIS as an electronic system. According to Figure 4, AI tools make part of the interface of smart clinic applications and often perform the functions of a medical decision support system. Therefore, they can be implemented as a service or program. Many medical applications used in practical medicine have already been developed, including TzanckNet, AI Skin or AI Resp. Nevertheless, quite often, ANNs are presented as a program code in one of the programming languages. Interaction with the core of the MIS is implemented through APIs. In order to ensure full understanding of data exchange between ANN and MIS core, it is necessary to take into account the peculiarities of data architecture of each medical institution. For example, if all data are stored on one server and managed by one DBMS, then HTTP/HTTPS data protocols are used for data exchange between MIS databases and ANN service databases; data are freely moved in XML or JSON format. This format of data architecture organization significantly reduces data integrity errors and simplifies data access.

Results and Discussion

The introduction of artificial intelligence and neural networks into medical organizations is associated with a number of both legal and ethical concerns, as well as integration problems related to the peculiarities of the architecture of IS and data structure. Inspite of the fact that it is not possible to directly influence the laws, we can still figure out the constraints that medical information systems impose. Figure 5 shows the IT architecture of a medical organization that the authors have developed in accordance with the TOGAF standard.

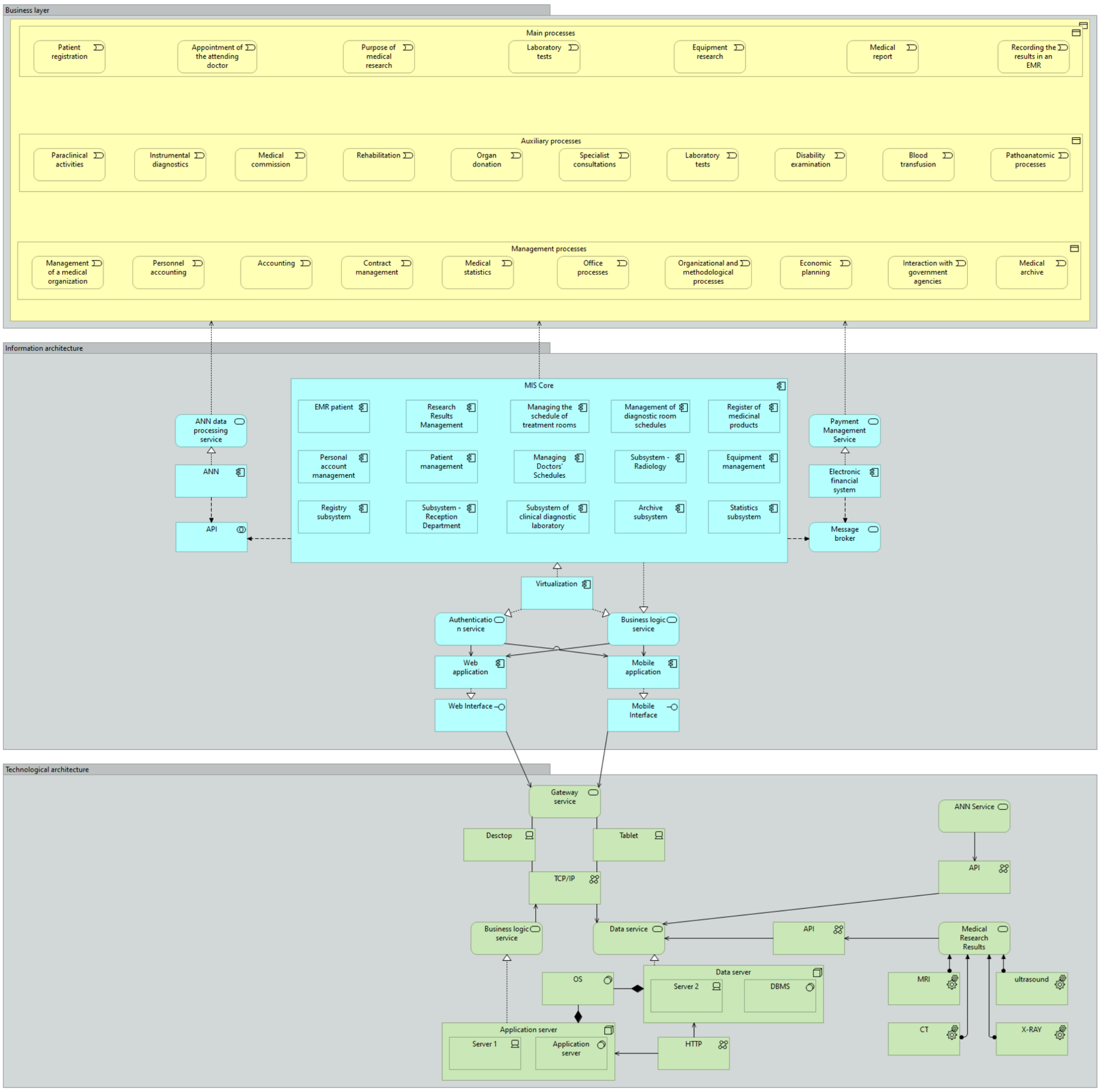

Fig. 5. IT architecture of a medical organization in accordance with the TOGAF standard.

The presented model is simple enough, however, it gives a general idea of how the investigated technologies can be realized as services. For a more detailed representation of data flows, Figure 6 depicts a more comprehensive data architecture model.

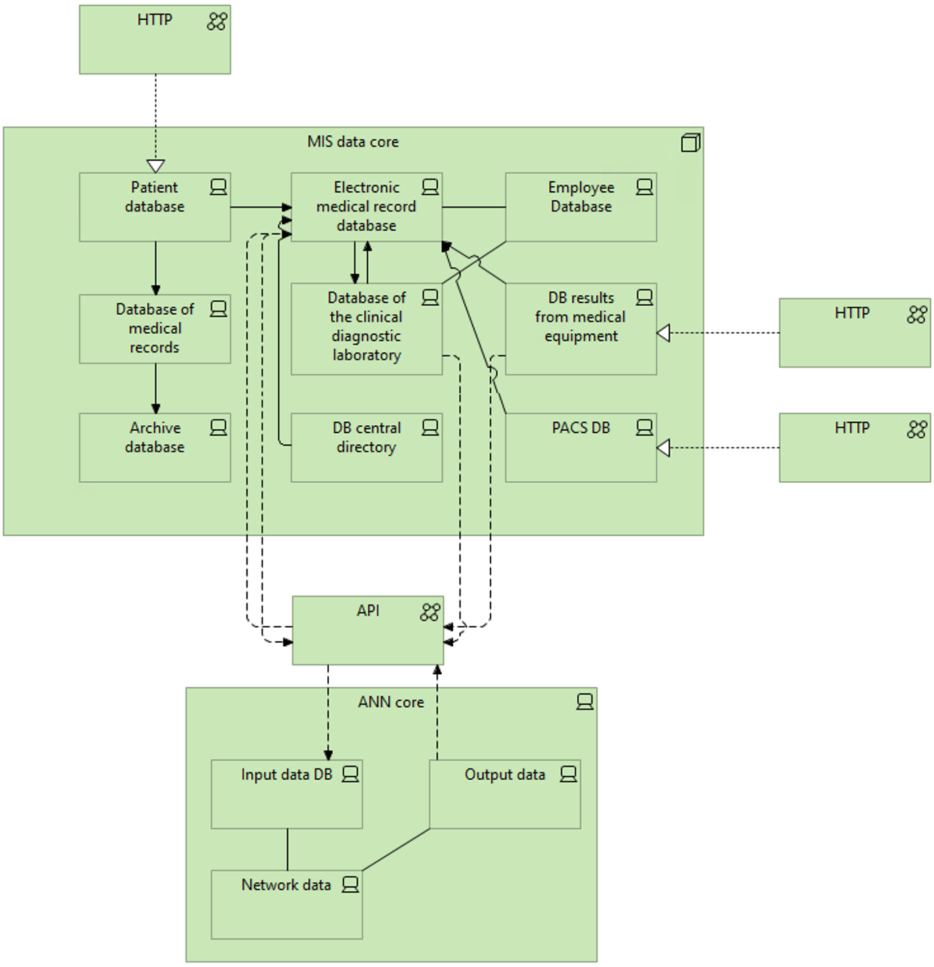

Fig. 6. IT architecture of a medical organization.

The developed model of data flows is more theoretical, as it strongly depends on the service architecture of the medical organization and the used MIS. However, at this stage even, it can be seen that it is necessary to build logical models and prepare the information infrastructure of the enterprise in advance in order to ensure a whole scale implementation of AI and ANNs.

Conclusion

Having studied a number of sources reviewed in this article, it is possible to state that artificial intelligence and neural networks represent serious tools in the development of healthcare. Due to the versatility of neural network algorithms and artificial intelligence tools, these technologies can be actively employed in various areas of healthcare, thereby expanding the instrumental and technological apparatus of doctors and researchers.

AI and ANNs allow doctors to recognize tumours at early stages and to determine the development of complex and predictable diseases with a high degree of reliability. For example, most networks have the capacity to identify heart rhythm abnormalities and ischemic heart disease with more than 90% accuracy. In its turn, breast cancer is detected with a 84% accuracy. Machine vision is actively used in medicine, which has already gone beyond doctors' offices and research centres. Thanks to enthusiastic scientists, startups such as “AI Skin” already allow ordinary users to get preliminary results of skin diseases before a doctor's appointment.

Overall, AI technologies have the potential to significantly broaden the horizons of medicine, genetics, psychology, and pharmaceuticals while reducing both costs and time to achieve the desired result. However, this mission makes no easy task. In order to integrate AI and ANN into healthcare processes, many challenges need to be addressed, including: ethical concerns and compatibility issues between AI-based applications and existing electronic health systems.

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IMPLEMENTATION OF CHATBOTS IN HEALTHCARE ORGANIZATIONS FOR PROCESS AUTOMATION

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Abstract. This article examines the implementation of chatbots in healthcare as a means to automate the patient flow management. The authors analyze the current state of this process, identify operational bottlenecks, and propose chatbot-based solutions for automation of patient registration, document processing, and room allocation. The research method rests on modelling using chatbot technologies and evaluating their overall impact on healthcare efficiency and service delivery. According to the results, the introduction of chatbots reduces administrative workload, facilitates paperwork, and significantly improves service quality. Specific attention is paid to the risks associated with chatbot implementation, such as privacy concerns, and strategies for their mitigation. As a result, the introduction of chatbots proved to have a significant positive impact on operational efficiency, resource optimization, and patient satisfaction in healthcare.

Keywords: chatbots, process automation, patient flow management, medical documentation, healthcare efficiency, healthcare information systems

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ВНЕДРЕНИЕ ЧАТ-БОТОВ В МЕДИЦИНСКИЕ ОРГАНИЗАЦИИ ДЛЯ АВТОМАТИЗАЦИИ ПРОЦЕССОВ

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Аннотация. Данная статья посвящена исследованию внедрения чат-ботов в медицинские учреждения для автоматизации процесса управления потоками пациентов. В статье описан анализ текущего состояния данного процесса, выявлены несовершенства и предложены решения, основанные на использовании чат-ботов для автоматизации различных этапов. Методология исследования включает моделирование процессов с использованием технологий чат-ботов и оценку их воздействия на эффективность работы медучреждений. Результаты показывают, что внедрение чат-ботов способствует снижению административной нагрузки на персонал, сокращению времени обработки документации и улучшению качества обслуживания пациентов. В статье также рассмотрены риски внедрения таких технологий и предложены стратегии их минимизации. В заключение, внедрение чат-ботов оказывает значительное положительное влияние на улучшение операционной эффективности и удовлетворенность пациентов в медицинских организациях.

Ключевые слова: чат-боты, автоматизация процессов, управление потоками пациентов, медицинская документация, эффективность медицинских учреждений, информационные системы здравоохранения

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Introduction

Integration of artificial intelligence and automated communication systems, such as chatbots, opens new horizons for better quality of medical care. Chatbots based on machine learning algorithms and natural language processing provide opportunities to optimize multiple processes in healthcare facilities, from patient admission to post-discharge support.

This research aims to comprehensively analyze and evaluate the impact of chatbots on the structure of a medical organization. Special attention is paid to the assessment of the effects produced on performance of medical staff and patient satisfaction, as well as the economic aspects of medical institutions.

Within the framework of this research:

1. healthcare specifics were defined;
2. chatbot solutions were reviewed;
3. potential risks and prospects were assessed.

Materials and Methods

This research invites the following methods: collection and analysis of information, description, comparison, and synthesis. Analytics involves gathering information on data technologies, and assessing information on the structure of medical organizations.

Various articles, journals, and training manuals have been analyzed as a theoretical basis of the research. They include the works by:

– Altayeva A.U., Kaipova A.Sh., Mukhamedjanova A.U., and Ospanova G.K. consider the prospects of using chatbots in medicine, emphasizing their potential to automate processes and increase efficiency. The study focuses on positive aspects of technology implementation in medicine (Altayeva, Kaipova, Mukhamedjanova, Ospanova, 2023).

– Janarsanam S. in his book "Developing Chatbots and Conversational Interfaces" describes the technical aspects of chatbot performance. This source is used to understand the architecture and technical capabilities of the given solution (Janarsanam, 2022).

– Khairullin A.M. and Zaripova R.S. explore the implementation of chatbots and online counselling in medicine. Special attention is paid to improving the interaction between patients and medical staff, as well as the impact of technology on the accessibility of medical services (Khairullin, 2020).

– Potapov D.A. in his paper "Overview of chatbot creation technologies" reviews the evolution of chatbots, thus helping to assess their applicability in medicine (Potapov, 2017).

– Epanchintsev M.Y., Starichenko B.E., and Shakirova A.A. study the use of chatbots in education at medical colleges, showing their significance in learning and interaction with students (Epanchintsev, 2022).

Results and Discussion

One of the key aspects of health care facilities is patient flow management – a complex system that includes organizing, planning, and controlling the movement of patients in a health care facility at all stages of medical care. This process is aimed at maximizing the quality and efficiency of services provided, as well as meeting the needs of patients and reducing the burden on medical staff.

The following facets of the medical care process deserve special attention:

1. Admission of patients – initial examination of patients with due respect to original complaints;

2. Optimization of the staff's schedule – efficient scheduling that takes into account both patient needs and staff capacity, minimizing wait lists and overload;

3. Optimization of waiting lists –reduction of waiting through improved scheduling and better coordination between departments;

4. Improved access to medical equipment and resources – efficient utilization of medical facilities to ensure that necessary procedures and tests are performed in time;

5. Implementation of technologies – utilization of information systems to track patient status, manage data, and communicate within the facility;

6. Training and protocols – development of clear protocols for handling patient flow and training staff;

7. Continuous analysis and improvement – regular update of patient flow management processes and implementation of improvements based on data and feedback from staff and patients.

Patient flow management is a key to maintaining high quality care and ensuring patient safety. It not only helps improve patient experience, but also contributes to overall efficiency and cost reduction in healthcare.

In order to carry out a comprehensive overview of this process it is necessary to examine the major stages involved. During the admission stage, the patient is admitted to the healthcare facility. Primary diagnosis of the patient is established via the examination and referral to specialists. After admission to the inpatient unit, the necessary pre-operation treatment is prescribed, followed by the surgery. Then comes the final stage – preparation for discharge, recovery planning and the discharge itself.

Effective patient flow management requires transparent organization, advanced technology, and aligned communication between all participants of the medical process, which directly affects the success of treatment and patient satisfaction.

This research primarily focuses on optimizing staff performance, and opportunities to improve patient experience. Based on the above presented description of all stages involved, the “AS IS” model was developed for the “Patient Flow Management” process. Figures 1-3 provide a full-scale structure of this model.

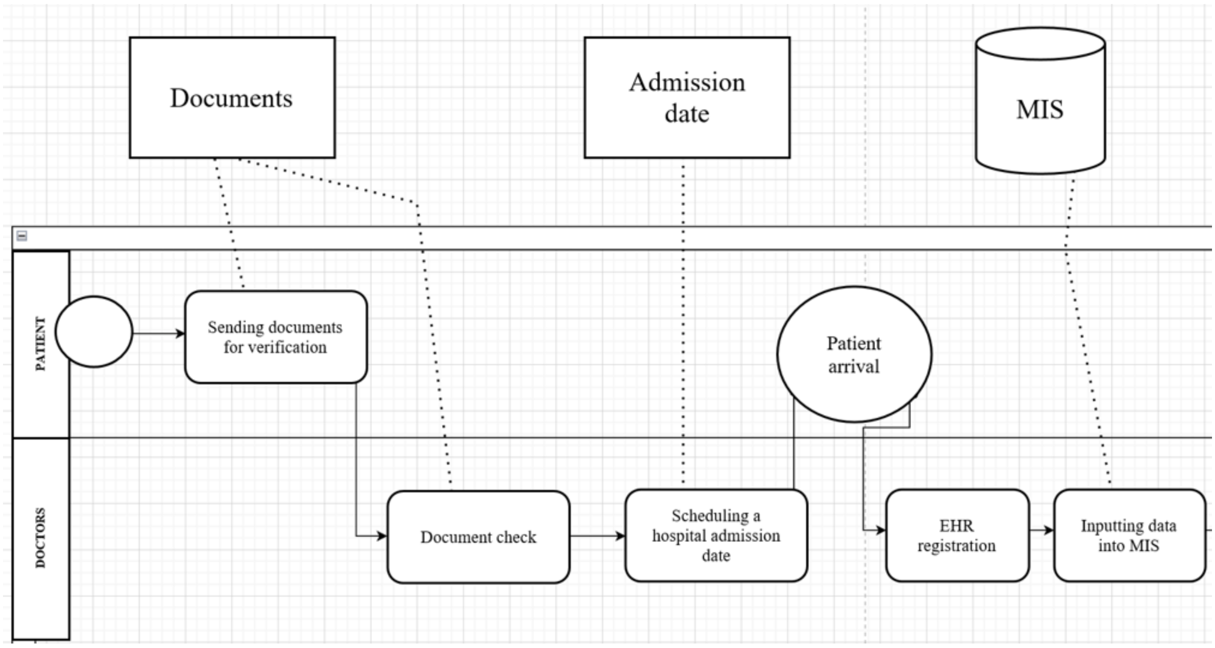

Fig. 1. “Patient Flow Management”: “AS IS” process model (Part 1).

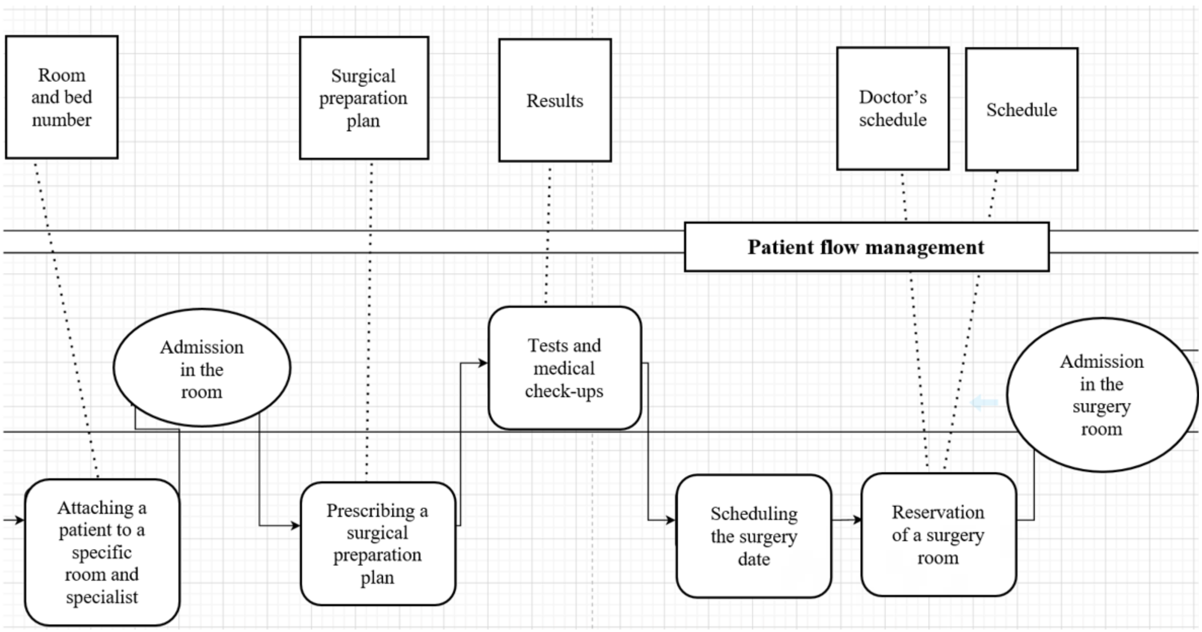

Fig. 2. “Patient Flow Management”: “AS IS” process model (Part 2).

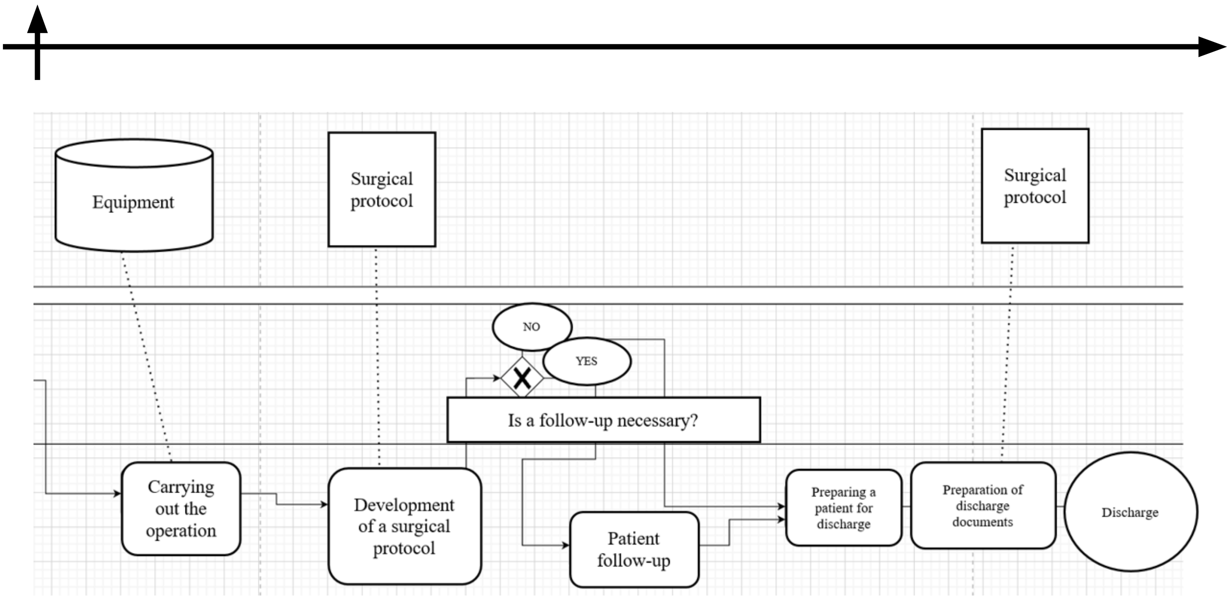

Fig. 3. “Patient Flow Management”: “AS IS” process model (Part 3).

Having studied the process of patient flow management, it is possible to detect a wide range of challenges which require additional support based on a chatbot (neuro-employee). In modern medical practice, paperwork takes up a significant share of physicians' time. Normally it includes completing, verifying, and archiving various forms and reports such as medical record, prescriptions, discharge summaries, etc. Often, physicians have to enter data into electronic medical systems manually, which is a time-consuming and error-prone process.

The excessive staff workload is primarily represented by such tasks as document verification, selection of a roon in the inpatient unit, preparation of treatment plan, prescription of tests and check-ups, operating room reservation, drawing up an operation protocol, etc. All these stages require a whole-scale automation in order to improve the patient flow management.

One of the most promisint solutions is chatbots that can carry on conversations with humans or other computer programs using natural language. They are typically used to automate communication with users via text messages but can also support voice interaction. Simple chatbots can perform a limited set of tasks, such as providing information about a company's schedule or answering FAQs. More sophisticated chatbots use artificial intelligence to interpret user queries, analyze context, and provide more complex services such as consulting, ordering products, or booking services.

Chatbots can be integrated into various platforms and applications such as (Dubgorn, Esser, 2022; Lepekhin et al, 2022):

– websites;
– messengers (e.g., Facebook Messenger, WhatsApp);
– mobile apps;
– voice assistants (e.g., Siri, Google Assistant).

Chatbots are widely used in a variety of areas, including business, education, healthcare, customer service, etc. In medicine, chatbots improve access to healthcare services, optimize workflows, and enhance the quality of patient care. They provide continuous access to medical information and support, automate administrative tasks, and contribute to cost reduction.

In the following section of the article the authors discuss the prospects of chatbot implementation in healthcare in terms of the major challenges of the industry.

Stages: “Document verification”, “Preparation for discharge”

Problem: heavy workload associated with paperwork.

Solutions:

1. Integration with the hospital information system. The chatbot is integrated with the hos-

pital database and electronic medical documentation system.

2. Patient identification. At check-in, the patient provides their ID and insurance, which are scanned via a mobile app or the admissions department.

3. Automated verification. The chatbot automatically checks the information provided against insurance policies and all required medical records. The bot can also request additional data or clarifications from the patient through an interactive interface.

4. Notification to medical staff. Once all documents are verified, the chatbot sends a notification to the responsible medical staff that the patient is ready for further care.

5. Collecting data for discharge. The chatbot automatically collects all necessary medical data from the electronic records system, including the results of recent tests and procedures.

6. Document generation. Based on the collected data, the chatbot generates preliminary versions of discharge documents, including recommendations and prescriptions.

7. Verification by the doctor. The doctor receives the generated documents through the MIS system, checks them and introduces corrections, if necessary.

8. Discharge. The chatbot sends the final versions of the documents to the patient via email or the hospital app, notifying the patient of the discharge date and time.

Stage: "Selection of a room in the inpatient unit"

Problem: lack of automation in selecting rooms/beds in the inpatient unit.

Solutions:

1. Integration with the hospital management system. The chatbot is integrated with the central medical information system that tracks the status of all rooms/beds in real time.

2. Automatic data query. When a patient is admitted to the hospital, the chatbot automatically requests information on the patient's status and medical needs (e.g., special medical equipment, etc.).

3. Matching algorithms. The chatbot uses algorithms to assess available rooms/beds, taking into account the patient's medical needs, current unit occupancy, and logistical factors (e.g., proximity to the needed department or specialists).

4. Placement optimization. The chatbot identifies the optimal room/bed to meet the patient's medical and logistical requirements, and reserves them automatically.

5. Notification of staff and patient. The chatbot sends notifications to the appropriate medical staff and patient on their placement.

Stages: "Drawing a preparation plan for surgery," "Tests and check-ups"

Problem: complexity of coordination between different departments and specialists, including anesthesiologists, surgeons, nurses, and dietitians; the patient's medical and personal needs.

Solutions:

1. Gathering patient data. When a patient or healthcare provider first seeks care, they enter basic data into the chatbot interface. The data includes medical record, current medical problems, allergies, and previous surgeries.

2. Automatically generated checklist. Based on the information entered, the chatbot uses built-in algorithms to generate a personalized pre-operation checklist that can include lab tests, procedures, medication instructions, dietary restrictions, and pre-surgery lifestyle recommendations.

3. Coordination with medical departments. The chatbot automatically sends notifications to the appropriate departments and specialists about upcoming procedures and tests that need their input. This solutions eliminates scheduling conflicts.

4. Patient reminders. The chatbot is configured to send regular reminders to the patient about upcoming tests, procedures, and changes via SMS or a mobile app.

5. Feedback and plan adjustments. The patient can report task completion or problems via

a chatbot interface, which can automatically adjust the plan and inform medical staff when needed (Dillon, 2020; Caroline, 2019).

Stage: "Reserving an operating room"

Problem: coordinating room availability, surgeon schedules, inefficient equipment and associated delays.

Solutions:

1. Data entry of upcoming surgery. The medical staff or surgeon enters information about the planned surgery into the chatbot, specifying the date, expected duration, type of surgery and equipment requirements.
2. Automatic reservation of an operating room. The chatbot scans the available operating rooms, checks compatibility with all the requirements and automatically books the most suitable room.
3. Notification and confirmation. The chatbot sends notifications to the surgeon, medical staff and operating room management department.
4. Dynamic rescheduling. In case of schedule shifts or emergencies, the chatbot can automatically reschedule reservations and notify all participants.
5. Interactive reservation management. Staff can interact with the chatbot via text commands or GUI to modify reservations or request additional information.

Stage: "Surgical protocol"

Problem: labour intensive and error-prone nature of manual drafting (Batson, 1984).

Solutions:

1. Baseline data collection. The chatbot requests the surgical staff to provide the baseline data on the type of surgery, basic medical instructions, list of equipment, names of participating specialists, and anesthesia preferences.
2. Automated protocol generation. The chatbot automatically generates a surgical protocol and organizes all information in an appropriate format.
3. Revision and approval. The generated document is sent to the surgeon and anesthesiologist for revision and approval. The chatbot can include change tracking and comments to simplify editing.
4. Distribution and archiving. Once approved, the protocol is distributed to all medical staff involved in the surgery. A copy of the protocol is also archived in the electronic medical system (Tairov, 2023; Medvedeva, 2023).

Having observed the "AS IS" model for the "Patient Flow Management" process, a "TO BE" model can be shaped (Figures 4-8).

Despite the fact that the overall process has expanded, the introduction of chatbots will remove excessive workload and increase staff efficiency. However, the implementation of chatbots is associated with a wide range of risks. In order to exclude or minimize them it is necessary to develop a matrix of risk response (Zaripova, Kudryakov, 2023; Parate, 2024).

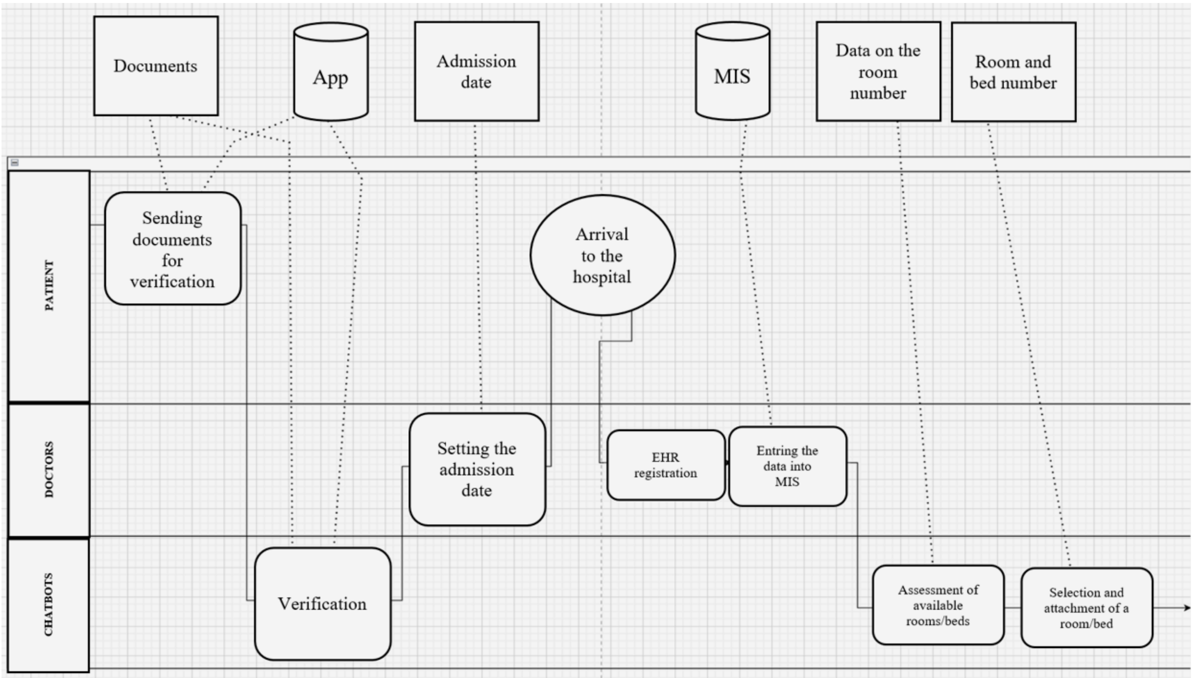

Fig. 4. “Patient Flow Management”: “TO BE” process model (Part 1).

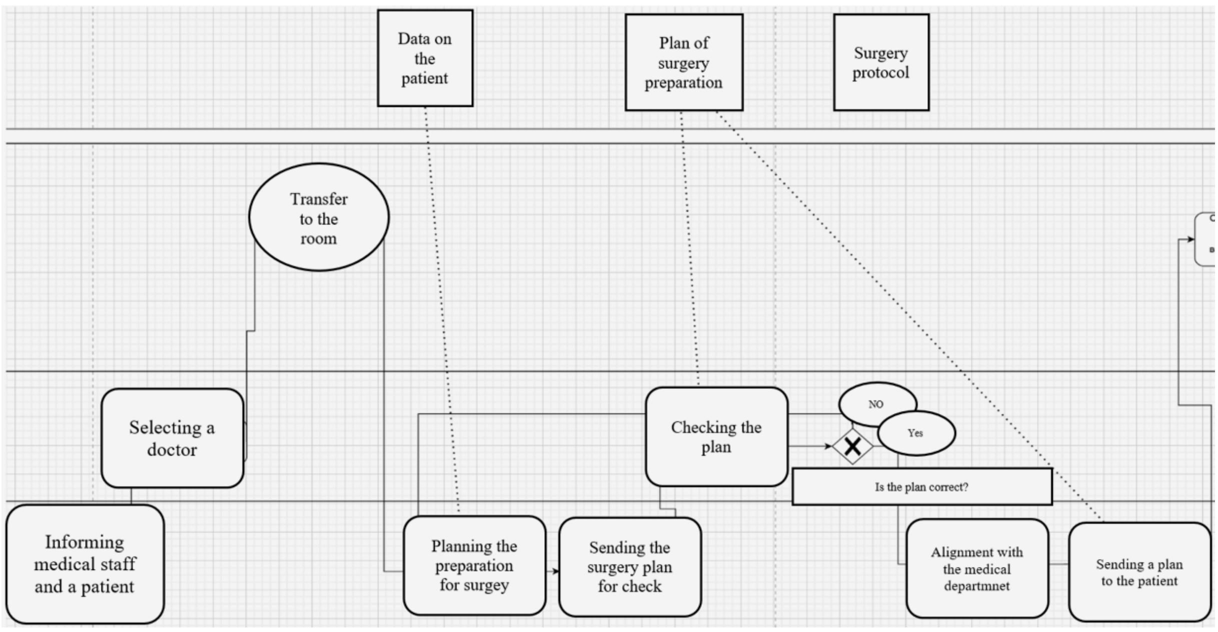

Fig. 5. “Patient Flow Management”: “TO BE” process model (Part 2).

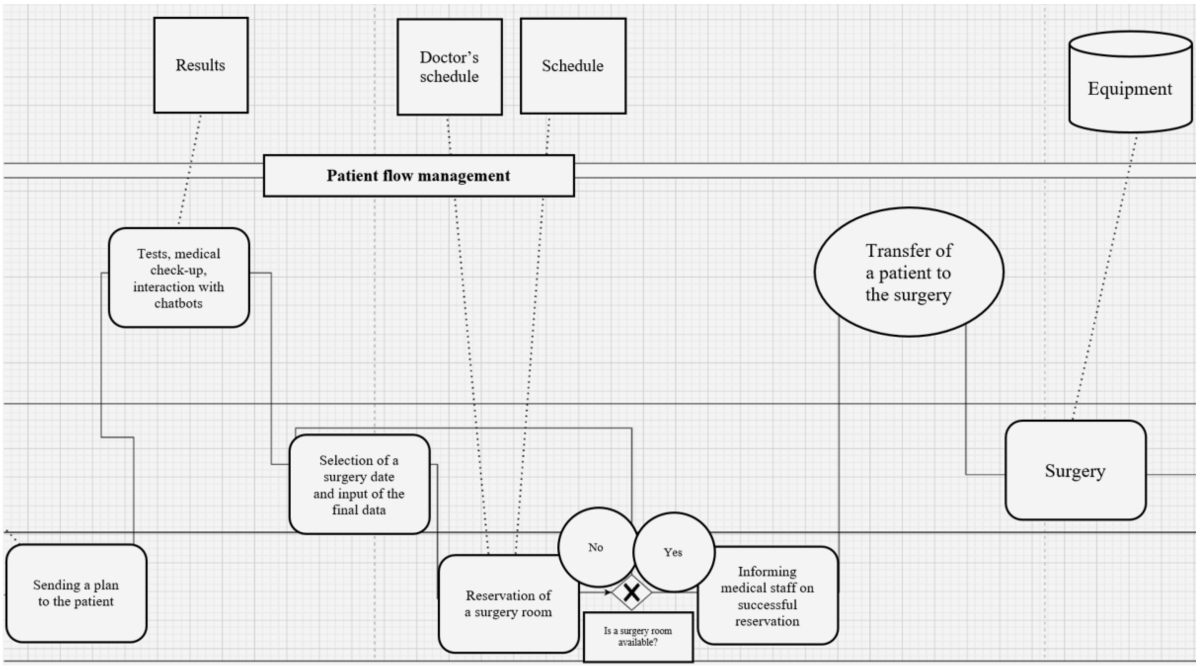

Fig. 6. "Patient Flow Management": "TO BE" process model (Part 3).

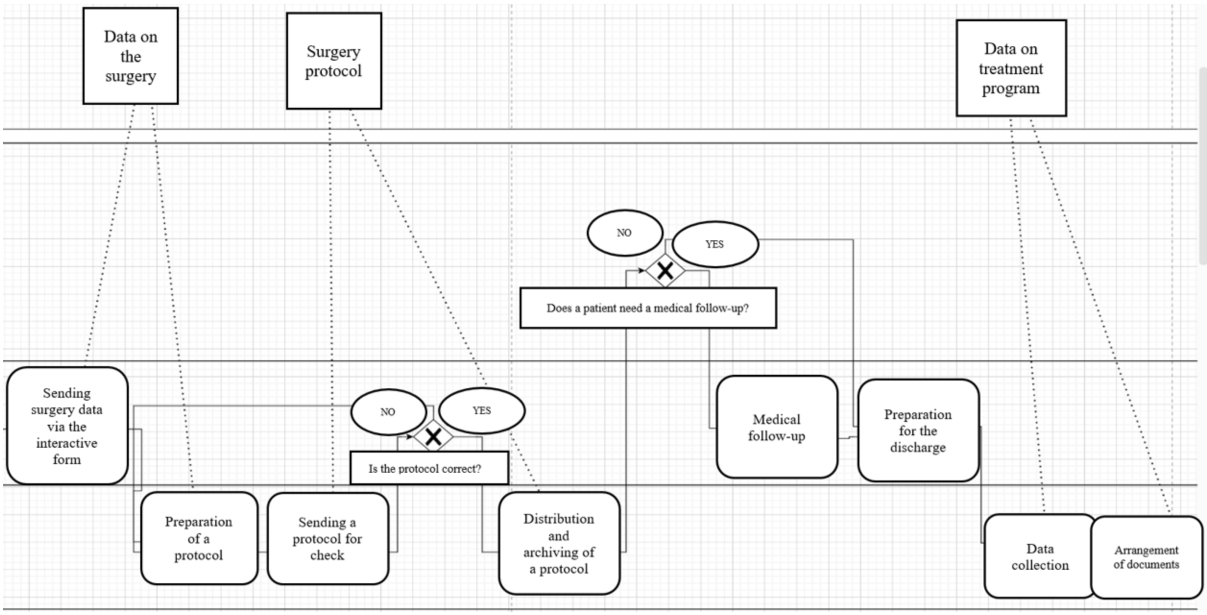

Fig. 7. "Patient Flow Management": "TO BE" process model (Part 4).

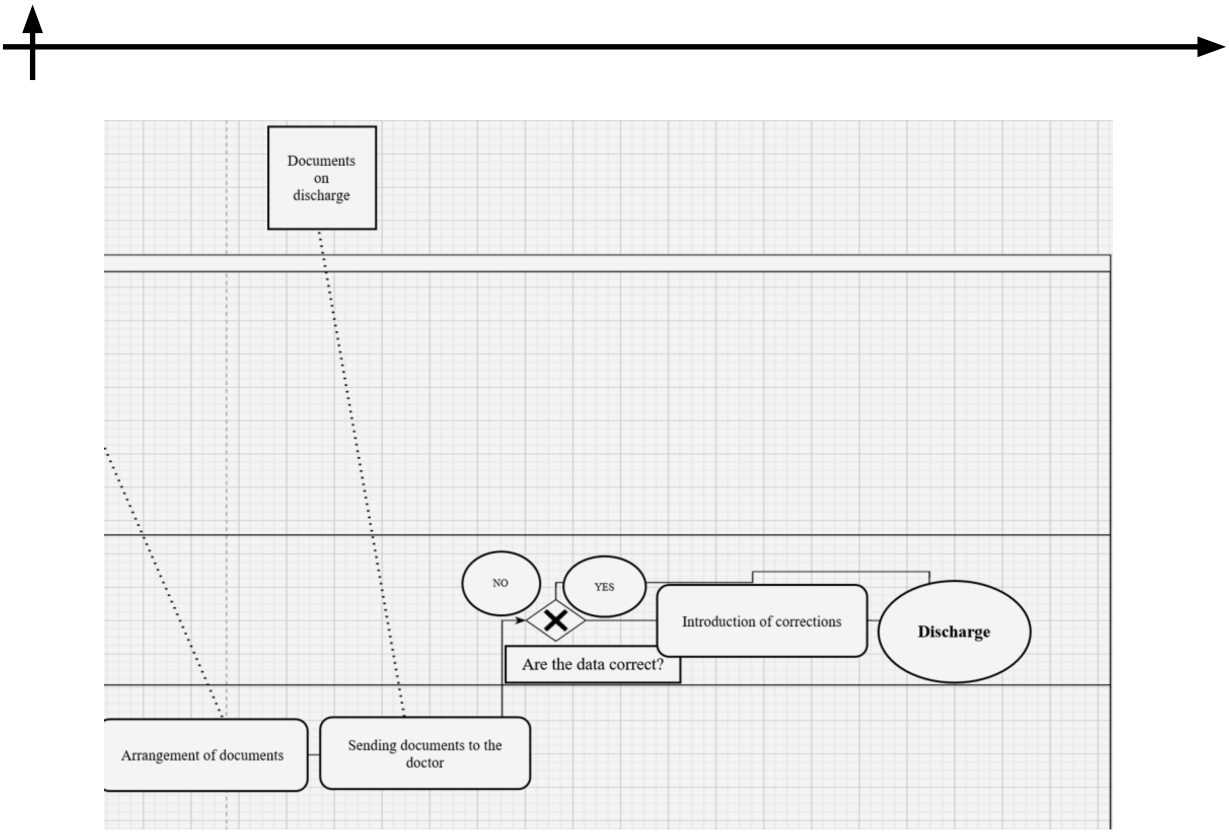

Fig. 8. "Patient Flow Management": "TO BE" process model (Part 5).

Table 1. Risk response matrix

Risk	Probability	Impact	Response strategy
Insufficient data accuracy	High	High	Thorough data verification, validation with medical professionals
Violation of privacy	Medium	High	Implementation of advanced security measures, regular security audits
Staff resistance	Medium	Medium	Training and informing staff on the benefits of the system
Technical failures	Low	High	Developing an emergency recovery plan, regular maintenance
Systems integration problems	Medium	High	Utilizing interoperability standards, pre-integration testing
Legal issues	Low	Medium	Consultations with health care attorneys to ensure compliance with legislation
Incorrect use	Medium	Medium	Creating detailed user manuals, staff trainings

This matrix will help project managers and stakeholders to be prepared for possible problems and respond quicker.

Conclusion

Overall, as a result of chatbot implementation the following effects will take place:

1. Increased efficiency. Reduction of the time needed to process documents allows doctors to focus on patient care.

2. Reduced number of errors. Automation reduces the likelihood of human error in data entry, thus increasing the accuracy of medical records.

3. Improved patient satisfaction. Fast and efficient document processing improves patients'

impression of hospital services.

4. Resource savings. Reducing the cost of administrative processes allows resources to be reallocated to other important needs of the healthcare facility.

5. Better data security. Chatbots that comply with data protection standards ensure that medical information is stored and processed securely (Rikhi, 2023).

6. Accelerated placement.

7. Facilitated preparation. Automating data collection and notifications significantly reduces the time needed to prepare for surgery.

8. Improved staff communication.

9. Improved operational efficiency. Automation allows minimizing downtime, optimizes schedules, and boosts the capacity of the medical facility.

10. Reduced administrative burden. The volume of manual work associated with scheduling and coordination decreases.

11. Higher scheduling accuracy. Automatic reservation eliminates errors associated with double booking or misallocation of resources.

12. Increased staff satisfaction. Smoother and more predictable schedule improves overall interaction within the health system.

13. Quick adaptation to change. Chatbots can be easily updated to accommodate new requirements or schedule changes, providing management flexibility (Huo, 2023; Gцndцcs, 2024).

14. Better coordination.

15. Easy access to medical records. Improved archiving provides all stakeholders with the opportunity to access documents at any time. What is more, automating the surgical records with chatbots ensures standardization.

As seen from a large list of prospective benefits, the introduction of chatbots in medical institutions proves to be an absolute win-win that improves the efficiency of medical processes and boosts patient satisfaction.

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STRATEGIC TRANSPORT MOBILITY OF MODERN RUSSIA

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Abstract. Recent geopolitical disagreements have caused tectonic changes in economic, technological and scientific ties between the North-South countries. Russia, as a country with the largest territory and substantial natural resources, found itself at the epicenter of these changes. Numerous sanctions adopted by the collective West after February 2022 created a new geopolitical reality, when Russia can rely only on its own intellectual and technological resources. In such external conditions, Russia will most likely be guided only by its national interests, with the climate agenda playing a secondary role. This research examines a conceptual model of transport mobility, when not the climate agenda, but technological development becomes the main dominant of development. The basis of such transport mobility is the existence of critical technologies and new economic mechanisms for their implementation. In this paper the possible implementation of such a new model is presented, in particular, on the basis of national-scale projects to create a country's own technological base in the field of electric vehicle (EV) manufacturing, hydrogen fuel cell locomotives, and modern shipbuilding.

Keywords: transport mobility, critical technologies, economic tools, national projects, global economic trends

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СТРАТЕГИЧЕСКАЯ ТРАНСПОРТНАЯ МОБИЛЬНОСТЬ СОВРЕМЕННОЙ РОССИИ

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Аннотация. Геополитические разногласия последнего времени стали причиной тектонических изменений в экономических, технологических и научных связях стран Севера и Юга. Россия, как страна с крупнейшей территорией и значительными природными ресурсами, оказалась в эпицентре этих изменений. Многочисленные санкции, принятые коллективным Западом после февраля 2022 года, создали новую геополитическую реальность, когда Россия может рассчитывать только на собственные интеллектуальные и технологические ресурсы. В таких внешних условиях Россия, скорее всего, будет руководствоваться только своими национальными интересами, а климатическая повестка будет играть второстепенную роль. В статье рассматривается концептуальная модель транспортной мобильности, когда не климатическая повестка, а технологическое развитие становится главной доминантой развития. Основой такой транспортной мобильности является наличие критических технологий и новых экономических механизмов их реализации. В статье рассматривается возможная реализация новой модели, в частности, на основе проектов национального масштаба по созданию собственной технологической базы в области производства электромобилей (ЭМ), локомотивов на водородных топливных элементах и современного судостроения.

Ключевые слова: транспортная мобильность, критические технологии, экономические инструменты, национальные проекты, глобальные экономические тренды

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Introduction

A key feature of global economic trends over the past five decades has been the exponential growth in energy consumption. Between 1973 and 2022, energy use around the world doubled from 6,210.8 million tons of oil equivalent (Mtoe) to 14,591.1 Mtoe (IEA, 2023). This growth in energy use has been driven not only by the development of industries but also by an expanding range of goods and services, as well as the emergence of new sectors that rely on high-tech applications. As further increases in energy consumption are expected to lead to climate change, experts have called for a reassessment of current energy practices. The transition to a new energy paradigm is underway, driven by the widespread adoption of digital technologies kicking off at the turn of the 21st century. The first trend relates to the development of critical technologies that are shaping the formation of new product markets, which is driven by the increasing significance of these technologies in determining the future of industries and economies. The second trend is centered around the intensification of the climate change agenda, resulting in the creation of new segments in the energy sector. This includes the development of renewable energy sources and energy-efficient technologies for transportation, energy distribution, and energy use. A third trend involves a shift in the nature of labour, with an increase in online employment opportunities, emergence of digital platforms, and a substantial rise in the share of services. This trend has led to changes not only in the lifestyles of employees but also in the functioning of social and industrial infrastructures. The fourth trend has demographic implications and is directly linked to the rapid growth in the number of large cities, particularly on the Asian continent where the phenomenon significantly exacerbates challenges related to transport mobility and environmental conditions in these urban areas.

The total global carbon dioxide (CO2) emissions in 2022 amounted to 36.8 billion metric tons (IEA, 2023), with approximately 15% (about 5.5 billion metric tons) emitted from global road transport (Ritchie, 2020). In the Russian Federation, the Transport Strategy for the Russian Federation 2030, with a forecast up to 2035, serves as the primary document for long-term planning and development of the transportation industry and sets objectives for reducing greenhouse gas (GHG) emissions from all modes of transportation (Transport Strategy of the Russian Federation, 2021). An ambitious target for reducing GHG emissions through 2035 was set: a 30%-70% reduction in the "carbon footprint" of public transportation in large and major urban areas compared to 2019. Moreover, the results of the joint research "Scientifically Based Forecast of Adaptation of the Road Transport Sector to the Likely Consequences of Climate Change and Possible Scenarios of Its Decarbonization in the Russian Federation" summarizing international and domestic experience and assessing the prospects for the decarbonization of the Russian road transport sector and its adaptation to climate change, were also published in 2022 (Skolkovo – MADI, 2022). However, it must be noted that these significant documents were published prior to the events of February 2022. A sharp change in the geopolitical situation has made it almost impossible and unfeasible to implement the significant number of measures outlined in the aforementioned documents.

After February 2022, Western economic sanctions have taken on a more complex nature and are now aimed at undermining the economic foundation of Russia. A significant number of Western companies have withdrawn from the Russian market, leading to a near-complete halt in economic and technological cooperation. Currently, the number of sanctions imposed on Russia has exceeded 12 000, encompassing a wide range of economic measures. These include 14 packages of sanctions from the European Union, over 3 600 restrictive measures from the United States, as well as additional measures from Britain, Canada, and Japan.

In the financial sector, these sanctions include a prohibition of direct or indirect trading in investment services related to securities and financial instruments, measures preventing the Central Bank of Russia from utilizing its international reserves, restrictions on debt and equity transactions, and the exclusion of major Russian banks from the SWIFT international payments system.

In addition to the financial sector, strict sanctions are also aimed at the operations of the energy companies, which are crucial for the Russian economy. The industry has imposed a ban on the export of high-tech and crucial technical equipment and components for sectors such as electronics, telecommunications, and aerospace, as well as aircraft, spare parts, and equipment. This includes a ban on insurance, reinsurance, and maintenance services. Drastic restrictions have also been imposed on the import of computer chips to Russia. Particularly noteworthy are the negative effects of these economic sanctions on the oil and gas production sectors, as well as on energy production. These sectors accounted for approximately 2/3 of the country's foreign exchange earnings. The country now faces the challenge of reorienting significant commodity flows geographically and towards East (in 2021, Russia accounted for 8.4% of global oil exports and 6.2% of gas exports).

The above-mentioned circumstances have served as a basis for the elaboration of new strategies in the development of transportation mobility in modern Russia. It is primarily related to an increased understanding of the importance of critical technologies in the formation of new market niches for products on a global scale.

Materials and Methods

This research implements the methods of collection and information synthesis, comparison, and description. The authors largely rely on the UN resolutions and other legal documents that focus on the matter of tranport mobility.

The main concepts of transport mobility system stem from the need to (a) achieve the goals of sustainable development, and (b) prevent further warming of the Earth's climate through reduction of CO2 emissions.

It is largely due to the adoption of directives set in two important documents in 2015 based on a broad international consensus: the UN General Assembly resolution "Transforming Our World: The 2030 Agenda for Sustainable Development" and the Paris Climate Agreement. With the practical implementation of various transport mobility models, the focus has begun to shift towards the problem of large cities, given the following objective prerequisites:

1. The mobility of many urban residents currently relies heavily on cars and other motorized vehicles, meaning that the number of worldwide vehicles amounts to approximately 1.44 billion, many of which operate within or near urban areas.

2. The share of the global urban population has increased from approximately 30% in 1950 to 55% in 2015 and is expected to reach 68% by 2050 (UN, 2019). This trend is observed against a backdrop of significant regional disparities.

To support the prerequisites, the proportion of urban residents in East Asia more than tripled over the past 65 years, rising from approximately 18% in 1950 to over 60% by 2015. In contrast, a similar shift required 80 years in more developed regions between 1875 and 1955 (UN, 2018). At the time, ground passenger transportation emissions in 2015 accounted for nearly 50% of all global CO2 emissions from transportation, primarily due to an increase in private vehicle ownership, particularly in urban areas (OECD, 2019). Cars, having become a symbol of industrialized society and providing greater personal mobility, have literally "tied" people as the most common mode of transportation. For example, in the United Kingdom, 87% of personal journeys in rural areas are undertaken by car or minibus, while in urban areas this figure is 78%. (Taylor et al., 2019)

Therefore, it is not surprising that reducing reliance on cars has emerged as one of the primary objectives in the development of transportation mobility models, initially in major cities and, subsequently, in rural areas of many developed European nations. Further significant principles of transportation mobility systems have included accessibility and an optimal price-to-quality ratio. Design and planning of transportation systems have become critical components of these models. Making significant infrastructure decisions for long-term use has been recognized as an essential element of balancing local interests with financial, operational, and strategic objectives. The integration of passenger and freight transportation, as a means to reduce future uncertainties in the use of urban spaces for housing, has become a central component of a comprehensive policy for the development of urban infrastructure. The widespread adoption of digital technology has demonstrated that its use can contribute to the overall sustainability of urban transportation systems by optimizing freight transportation and implementing new logistics strategies (Taylor et al., 2019). Additionally, adjustments to institutional arrangements, budgeting processes, data collection, and management, as well as improvements in institutional coordination mechanisms, have emerged as essential components of these models (GEF-STAP, 2010).

Results and Discussion

"Mobility as a Service"

Although the principles and approaches discussed above have shaped the basis for modern models of urban transport, new ideas and methods are continuously emerging with the aim of further improvment. One of the concepts is similar to terms used in computer science – "Mobility as a Service" (MaaS), which aims to integrate complex transport systems and address the challenges of urban mobility. The approach has been proposed as an alternative to traditional planning and provision methods (Brown et al., 2022). The development of electric vehicle (EV) technologies has provided a significant impetus for the growth of carbon-neutral public transportation. The concept of green transport, for example, – a low-emission mode of transportation that aims to reduce greenhouse gas emissions, pollution, noise, and land use – has gained attention as a means to promote economic growth and reduce poverty (Larina et al., 2021). It is to be noted that transport mobility models are also being developed in relation to the specific economic development of individual countries, such as India and Turkey, as well as the territories of specific communities, such as universities (Downes et.al., 2022; Cevheribucak, 2021; Aniegbunem, Kraj; 2023). New technological solutions, including unmanned vehicles, are also influencing transport mobility scenarios and models, particularly in the context of investment strategies and "smart" cities (Richter et.al., 2022).

Indirect policy measures

Indirect policy measures aimed at reducing emissions, in the form of managerial, regulatory, and economic solutions tailored to the specific circumstances of large cities and urban areas, have become an integral part of many transport mobility models. As demonstrated by the accumulated experience of numerous countries, such policy interventions include:

– Low-emission zones, in which vehicle entry is restricted based on the level of environmental standards;

– Restrictions on car use, prohibiting residents from using personal vehicles during peak hours on certain days;

– Limits on the importation of second-hand vehicles, such as banning the import of vehicles older than a specified year or imposing higher import duties;

– Regulation of the parking system, including the establishment of low-emission areas and restrictions on access to city centers;

– Modernization of urban spaces. Encouraging the use of non-motorized modes of transportation such as hiking and cycling, as well as public transportation, is essential. Additionally, the use of alternative fuels such as gas, hydrogen, and biofuels in place of diesel fuel, and the introduction of electric vehicles with zero emissions, are all important steps towards a more sustainable future (Shergold, Bartle; 2016).

"Europe on the Move" – AI supported transportation models

New developments in information and communication technology (ICT), particularly in mobile and big data applications, have enabled us to address practical challenges in creating a more integrated and efficient transport system in Europe, while erasing traditional boundaries between public and private modes of transportation. This principle of integrated transport and mobility strategies brought to life the new "Europe on the Move" package in 2017, adopted by the European Commission (Tsakalidis et.al., 2020).

The significant breakthroughs in artificial intelligence (AI), cloud services, and fifth-generation (5G) technologies have created conditions for automakers to utilize these new technologies to develop modular integration systems that enable independent, highly efficient, and multi-modal connections between vehicles, drivers, and passengers. For the Chinese market, for instance, such developments are spearheaded by Mercedes-Benz and Alibaba (Ng, Gao; 2020).

Thus, modern models of transportation mobility primarily focus on addressing environmental and transportation challenges in urban areas through the development of a cost-effective infrastructure that ensures safe and reliable transportation services for both individuals and goods, while minimizing negative environmental impacts. These transportation mobility models do not directly aim to develop new technologies themselves, they rather draw upon existing technologies that are the product of the scientific and commercial efforts of various economic actors, often not directly connected to transportation systems or efforts to reduce emissions.

Russia's transportation system status

To some extent, Russian concepts of transportation mobility have undergone a similar evolutionary process to those in the West. If we look at the Transport Strategy of the Russian Federation until 2035, we can see that the goals, objectives, and means for achieving transportation mobility are similar in formulation (Transport Strategy of the Russian Federation, 2021). The analysis presented above has shown that most research on transportation mobility issues, with some exceptions, focuses on large urban areas, which is explained by the fact that urbanization and motorization processes in Russia, like in the rest of the world, occur in parallel.

According to the NAPI marketing agency, there were 50.6 million registered passenger cars in Russia by the end of 2022, out of which half (50.9%) were older than 10 years, one-fifth (21.6%) were between 5 and 10 years old, and 27.5% were under 5 years old. At the same time, 96.6% of all cars in the fleet could only use gasoline and diesel fuel (NAPI, 2023). The growth of motorization in cities is facilitated by continued urban planning practices, where large-scale construction occurs without sufficient consideration for social and transportation infrastructure. It is no coincidence that, since the end of the Soviet era 30 years ago, the average daily car mileage in Russia has increased by 37%.

"Green and Healthy Streets" — Moscow initiative

Transport mobility problems are most pronounced in the Moscow metropolitan area. In response, the Moscow government launched a program in 2010 to improve the efficiency of its transport system. This has led to a 62% increase in passenger traffic on public transportation over the past 10 years (Kargin, Putilov, Khametova; 2020). Additionally, as part of its "Green and Healthy Streets" initiative, Moscow has announced its intention to fully replace its bus fleet with electric buses by 2032. The challenges and ways of developing transport mobility systems within the Moscow agglomeration have been detailed for example in the studies by Kargin et al. (Kargin, 2020) and by Zavyalov (2023). The social functions of transportation mobility and its impact on the quality of life for citizens are discussed in the study by Berezhnova and Grishine (2019) as well as by Tinkov (2023). The development of new forms of mobility in the urban environment based on the use of small transport (bicycles, scooters, segways and other self-balancing electric transport devices, including even such futurological means as an individual social transport system) is analyzed by Kogan (2016). The appeal to the concept of utilizing small-scale transportation is not unfounded. In fact, the underlying issue that characterizes most Russian cities lies in the implementation of a vehicle—centric development model, where their planning is unable to adapt to mass motorization (Komarov, Akimova, 2021), which results in the fact that, in Russia, a car requires an area four times greater than the average living space per person (22—23 square meters), and each additional vehicle is equivalent to the construction of a single-story private home in the city (Komarov, Akimova, 2021, p. 96).

Models of transport mobility in a narrow sense, as shown above, are mainly related to transport problems of large agglomerations. The approach we propose is based on the need to create strategic transport mobility, which primarily involves spatial development based on new transport systems. The latter can be implemented using critical technologies.

Critical technologies and their status in Russia

The diverse range of industrial technologies available today can be categorized into two groups based on their prevalence and strategic significance. The first category comprises general-purpose technologies, while the second category includes breakthrough or critical technologies. Both categories are essential for the successful implementation of economic activities.

The second category of technologies comprises a subset of advanced technologies which have the potential to be significant for national security. These are typically technologies associated with promising areas of scientific research, development in the most technologically significant sectors of the economy, and require investment of highly skilled labor. In Russia, critical technologies, as defined in the Concept of Technological Development of the Russian Federation until 2030, are understood to be "industrial technologies that are essential for the production of significant types of high-technology products and the provision of high–quality services that are systemically important for economic functioning, addressing socio–economic challenges, and ensuring national defense and state security".

One of the major challenges for modern Russia is the advancement and development of crucial technologies, particularly given the prominent position that Russia currently holds in global technology rankings (Zavarukhin et al., 2023). A most recent study by the Institute for the Development of Science at the Russian Academy of Sciences analyzed the main indicators that characterize the state of the scientific potential and the indicators that reflect the effectiveness of scientific activity in 43 countries, including Russia and China. The analysis revealed that Russia currently has a scientific potential that is closest to that of countries such as Australia, Canada, Czech Republic, Estonia, Greece, Hungary, Italy, Latvia, Lithuania, Malaysia, New Zealand, Poland, Portugal, Slovakia, Slovenia, and Spain (Zavarukhin et al., 2023).

Over the past 15 years, more than 10 government–level regulatory documents have been adopted in Russia in order to ensure a new quality of scientific and technological development of the country. But as practice has shown, the adoption of the regulations and provisions defined in these documents did not solve the issue of ensuring the competitiveness of the Russian industry and saturating the consumer market with high-quality domestic products. The problem of chronic lagging behind the West in the development of high technologies is due to a number of various reasons, including the following (Lenchuk, 2022):

a) There have been serious miscalculations in the scientific and technological policies and reforms in the field of science.

b) There has been a decline in the scientific and technological potential.

c) Applied sciences have been almost completely eliminated.

d) Science has become separated from the real sector of the economy.

An additional systemic factor was the "gap" between the levels of the country's scientific and technological system, which resulted in the formation of "four different branches" of science, loosely related to each other. These include fundamental "academic" science; "applied" science and technology within state scientific institutions and corporations; a majority of medium-sized companies; and cutting-edge technology companies (Belousov and Frolov, 2022).

Among other factors contributing to the technological lag, researchers have identified the following problematic issues (Mazilov and Davydova, 2020):

1. A reduction in the cost of internal research and development (R&D), which has decreased

from 2% to 1% of GDP over the past 30 years.

2. A threefold reduction in the number of personnel involved in R&D.

The current higher education system, which focuses primarily on training specialists in accordance with the technologies of the third industrial revolution (1950–2010), has not been effective in reducing the gap in technological development despite the fact that rapidly evolving technologies of the fourth industrial revolution are constantly shifting the demand for workers towards highly qualified professionals, particularly specialists and researchers in STEM fields (Akaev et al., 2020).

Development of critical technologies in Russia – the "Catch-up development"

One possible scenario for Russia's technological development could be based on the trajectories of "catch-up development", which is a historical practice seen in countries that have achieved significant success in technology, such as 19th-century England and the United States, and 20th-century Japan, South Korea, and Taiwan (Chang, 2002). It should be noted that, in relation to Russian practice, the conceptual provisions of such a scenario are set out in the works by Polterovich (2007; 2016).

The main points of their provisions are:

– establishment of catch-up development institutions to ensure economic growth under conditions of cultural, institutional, and technological constraints that are typical of developing countries;

– creation of corporatism, a system of political and economic decision-making that is based on the interaction between the government and organizations representing interest groups, primarily employees and employers;

– establishment of a national planning system, including indicative and programmatic approaches, and the creation of a federal development agency to prevent market failures and the unpredictability of government and partner behavior when considering large projects that are not managed as a single planning unit;

– development of a modern scientific sector and enhancement of human capital;

– combination of public-private partnerships and project funding;

– implementation of a policy to reduce economic inequality. The development of a national innovation system is seen as a tool to effectively adopt technologies and innovations from abroad.

The aforementioned provisions of the "catch-up development" scenario are largely reflected in the Concept for Technological Development of the Russian Federation until 2030 (The Concept, 2024), according to which, the main mechanism for achieving technological development is through the implementation of major projects (megaprojects) for the production of new complex machinery, mobile equipment, and pharmaceutical products in various industries such as aerospace, shipbuilding, electronics, radioelectronics, engine manufacturing, railway engineering, transportation engineering, machine tools, heavy machinery, and pharmaceuticals. These megaprojects will be executed through the establishment of associations that include educational, research, development, and production components, involving technological startups.

The Concept identifies four groups of measures:

1. formation of government orders for research and development in all forms (excluding basic research), based on cross-cutting technological priorities;

2. change in general approaches to development of incentive mechanisms;

3. creation of new markets for promotion of fundamentally new high-tech products based on end-to-end technologies and development of business models through a number of pilot projects;

4. overcoming technological barriers hindering the development of new markets based on

end–to–end technologies through the launch and development of an open technology competition system, including within the National Technology Initiative framework.

In accordance with the Concept, the main functions of the state in ensuring technological development are: (a) strategic planning and goal setting, (b) management of lists of critical and end-to-end technologies; (c) financial support for private innovative projects, including development institutions and state corporations and companies with state participation; (d) state order for fundamental and applied research and development, priority technological solutions; (e) taking risks and part of the costs in the implementation of certain long-term non-repayable innovative projects; and (f) support for the development of small technology companies. It should be particularly noted here that in order to ensure a new quality of technological development, the state is ready to take on the risks and part of the costs of certain non-funded innovative projects.

There are certain hopes that the institutional and organizational mechanisms outlined in the Concept will give a new impetus to Russia's technological development, especially given that the "Strategy for Scientific and Technological Development of the Russian Federation" approved in February 2024 aims to "increase total expenditures on research and development to at least 2% of GDP, including proportional growth of private investments, the level of which should not be lower than the state by 2035 (The Concept, 2024).

The concept of technological advancement is based on the establishment of domestic manufacturing facilities for the production of new sophisticated equipment and mobile devices, particularly in industries such as aviation, shipbuilding, railways, and transportation engineering.

It is evident that the necessity for implementing such projects, particularly in the fields of energy and transport engineering, is driven by a number of factors specific to Russia. Firstly, the geographical factor, namely the existence of a vast territory necessitates the establishment of a transportation mobility system as a crucial element of the nation's economic stability. Secondly, there is a need to support modes of transportation that have not been previously developed by Russian businesses, but which are essential for establishing new export routes, particularly for hydrocarbons. Thirdly, the technological aspect, which relates to the requirement for concurrent development of novel technologies as critical components of transportation mobility models. Due to the fact that the future technological development of Russia will occur without the transfer of Western technology, it becomes an important task to develop models of transport that are simultaneously aimed at developing critical technologies. A fourth consideration relates to the need for a balance between energy development and the transition to renewable energy sources. Significant progress has been made in the production of electric vehicles and the development of charging infrastructure. The creation of fuel cells that use hydrogen as a fuel has allowed for the development of the world's first 100% hydrogen train routes.

Taking into account the new institutional and organizational mechanisms laid down in the Concept of Technological Development of the Russian Federation, the production of electric vehicles, railway locomotives on hydrogen fuel cells and large-capacity vessels for LNG transportation must be considered as national-level projects aimed at creating a system of strategic transport mobility.

Three national-level projects in Russia

1. EV production

By the end of 2022, there were 50.6 million registered passenger cars in Russia, out of which, cars older than 10 years made up 50.9% of the total, cars between 5 and 10 years old accounted for 21.6%, and cars up to 5 years old made up 27.5%. At the same time, 96.6% of the entire car fleet could use only gasoline or diesel fuel. This is understandable, considering that the total number of EVs in Russia totalled 23 000 units and the number of hybrids equalled 138,500 units. In August 2021, the Government of the Russian Federation approved the "Concept for the Development of Production and Use of Electric Motor Transport in the Russian Federation until 2030", the provisions of which will be implemented in two phases, the first being from 2021 to 2024, and the second one from 2025 to 2030. By the end of the initial phase, it is projected that at least 25 000 EVs will be manufactured and 9 400 charging stations will be deployed across the country. By the year 2030, one in every ten cars produced will be electric, with an annual output of 220 000 units, and the number of electric fueling stations will increase to 72 000. In Russia, plans call for the launch of battery cell production by 2030 and the establishment of 1 000 hydrogen fueling stations for hydrogen fuel—driven vehicles by the same date. The departure of Western automakers from the Russian market has not led to a revision of these plans, but the disruption that occurred in the Russian market in 2022 has, to some extent, stimulated the development of EV manufacturing, which developments are still preliminary and uncertain though.

According to the review of the information available on the TAdviser business portal, approximately 10 companies and research institutes have currently announced their plans for the design and production of EVs in Russia. One initiative out of the 10 projects announced, has a high probability of being successfully implemented. A new series of atom electric cars is expected to be launched in the year 2025, featuring domestic high-tech software developed in Russia. These vehicles will be powered by lithium-ion batteries manufactured by Rosatom's subsidiary, Renera. Approximately 75 000 units of these electric vehicles are planned to be produced annually in various configurations. This project represents the first attempt by a Russian company to establish a production line for EVs. The current annual production of EVs of approximately 75 000 units It seems to fall far short of what would be required to significantly influence technological trends in the industry's development. Based on China's experiences, such trends may be considered to have occurred when EV sales approach one-quarter of the total market volume. Considering the Russian market as of 2021, with approximately 1.7 million vehicles sold, this number would equate to approximately 450 000 – 500 000 electric vehicles per year. Furthermore, it is essential to take into account the significant factor that EVs comprise approximately 15 000 components, which is half the number of components found in vehicles with internal combustion engines.

Considering the above, it is impossible to create a new competitive industry for the production of EVs that takes into account the requirements of a low-carbon economy without state participation. This is due to the specific historical, economic, and technological conditions in modern Russia. State involvement is necessary in the form of investment support to acquire the entire chain of technological equipment in three key areas:

1. Production of traction batteries for EVs;
2. Production of electric motors;
3. Production of assembly lines for electric vehicles.

A prerequisite for the implementation of the project is the presence of a foreign partner and the localization of all components and parts for 100% within five years. An essential component of the project will be the creation of a Russian ecosystem that supports the project, based on a network of local manufacturers with the ability not only to replicate and create new industries, but also with scientific and technical capabilities to address important issues such as lithium-ion battery disposal and the development of a comprehensive charging station infrastructure. As demonstrated by global experience, state involvement through economic incentives and support for R&D, production, and consumer demand can provide greater market stability and consumer demand formation.

2. Production of large-capacity vessels for LNG transportation

The second, strategically important element of the country's modern transport mobility system should be the production of large-capacity vessels for LNG (Liquefied Natural Gas) transportation in order to develop new export routes.

As one of the world's largest producers of natural gas, Russia has focused on exports through trunk pipelines. In the new geopolitical realities, Russia is forced to significantly transform export energy flows from the West to the East and South, where Russian oil and gas can be supplied mainly only by sea.

The creation of its own gas carrier fleet of 100-120 vessels is becoming a strategically important task aimed at increasing exports and ensuring high transport mobility in the cargo transportation segment. The special importance of this task is also associated with the unique logistical opportunities that the Northern Sea Route opens up as a new transport route. The solution to this problem will require not only the mobilization of the intellectual potential of domestic shipbuilding, expansion of production capacities, but also maximum use of the scientific and technical potential of the state corporation Rosatom. The main components of such a development model should be: (a) design and production of large-tonnage vessels at domestic shipyards, and (b) creation of technologies and organization of production of large-capacity cryogenic devices. The state should also provide for the creation of a system of economic incentives and measures to support R&D and production.

3. Hydrogen Fuel Cell Locomotives

Today, global hydrogen production is about 85 million tons, of which 48% is produced from gas, 30% from oil, 18% from coal and 4% from water electrolysis (IOGP, 2018).

In August 2022, the French company Alstom made an official announcement about the creation of the world's first hydrogen-powered train Coradia ILint. The first 14 trains are used on the world's only 100% hydrogen passenger train route in Bremerwдrd (Germany). American Wabtec, Canadian Pacific and Japanese East Japan Railway are also working on creating a similar train. This means that a new stage in the development of low-carbon transport has begun, already in the railway segment, which would not ensure transport mobility without new technologies for the electrolysis of renewable hydrogen.

Transport mobility in this segment of transportation can be ensured if three tasks are solved in parallel, namely, (a) materials and technologies for the production of industrial electrolyzers and efficient fuel cells are developed, (b) industrial prototypes of new hydrogen-powered locomotives are created, and (c) economic incentives and measures of state support for R&D and production are adopted.

Conclusion

In the context of ongoing geopolitical changes, technological development is becoming one of the decisive conditions for maintaining the economic and political sovereignty of states. A new redistribution of global energy markets is becoming a reality, and the technological race for new renewable energy sources has entered an active phase. In this regard, the stability of the Russian economy will be largely predetermined by its competitiveness not only in the segment of traditional, hydrocarbon energy sources, but also by the pace of industrial development of critical technologies. Since Russia has entered the stage of mobilization development of the scientific and technological sphere under the pressure of sanctions, the formation of technological development institutions should proceed in two directions, the maximum possible borrowing of technologies from friendly states, and the formation of leading areas based on domestic fundamental and applied scientific research.

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AI-SUPPORT ARCHITECTURE IN DIGITAL MARKETING

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Abstract. In recent years artificial intelligence (AI) has become an indispensable tool in digital marketing that is able to simplify human performance and expand business opportunities. This research considers the current AI (artificial intelligence) architectures in digital marketing, reflects on their impact on the activities of companies, and develops a range of optimization recommendations. The authors identify the most important tasks in evaluating existing solutions and their efficiency, as well as assess the possibilities of switching to AI technologies in business. Specific attention is also devoted to the examples of the neural networks implementation in marketing. As a result, the main components of the AI support architecture are identified, together with the further development prospects, with due consideration of current trends and ethical aspects. This research employs the practical achievements of marketing specialists and suggests a range of step-by-step strategies to optimize the business processes.

Keywords: digital marketing, artificial intelligence, information systems architecture, decision support system, business processes

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АРХИТЕКТУРА AI-ПОДДЕРЖКИ В ЦИФРОВОМ МАРКЕТИНГЕ

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Аннотация. Искусственный интеллект (ИИ) в последние годы стал незаменимым инструментом в цифровом маркетинге, упрощая работу специалистов и расширяя возможности для бизнеса. В данной работе произведен анализ текущих архитектур AI (artificial intelligence) в цифровом маркетинге, отражено их влияние на деятельность компаний, а также разработаны рекомендации по оптимизации. Рассмотрены наиболее важные задачи в оценке существующих решений и их эффективности, проанализированы возможности перехода к AI-технологиям на постоянной основе в работе бизнеса. Рассмотрены примеры использования нейросетей в маркетинге существующих компаний на рынке. В результате выявлены основные компоненты архитектуры AI-поддержки и предложены направления дальнейшего развития, учитывая действующие тренды и этические аспекты. Данная работа подчеркивает практическую ценность полученных результатов для специалистов по маркетингу, предлагая пошаговые стратегии по оптимизации своих бизнес-процессов.

Ключевые слова: цифровой маркетинг, искусственный интеллект, архитектура информационных систем, система поддержки принятия решений, бизнес-процессы

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Introduction

This research considers the AI support architecture in digital marketing. The topic proves to be highly relevant due to a wide range of factors. First of all, the rapid development of technology and the increase in the amount of analyzed data make artificial intelligence (hereinafter, AI) a significant tool that can facilitate human performance and expand business opportunities. Secondly, companies are experiencing an urgent need to adapt to new conditions, hence the need to comprehend how to use new technologies to optimize their business processes.

Despite the growing interest in the use of AI tools in all application areas, especially in marketing, a systematic analysis of AI support architecture is still lacking. Existing research has often examined individual aspects of AI use, such as process automation and data analysis. However, the overall impact of AI on marketing efficiency has not been addressed yet. This emphasizes the importance of exploring the topic in a more detailed way.

This paper aims to investigate the AI support architecture and its impact, as well as generate recommendations on how to construct an optimal architecture. In order to achieve this goal it is necessary to:

– analyze the current architecture of AI support in digital marketing;
– develop proposals for building an optimal architecture;
– evaluate the efficiency of AI implementation in digital marketing based on specific business examples;
– assess the possibility of transition from traditional digital marketing to digital AI market-

ing;

– examine the impact of AI tools produced on the competitiveness of companies.

This work represents specific practical value for marketing specialists. The results of this research can be implemented in development of marketing strategies and effective advertising campaigns. What is more, it provides grounds for optimization of business processes and discovery of new growth opportunities.

Materials and Methods

Open-source literature, including academic articles and specialized studies on digital marketing and AI, were employed in the course of this research. A systematic review of existing research on the application of AI in digital marketing was conducted. The authors refered to Scopus, Web of Science, Google Scholar, MDPI, elibrary, and others scientific databases. In addition, a qualitative analysis was used to explore the current architecture of existing companies. Regression analysis and other statistical methods helped evaluating the relationship between the use of new technologies and marketing performance. Comparative analysis was applied in identification of the most effective technological strategies.

Results and Discussion

The architecture itself consists of components, approaches, and methods required to solve business problems effectively. Table 1 shows what AI consists of and how the information is organized, collected and used.

Table 1. Main components of AI support architecture

№	Component	Features	Implementation prospects
1	Data	Structured data types	Tables, databases
		Unstructured data types	Text, pictures
		Internal data sources	Corporate databases
		External data sources	Open sources, social media
2	Machine learning models	Deep learning	Text and image assessment
		Reinforcement learning	Making relevant decisions in accordance with the context
3	Infrastructure	Cloud platforms	Google Cloud Platform (GCP)
		Local servers	High level of data security
4	Interaction interfaces	API	Integration in other apps
		Chatbots, assistants	Interaction with users

Each component should be observed in a detailed way. The first and most important component is data, information. They shape the basis of all artificial intelligence systems and have a direct impact on performance, efficiency, reliability, etc. Data can be grouped into structured and unstructured types. For instance, when the neural network is provided with analytical tables, product features, and customer purchases, it will draw relevant conclusions. Since texts and images cannot be subjected to structure, they are allocated to a different domain. AI draws information from a variety of sources, whether provided in advance or found on the Internet. Internal sources include corporate databases, for example chatbots with neural networks as user support (Abdullaeva, 2022; Song, 2024). If a prompt is written without setting search constraints, all open sources will be engaged.

Machine learning is based on models – prediction algorithms, and involves deep learning.

In this case, algorithms do not need to set the features or select strategies separately. Instead, they distinct the features themselves, so it becomes possible to analyze text and illustrations as well as sound files. In reinforcement learning, on the other hand, the system learns via the circulating information. This method is mainly used when the network has to produce some solution under given conditions (Evans, 2024).

Since AI systems are supposed to be based on something, i.e. servers or a network of servers. In companies where a high level of data security is required with high entry requirements, local servers are implemented. In this way, companies have full control over the data and apply their protection policy. Cloud platforms, on the other hand, utilize the servers available from the provider over the Internet. In order for AI systems to interact effectively with the user, a suitable interface is also required (Bratucu, 2024; Skatova, 2024; Sobolevsky, 2023).

It can be concluded that the AI architecture is quite realistic and clear to the user. The mechanisms themselves contain basic components, like any field of science that investigates computer programs. Speaking about the high pace of development, the system needs to be flexible and adaptable to new technologies, consumer behaviour, business demands, and an unstable external environment.

In order to propose an optimal AI support architecture based on the development trends, the following suggestions are presented in Table 2.

Table 2. Suggestions for optimal AI support architecture

№	Scope of application	Components
1	Data interaction	Centralized data storage
		Big data processing
2	Personalization of content	Machine learning algorithms
		Content generation with AI
3	Process automation	Chatbots and assistants
		Optimization of advertising campaigns
4	Predictive analytics	Customer behavior analysis
		Evaluating the effectiveness of advertising campaigns
5	Ethical aspects	Algorithm transparency
		Impact on people

Since data shapes the basis for AI, data unification should be centralized, i.e., a single source should be created to absorb other necessary sources. For example, open-access information: social networks, corporate websites, etc. In the future, it would increase the accuracy of forecasts and the efficiency of decision-making. Big data processing (for example, customer purchases over a certain period of time) is obviously needed in real time, because it allow getting information about customer preferences faster, respond in time, and adjust marketing strategies, as well as predict trends.

Content that is created by neural networks can, and should, be customized. It implies introducing algorithms that not only analyze customer behaviour but also draw recommendations of products for a specific user. In doing so, unique buyer experiences could be created. Content generation is already the responsibility of specialists, but here we can also add automatic content creation, so that the specialist only needs to check solutions (Florido-BenНtez, 2024; Sheikh, 2024). It is especially relevant with social media posts, email newsletters, advertisements, and even the entire marketing campaign. Logically enough, such measures would free up time for other tasks, reduce the preparation of materials, and increase customer focus and alignment of content with the company's goals.

Automation of business processes through chatbots and neuro-assistants has not been familiar to users for a long time. There is currently an urgent need for widespread introduction of such assistance for the processing of standard questions to go faster. Thus, users will be able to get response regardless of the working hours of employees, meaning that the level of customer service will skyrocket. Automation is possible not only for basic and standard questions but also for managing full-fledged advertising campaigns. If AI participates in analyzing such strategies and campaigns in real time, it will be possible to respond quickly.

What is more, predictive analytics based on historical data can also be utilized more efficienty with the help of AI. For example, analyzing consumer behaviour in real time and based on their past behaviour will help to tweak strategies in advance. The same can be applied to the evaluation of marketing campaigns in general.

Since ethical aspects are an important factor in the development of new models. When AI algorithms are used, data processing should be transparent to the user. In this regard, additional regulations and standards are required to ensure that marketing solutions are not abused. Next comes the influence on people: both potential and existing. There is a need for accountability for emergent processes, development, and empowerment. After all, AI was designed to solve problems, not to replace humans (Goldybaev, 2023; Romanishina, 2024).

Taking into consideration all the above-mentioned areas of architecture suggestions, it is possible to increase the effectiveness of company marketing, improve customer loyalty, and boost profits. Artificial intelligence should become an indispensable tool for marketers and provide companies with a competitive advantage.

The main indicator of return on investment in marketing is ROMI (ROI in advertising). The formula uses marketing (advertising) costs and marketing (advertising) revenues. It is assumed that AI allows reducing advertising costs by using internal resources of the company, rather than resorting to specialists. At the same time, revenues increase by attracting consumers through personalized content, precisely tailored advertising (targeting), and so on.

According to a study conducted by McKinsey, if a company uses artificial intelligence in their marketing strategies and advertising campaigns, they see an average 30-50% increase in ROI.

The next important metric for marketing is the CCA (cost of customer acquisition). With AI, companies can also effectively allocate not only communication channels but also the funds, which reduces costs and improves the quality of incoming leads. In this case, the cost of engagement is reduced by about 20-30.

Targeting can also be analyzed more specifically. For example, AI algorithms can be applied to such ads so that users see only relevant and appropriate ads. As a consequence, this leads to a 20-30% increase in the click-through rate (CTR) of advertising. For example, at VTB, the introduction of AI to personalize marketing campaigns increased click-through rates by 50%, with conversions increasing from 2% to 6%. Artificial intelligence identified the user segment and presented pre-prepared solutions and offers in the ads (Gьndьzyeli, 2024; Liu, 2024).

If AI helps customize ads, it brings leads, and then the conversion rate increases. Out of the total number of visitors to the site, the number of those who took the required action should increase. Similarly, conversions increase by 15-25%.

An optimal AI architecture will enable more and more processes to be automated than just chatbots for technical support. Delegating business processes to AI reduces up to 30% of employee time. Now, with almost complete replacement of micromanagement, professionals can allocate time to long-term tasks. In addition, these chatbots handle up to 80% of the questions that come from users. It increases customer loyalty because they get a quick and detailed response to their question.

AI-powered predictive analytics also helps achieve greater efficiency. Predictions become 70% more accurate and stable, which helps both to respond quickly to customer behaviour and the dynamic environment and to adjust existing marketing strategies to new realities.

Thus, the help of AI in increasing the efficiency of digital marketing is confirmed by growing performance. It is a matter of absolute necessity to capitalize on these opportunities to have a competitive advantage in the market. (Gupta, 2024; Islam, 2024).

In order to fully assess the possibility of transition from traditional to digital marketing, it is necessary to be well aware of the difference between these concepts. Digital marketing utilizes online and offline promotional methods, all digital communication channels, content, newsletters, social media, etc. In its turn, AI marketing utilizes artificial intelligence technology. With its help, employees can analyze data by predicting consumer behaviour, automate processes by delegating content creation to neural networks, and personalize interaction with users by managing advertising. It can be concluded that the concept of digital marketing is broader and includes AI marketing in its structure.

Development of an AI-marketing industry requires recognizing both the anvantages and challenges (Table 3).

Table 3. Advantages and challenges of adopting AI marketing

Advantages		Potential challenges	
Increased efficiency of advertising campaigns and marketing strategies	Improved customer experience and loyalty	Long-term investments in software and training	Ethical concerns over AI application

If a company has considered all the benefits and risks, and decided to reshape the marketing department in order to move from traditional marketing to digital AI marketing, it is possible to invite some existing strategies, or tips, that will facilitate this transition.

To begin with, a company needs to choose a department of business for AI to be integrated. It is important to bear in mind that a small project should be first subjected to such automation, for example, an advertising campaign for one product only. After the campaign is over, it should be verified on the basis of performance indicators to prove that the implementation has brought visible improvements. If optimization is successful, a full-scale implementation of AI can be considered in both advertising campaigns and other marketing strategies.

Successful automation also depends on the company's internal human resources. In order for the implementation to go smoothly and without interruptions, specialists should be engaged in working with AI, platforms, and software. It will help not only to speed up the process of employee adaptation but also to avoid mistakes at the beginning of interaction.

Here is a range of specific steps to achieving AI marketing adoption:

1. Identify business needs. This step requires analyzing what processes the company currently has in place and which can be improved in order to figure out what exactly needs to be automated, for intance, data analysis, prognosis, control, or process management.

2. Set goals and objectives. If a company is currently striving to increase the advertising efficiency it is necessary to select the appropriate indicators and metrics to track the performance. For example, it can be ROI (ROMI), CCA, CTR, or conversions. In order to boost personalization, it is crucial to see how AI can help with individualized user experience on a

specific example.

3. Selection of methodologies, tools, and technologies. According to the needs, AI technologies and platforms are selected to work with AI. For this purpose, the existing platforms are assessed, together with the implementation prospects and completeness of actions. Another aspect to consider is functionality of programs and their alignment with existing processes. In addition, the platforms and software should correspond to the funds for AI implementation.

4. Employee training. In order to be qualified enough to use the software, employees need to be trained. In addition to successfully using the functionality of the platforms, it is also important to understand how to apply these functions in practice and effectively generate development strategies.

5. Start with small projects. Before launching full scale, a small process should be facilitated as a trial. Having tested the implementation in practice, strategies and approaches should be adjusted to boost functionality.

6. Evaluate effectiveness. Using the selected metrics and indicators, the effectiveness of AI implementation should be evaluated. The metrics should be monitored in real time to ensure a quicker response to external chang.

Undoubtedly, the transition from traditional digital marketing to digital AI marketing is possible. If properly implemented, it can improve the efficiency of business strategies, adapt faster to changing market conditions, and attract more customers. However, the implementation process requires significant investment, respect to ethical concerns, and readiness to introduce radically new strategies.

It is difficult to overestimate the impact of artificial intelligence, including neural networks, on both the effectiveness of marketing and the overall competitiveness of a company. The use of AI in operations allows organizations to adapt faster to changes in consumer behaviour, optimize budgets, and increase revenues.

OZON, a large Russian marketplace, automated the advertising process via targeting. For this purpose, OZON created its own tools for AI advertising campaigns. Targeting became more accurate with higher personalization, resulting in the increased volume of orders to 100 000 per day. In terms of competitiveness, the marketplace has significantly strengthened its position among competitors. In addition, the company has implemented AI in logistics as well. With the help of AI, transportation logistics involves detecting optimal routes in order to reduce the distance. It helps the company save its delivery funds and promotes customer loyalty.

Process automation based on neuroassistants and chatbots is becoming more accessible for many companies. For instance, T-Bank has developed a voice assistant for the call centre, thus saving support service time by handling about 80% of incoming calls. As a consequence, the bank's customers spend less time on hold and become more loyal. As a result, the overall number of customers grows and T-Bank ranks among the leaders in Russia. Another example of a successful implementation of AI-based chatbots is the French brand Sephora. The company analyzes customers and provides individual product recommendations. The conversion rate on the website increased, and as a consequence, the company's revenue grew. Among competitors in the cosmetic industry, Sephora has definitely obtained a much stronger position.

Companies that are automating businesses themselves are also incorporating AI into their operations. For example, HubSpot, a platform that automates the marketing and sales department of customers, has improved customer interactions through AI. As a result, labour productivity has increased by 17%, customer offerings have expanded, and the site saw a new wave of user growth.

Embedding AI capabilities into companies' operations is changing the way they do business. In order to remain competitive, compasnies need to adapt to new realities: change products and adjust approaches, etc. Methodological agencies that develop courses, including professional training, are currently receiving a large number of orders to adapt existing programa to AI capabilities. For example, programs for designer training already include modules on neural networks. In other words, consumer interest can only be maintained when a company keeps up with the growing demand and constantly changing trends.

Conclusion

Having reviewed the key components of AI support architecture and successful implementation cases, the authors developed an optimal structure for the application of artificial intelligence in various areas of digital marketing.

To sum up, the use of AI tools can improve marketing strategies and increase their performance indicators, thereby reducing advertising costs. What is more, the AI personalizes content and creates a unique user experience which results in higher consumer loyalty.

Digital AI marketing opens up new opportunities for businesses. Numerous examples of international and domestic cases prove that successful application of technologies brings in a wide range of benefits: growth in the number of customers, increased profits, stronger position in the market, and better competitiveness. In order to achieve this full-scale implementation, companies need to invest in technology, software, and training; reconsider smart strategies for building new business; and grow flexibility.

In fact, the more AI technologies are implemented in our lives, the more a qualified human professional is valued. Regardless of the number of challenges that these new realities of the market bring, the mankind has to acknowledge the change in order for the companies to maintain their competitiveness.

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PROSPECTS OF LEAN TECHNOLOGIES IN EDUCATION: MOVING TOWARDS STABILITY IN TERMS OF SOCIAL AND ECONOMIC CHANGE

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Abstract. This research focuses on summarizing statistical data on the total number of students enrolled in Bachelor, Specialist, and Master programs from 2005 to 2021. As a result, a general decrease in the number of students is determined. This trend can be associated with such factors as changes in demography, society, economy, and educational policies. The authors suggest introducing lean technologies into the learning process as a means to increase the number of people involved in education. The evident recent stabilization indicates possible changes in education, highlighting the importance of further research. The integration of lean practices in higher education not only responds to current challenges but also creates conditions for sustainable development of the educational system in the long run.

Keywords: student population, economic factors, dynamics of decline, lean technologies, demography

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ПЕРСПЕКТИВЫ ВНЕДРЕНИЯ БЕРЕЖЛИВЫХ ТЕХНОЛОГИЙ В ПРОЦЕСС ОБУЧЕНИЯ: ПУТЬ СТАБИЛИЗАЦИИ В УСЛОВИЯХ СОЦИАЛЬНО-ЭКОНОМИЧЕСКИХ ИЗМЕНЕНИЙ

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Аннотация. Настоящее исследование представляет собой анализ обобщеных статистических данных, отражающих совокупную численность студентов, обучающихся по программам бакалавриата, специалитета, магистратуры с 2005 по 2021 год. Определён общий тренд снижения численности студентов, который может быть связан с такими факторами как изменения в демографии, социально-экономической и образовательной политике. Предложены варианты внедрения в процесс обучения бережливых технологий с целью повышения количества привлекаемых к образованию людей. Эффект стабилизации, проявляющейся в последние годы данного временного ряда, свидетельствует о возможных переменах в образовательной сфере, подчеркивая важность дальнейших исследований в рассматриваемой области. Интеграция бережливых практик в высшее образование не только отвечает на текущие вызовы, но и создает условия для устойчивого развития образовательной системы в долгосрочной перспективе.

Ключевые слова: численность студентов, экономические факторы, динамика снижения, бережливые технологии, демография

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Introduction

In recent decades, education systems have had to face rapid economic, scientific, and technological changes, which required the adaptation of learning processes to new conditions (Fedotova, 2020; Gergalo, 2016; Krasnova, 2015). Lean technologies, which have proven their effectiveness in industry and other sectors, have become especially important in the context of limited funding, high-quality requirements, and the growing need for individualized approach in learning. Lean technologies are able to reduce costs, minimize wastage, and ensure more efficient resource use. According to research, implementing these methods can reduce the costs of administrative and training processes, allowing funds to be reallocated to innovative training programs and increasing student satisfaction overall.

Lean production methods in the form of Lean and Six Sigma systems are widely used in companies and daily prove their effectiveness in boosting productivity and quality. At the same time, the application of these methods in education is relatively new and, therefore, has great potential for optimization.

Materials and Methods

This research invites the methods of collection and analysis of information, comparison and description. The information base of the study is represented by a wide range of publications on innovative technologies in the energy supply, food industry and agriculture. The tabular method was used to present the results of the study.

Results and Discussion

Analyzing the indicator of change in the number of students in Russia in the period from 2005 to 2021, it is possible to identify some statistical regularities (Krasnova, 2015).

Table 1. Indicator of change in the number of students in Russia (2005-2021) (based on the Rosstat data)

Year	The number of students enrolled in Bachelor, Specialist and Master degree programs (total, mln.)	t
2005	7.065	1
2006	7.301	2
2007	7.461	3
2008	7.513	4
2009	7.419	5
2010	7.065	6
2011	6.49	7
2012	6.075	8
2013	5.647	9
2014	5.209	10
2015	4.767	11
2016	4.4	12
2017	4.246	13
2018	4.162	14
2019	4.068	15
2020	4.049	16
2021	4.044	17
Average	5.70	

As we can see from the table the beginning of the period (2008-2021) is marked by a decreasing trend in the total number of students; absolute and relative growth became negative. Primarily, it may have resulted from the demographic changes. According to Rosstat, the birth rate in the country decreased from 1.61 million children in 2008 to 1.46 million in 2021, which could lead to a decrease in the number of potential students and, thus affect the total number of university students.

The economic factors could have turned out to be another fundamental prerequisite. According to the report of the Ministry of Labor and Social Protection of the Russian Federation, the unemployment rate in the country fluctuated between 5.5% in 2008 and 5.8% in 2021. Logically enough, it contributed to the rising unemployment and instability of the labor market, which could have influenced the family's decision whether now is the right time for higher education.

And yet another factor is changes in the education system. Introduction of new standards and requirements, as well as optimization of educational programs could have created additional barriers for applicants (Bogdanova, 2018; Alekseeva, 2022).

Growth rates are mostly negative from 2009 to 2015. Figure 1 graphically represents this trend.

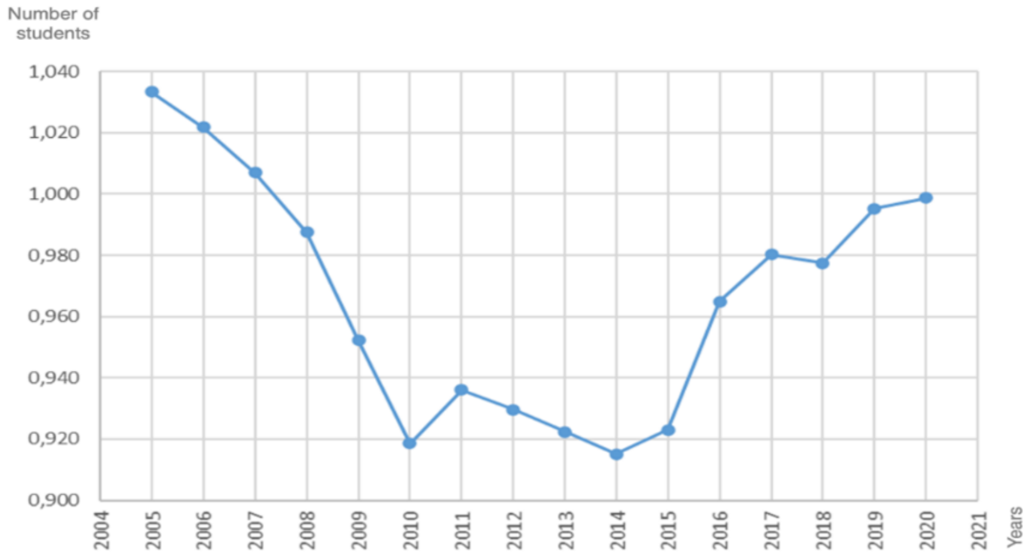

Fig. 1. Chain growth rates (designed by the authors).

Starting from 2009, we can observe a negative impact of external factors, which is reflected in negative values of Kc (chain growth rates) and Kb (base growth rates) (Table 2).

Table 2. Indicators of changes: 2005-2010 (based on the Rosstat data)

Year	Yt, Number of students enrolled in Bachelor, Specialist and Master programs (total, mln.)	APRc	APRb	TRc	TRb	Kc	Kb	TPRc	TPRb	A1
2005	7.065	-	-	-	-	-	-	-	-	-
2006	7.301	0.24	0.24	103.34	103.34	1.033	1.033	3.34	3.34	0.07
2007	7.461	0.16	0.40	102.19	105.61	1.022	1.056	2.19	5.61	0.07
2008	7.513	0.05	0.45	100.70	106.34	1.007	1.063	0.70	6.34	0.07
2009	7.419	-0.09	0.35	98.75	105.01	0.987	1.050	-1.25	5.01	0.08
2010	7.065	-0.35	0.00	95.23	100.00	0.952	1.000	-4.77	0.00	0.07
2011	6.49	-0.58	-0.58	91.86	91.86	0.919	0.919	-8.14	-8.14	0.07
2012	6.075	-0.42	-0.99	93.61	85.99	0.936	0.860	-6.39	-14.01	0.06
2013	5.647	-0.43	-1.42	92.95	79.93	0.930	0.799	-7.05	-20.07	0.06
2014	5.209	-0.44	-1.86	92.24	73.73	0.922	0.737	-7.76	-26.27	0.06
2015	4.767	-0.44	-2.30	91.51	67.47	0.915	0.675	-8.49	-32.53	0.05
2016	4.4	-0.37	-2.67	92.30	62.28	0.923	0.623	-7.70	-37.72	0.05
2017	4.246	-0.15	-2.82	96.50	60.10	0.965	0.601	-3.50	-39.90	0.04
2018	4.162	-0.08	-2.90	98.02	58.91	0.980	0.589	-1.98	-41.09	0.04
2019	4.068	-0.09	-3.00	97.74	57.58	0.977	0.576	-2.26	-42.42	0.04
2020	4.049	-0.02	-3.02	99.53	57.31	0.995	0.573	-0.47	-42.69	0.04
2021	4.044	-0.01	-3.02	99.88	57.24	0.999	0.572	-0.12	-42.76	0.04
Average	5.705	-3.02				0.572				
		-019				0.966		-0.034		

The first observation from the table is a steady decline in the number of students from 2008 to 2021, which is reflected in the negative values of APRc and APRb. A particularly sharp decrease is witnessed in 2011 and is confirmed by the negative values of APRc (absolute chain growth), APRb (absolute base growth), TRc (chain growth rate), and TRb (base growth rate), indicating the presence of a negative trend.

Subsequently, from 2010 to 2015, the oppsite trend becomes apparent, Kc and Kb become positive, indicating a change in the direction of the influence of external factors on student enrollment. This coefficient reflects the change in the number of students compared to the previous year in percentage terms. Positive values of Kc indicate an increase in the number of students, while negative values indicate a decrease. It is important to note that Kc decreases over time, which may be interpreted as a slowdown in the rate of change in the number of students (Figure 1).

Thus, positive values of Kc at the beginning of the period represent an active growth of the population, while closer to the end of the period, when Kc becomes closer to zero or negative, we can assume the onset of saturation or even a decrease in the population.

In the following years, from 2015 to 2021, Kc and Kb remain positive, emphasizing the stable positive impact of external factors on the level of student population at the university (Kuprina, 2016; Kupriyanova, 2012; Savelyeva, 2005; Bukharina, 2023).

Kb compares the current year with the base year (2005). Positive values of Kb before 2010 indicate an increase in student population compared to 2005. Negative values after 2010 indicate a decrease in the number of students in relation to the base year. It is important to note that closer to 2021, Kb values get closer to zero, which may represent the achievement of a new level stabilization within the education system itself (Chuks, 2022; Moe, 2021).

Joint analysis of Kc and Kb allows interpreting the dynamics of changes in the number of students much better. For example, if Kc is positive but Kb is negative, a temporary increase may take place, however, not leading to a sustainable increase in enrollment. A decrease in both coefficients may shape the grounds for concerns. (Figure 2).

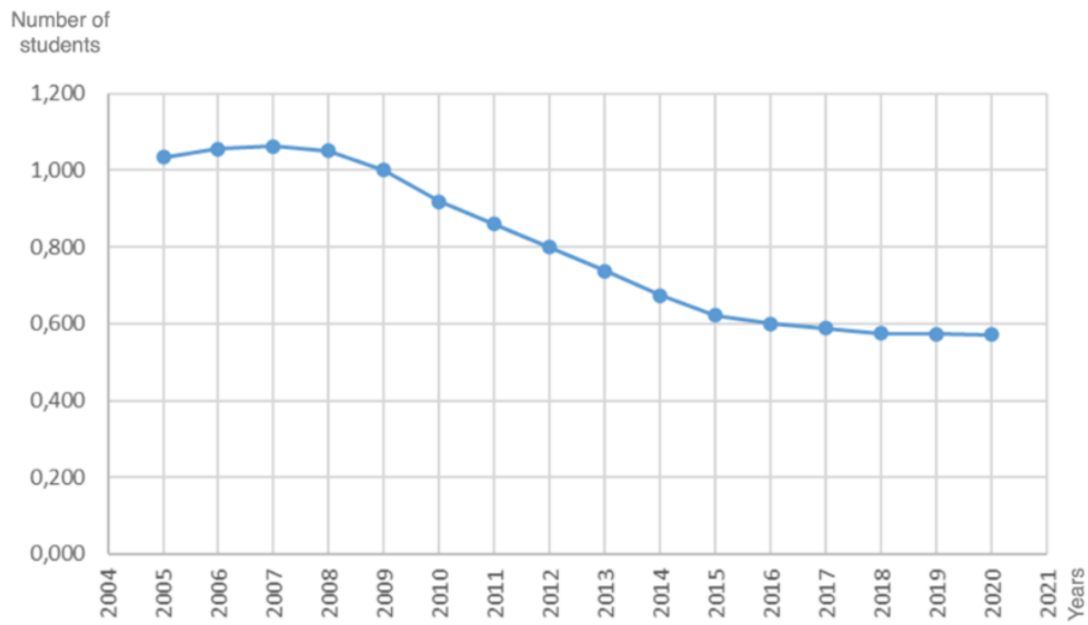

Fig. 2. Growth coefficients (designed by the authors).

The growth of Kc and Kb in the first half of the timeline may be explained by the economic development, since this period saw an increase in economic activity and improvement of the socio-economic situation in the country. GDP growth, higher incomes, and lower unemployment rates created favourable conditions for higher education; demographic changes (a temporary increase in the birth rate led to an increase in the number of young people in the following years, and subsequent number of students enrolled in universities. Another significant matter of the given time was the expansion of educational opportunities, including state support programs, infrastructure improvement, expansion of the university network, and optimization of study programs. A decrease in these coefficients in the second half of the period may indicate saturation or changes in the education policy.

Summarizing the trends mentioned above it is possible to derive the following:

– 2005-2010 – relative stability in the number of students, with a slight decrease in 2010;

– 2011-2014 –visible and rapid decline in student enrollment, reaching almost a 19% annual decline;

– 2015-2017 – continued decline in student numbers, however with a lighter decrease of a 7% annual;

– 2018-2021 – relative stabilization of the student population.

In 2000, about 1.567 million newborns were registered in Russia, but by 2010 this figure had fallen to 1.218 million, indicating a decline in the birth rate of about 22% (Brykin, 2020). The decline in the number of students in the early 2010s could be related to the demographic decline (Rupietta, 2021).

Economic challenges, especially during the 2011-2014 crisis, could have affected the accessibility of education as well as students' intension to continue their studies. During the crisis, Russia faced with an increase in inflation, a reduction of currency reserves, and a slowdown of economic growth, which led to the deterioration of the financial situation of the population. Students and their families had to deal with rising prices for goods and services, as well as growing unemployment and declining incomes (in 2010, 25.000 rubles; 2014 it fell to about 23.000 rubles, on average) (Dillinger, 2022).

Stabilization in the late 2010s may indicate the adoption of measures to adapt to demographic and economic changes, possibly with improved education conditions and financial support (Yu, 2022; Gruchmann, 2020).

In order to achieve high accuracy and minimize the impact of random fluctuations on the results, the authors employed the polynomial moving averages. This approach allows mitigating irregular oscillations and highlight the underlying trend. What is more, the application of polynomial moving averages as a filtering method helps eliminating short-term spikes that may distort data interpretation. Instead, it becomes possible to focus on long-term trends, which is particularly important for economic or managerial analysis.

As can be seen from the Table, the moving average method helped smoothing out short-term fluctuations and reveal the overall trend. The number of students has been decreasing over time, which may indicate long-term changes in the education system. The use of 5- and 7-term moving averages helped reducing the impact of random fluctuations and emphasizing more stable trends. Moving averages with 5- and 7-term components, by displaying averaged values, contribute to a better visualization of the overall stability of the trend in student population dynamics. These findings should be considered within the context of general trends in the higher education system, accounting for potential factors influencing student enrollment in Russia. The analysis of moving averages enhances the perception of student population dynamics by providing average values and highlighting more stable trends in the data.

Table 3. Implementation of the moving average method (designed by the authors)

Year	Number of students enrolled in bachelor's, specialist, and master's programs, total, million people	MA5	MA7
2005	7.065	-	-
2006	7.301	-	-
2007	7.461	7.352	-
2008	7.513	7.352	7.188
2009	7.419	7.190	7.046
2010	7.065	6.912	6.810
2011	6.49	6.539	6.488
2012	6.075	6.097	6.096
2013	5.647	5.638	5.665
2014	5.209	5.220	5.262
2015	4.767	4.854	4.929
2016	4.4	4.557	4.643
2017	4.246	4.329	4.414
2018	4.162	4.185	4.248
2019	4.068	4.114	-
2020	4.049	-	-
2021	4.044	-	-

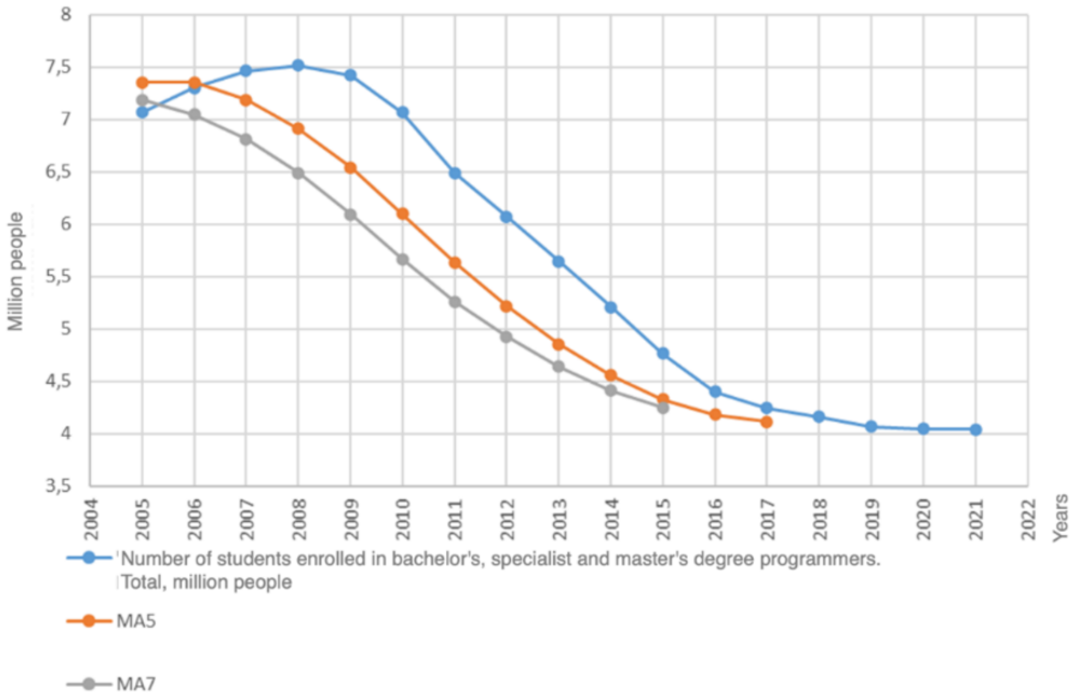

Fig. 2. Graphical representation of the original data overlaid with data obtained using the moving average method (designed by the authors).

A graphical display of the original data overlaid with the data obtained using the moving average method (Figure 3) provides a clearer representation of the difference in accuracy. In the moving average graph, periods can be identified in the point where the moving averages shift direction. These points may indicate potential changes in the dynamics of student population trends.

Conclusion

Currently, the government of the Russian Federation is taking measures to increase the number of available state-funded positions. According to the Ministry of Science and Higher Education of the Russian Federation, in 2021, the number of state-funded students in Russian universities increased by 5.4% compared to the previous year (Przybył ek, 2021). In addition, the government allocates significant funds to the development of educational infrastructure, including the construction of new and modernization of existing educational premises. In 2021 alone, more than 1000 new higher education facilities were built (Ansheles, 2020; Alami, 2022).

The introduction of lean technologies into education will significantly improve the scale of attracting and retaining new students. Analysis of trends over the last few years shows the number of learners remains stable at the level of 85-90%. Lean technologies shape a more flexible and learner-centred environment, making the learning process more engaging and adaptable to changing conditions.

An example of successful application of lean technologies in the education sector is the introduction of lean methods in STEM education in the United States. A study conducted by the Lean Enterprise Institute in 2022 showed that educational institutions that implemented lean principles were able to reduce the time spent on administrative processes by an average of 20-30%, increasing the focus on learning. By streamlining the processes of preparing and revising assignments, as well as reducing non-core teacher load, the average performance of STEM classes increased from 85% to 95%, while teachers' time spent on organizational activities was reduced by 15% (Wahl, 2022).

A key aspect of the application of lean technology is the reduction of non-core operations and the optimization of teaching resources. For example, schools and colleges that have implemented Just-In-Time have been able to reduce the costs of purchasing and refurbishing teaching equipment by 10 percent. This accomplishement enabled them to plan the needs and requirements more accurately, thus ensuring that students have access to up-to-date equipment and materials without overstocking. Another example of success is represented by the approach to continuous improvement through regular surveys among students and lecturers on the quality of the educational process.

To implement these improvements, it is important to develop and implement the concept of continuous improvement with the support of staff and management, which means engaging all employees in the process of optimization and reallocation of resources. Studies in other industries have shown that similar approaches (e.g., Kaizen) can improve performance by an average of 10-15% and can be adapted to the education sector.

In addition, methods of process visualization and standardization, such as value stream mapping or VSM, can be used to identify and eliminate bottlenecks in an organization.

Analyzing the student population in the context of the above mentioned factors emphasizes the importance of systematic research, considering the long- and short-term impact of different factors on student dynamics. Subsequent research could aim to better interpret the dynamics and reasons of fluctuations in the student numbers, as well as to identify tools to improve the overall performance of universities.

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APPLICATION OF LEAN PRODUCTION TOOLS AS A MEANS TO IMPROVE THE EFFICIENCY OF PROCESSES WITHIN A UNIVERSITY SUBDIVISION

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Abstract. This article discusses the relevance of mapping as a lean technology employed in the higher education institution in the conditions of digital transformation. The authors emphasize that modern challenges require optimization of business processes, which can be achieved by using lean production methods. In the course of the research a mapping tool was used to analyze and optimize the tracking of student attendance in the structural divisions of the university. This work aims to improve control over student attendance, including several major tasks: assessment of existing lean production tools, application of mapping in attendance tracking, optimization of the current control measures, and development of recommendations for further improvement based on the PDCA cycle. According to the results, mapping and the PDCA cycle proved their efficiency in terms of improving the quality of education in the digital environment.

Keywords: lean manufacturing, business processes, university, sustainable development, optimization

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ПРИМЕНЕНИЕ ИНСТРУМЕНТОВ БЕРЕЖЛИВОГО ПРОИЗВОДСТВА ДЛЯ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ ПРОЦЕССОВ СТРУКТУРНОГО ПОДРАЗДЕЛЕНИЯ ВЫСШЕГО УЧЕБНОГО ЗАВЕДЕНИЯ

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Аннотация. В статье рассматривается актуальность применения картирования как инструмента бережливых технологий в функционировании высшего учебного заведения в условиях цифровой трансформации. Подчеркивается, что современные вызовы требуют оптимизации бизнес-процессов, что может быть достигнуто в результате использования методов бережливого производства. В рамках исследования был применен инструмент картирования для анализа и оптимизации процесса учета посещаемости студентов в структурных подразделениях вуза. Основной целью работы является совершенствование организации контроля посещаемости студентов, что включает в себя несколько ключевых задач: анализ существующего инструментария бережливого производства, применение картирования для учета посещаемости, оптимизация текущего процесса контроля и разработка рекомендаций по постоянному улучшению на основе цикла PDCA. Результаты исследования демонстрируют эффективность применения картирования и цикла PDCA для повышения качества образовательного процесса в условиях современных реалий высшего образования.

Ключевые слова: бережливое производство, бизнес-процессы, университет, устойчивое развитие, оптимизация

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Introduction

Stochastic context in various sectors of the economy shapes the need for enterprises to develop an integral management system that would take into account the multifaceted factors affecting performance efficiency. In this regard, the importance of quality management increases not only for the final product but also for the processes occurring in organizations. A dynamically changing external environment and increasing uncertainty promote the relevance of lean production, since the later is aimed at optimizing processes, minimizing loss, and maximizing customer value. The application of lean manufacturing principles allows organizations to respond to changes in demand much faster, reduce costs, and improve the overall quality of products and services (Khadasevich, 2022; Petrova, 2019; Romanov, 2021).

Lean production focuses on creating a continuous flow of value, which requires enterprises to take a systematic approach to analyzing and improving all stages of the production process. In a volatile environment, where risk factors can significantly affect business results, it is important not only to control the quality of the final product but also to ensure high quality at all levels of operations.

Thus, the integration of lean production into management practices becomes a key driving force to achieve a sustainable competitive advantage. Effective process quality management contributes not only to improving the bottom line but also to creating a culture of continuous improvement, which is a prerequisite for the successful performance in conditions of uncertainty and instability.

Lean production is a comprehensive management approach aimed at maximizing customer value by continuously reducing inefficient processes through minimizing loss. Within this concept, losses relate to all types of inefficiencies that do not add value to the final product or service. The main goal of this approach is to create an optimal value stream that provides high-quality products and services with minimal resource inputs. Such effect is achieved by implementing principles and tools aimed at identifying and eliminating redundant processes and facilitating manufacturing operations. Within this approach, special attention is paid to the analysis of the value stream, which helps to identify rough patches where a potential loss may take place (Loginova, 2021; Chazova, 2021).

The relevance of the lean production principles in the context of sustainable development of higher education requires a deep and multifaceted analysis. Globalization and rapid changes in the educational environment set the need for universities to optimize their educational processes, improve efficiency and competitiveness in the market. (Zarubina, 2019; Chelombitko, 2020; De Souza, 2023).

The concept of lean production becomes especially relevant in the light of growing requirements for environmental sustainability and social responsibility of educational institutions. Now, universities are not only expected to provide high-quality education but also actively participate in social and environmental agenda. (Kudryavtseva, 2019; Lyamin 2023; 2024).

Currently, modern technologies such as the Internet of Things (IoT), Big Data, and artificial intelligence (AI) are being actively developed and implemented, which provides new opportunities for the introduction of lean principles in education. In particular, the Big data analysis allows universities to process large amounts of information, identify patterns and trends in learning, optimize decisions on optimizing study programs, and allocate funds more efficiently.

In the conditions of digital transformation, higher education can significantly reduce the time for adapting curricula and introducing new courses through more efficient management, thanks to the integration of different technological solutions. As a result, lean production combined with digital technologies not only increases the economic efficiency of higher education but also contributes to the reduction of the negative impact on the environment (Pulin, 2020; Golubenko, 2020; Sharafullina, 2020).

The main tool of lean production is mapping. It represents visualization of all production stages – from the receipt of raw materials to the delivery of finished products to the end user. Mapping the flow of value creation allows identifying bottlenecks and inefficiencies in the process, as well as optimization prospects.

The value stream visualization (VSM) is the major tool that eliminates losses and helps to optimize various processes (Elagina, 2021). Effective application of VSM enables organizations to not only identify potential problems but also develop strategies to address them in the future. Process visualization promotes involvement of employees at all levels. Thus, value stream mapping is becoming an integral part of strategic management, enabling organizations to achieve a high degree of efficiency and sustainability in a dynamically changing external environment.

The process mapping methodology was originally developed and actively implemented in the manufacturing sector. However, the last decades have seen a significant expansion of its application in the service sector as well.

This research aims to improve tracking student attendance at structural subdivisions of the university. In order to achieve this goal it is necessary to:

– analyze the toolkit of lean production;
– apply mapping to tracking student attendance;
– optimization of the existing process attendance control;
– development of recommendations for further improvements on the basis of the PDCA cycle.

Materials and Methods

This research employs direct observation and analysis to assess the employee efficiency. Thanks to direct observation it was possible to record the sequence of actions and time costs of individual operations, as well as to detect losses occurring in the process.

In order to visualize the existing process and identify loss sources, the value stream mapping was applied. As a result, the authors were able to assess the current processes, highlight excessive steps bottlenecks that impede the optimization of production flow. The PDCA cycle was also implemented to verify the efficiency of the proposed improvements. Each step of the cycle (planning, execution, verification, adjustment) was thoroughly documented and specified.

Results and Discussion

Considering the university activities, it is necessary to emphasize the significance of processes associated with the management of the educational process, as well as the administrative activities (Myslyakova, 2020; Silkina, 2023; Rajabova, 2022; Konkin, 2020). As for administartion, the dean's office includes both managers for different courses and levels of training and specialists performing operational activities. The main functionality is realized by specialists; their duties may include maintenance and constant updating of student data, registration of training certificates, and schedule control. In addition, they are engaged in collecting information from students on various issues and perform a number of other functions that contribute to the effective management (Trushin, 2021).

This research examines one of the ways of collecting information from students – in particular, logbooks to track student attendance. Attendance monitoring makes an important part of control over educational activities that help to identify possible problems. An effective attendance system increases student responsibility and improves the quality of education.

Keeping a logbook register is an important element of the organizational structure of any educational process in academic groups. It is important to note that the register is kept only in full-time 1st year academic groups. Group monitors are responsible for filling in logbooks and tracking attendance. This register serves not only as a means of tracking but also as a tool for analyzing students' learning activity. What is more, these data serve as a supplement to the information obtained from the monthly evaluation of the semester subjects conducted by the Academic department.

Overall, analysis of attendance data in combination with the results of current academic performance provides an opportunity to identify "struggling" students even before the exams. Teachers and administration get the opportunity to take measures in advance and support students who experience whatever types of difficulties in learning. As a result, the attendance tracking system contributes not only to the improvement of the educational process but also to the formation of a more responsible attitude of students to their academic activities.

Thus, keeping a logbook is an integral element of the education quality management system, contributing to the early identification of problematic situations and providing the necessary support for students. Time losses occurring at different stages of the educational process are an important aspect affecting the efficiency of educational activities. Figure 1 provides a visual illustration of the time costs associated with the preparatory stages of processing information on student attendance.

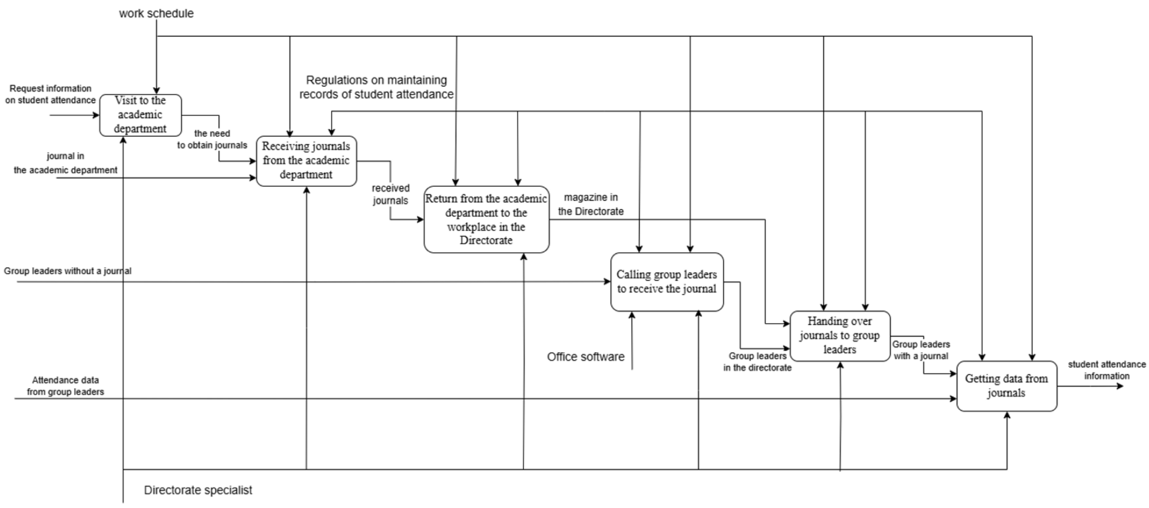

Fig. 1. Keeping a paper logbook (attendance register): process decomposition.

Six major steps of the process are mapped in Table 1.

Table 1. Mapping of the process "Maintaining a paper student attendance log" (developed by the author)

№	Action	Time	Core action (CA) / Non-core action (NCA) / Loss (L)
1	Going to the academic department	30 minutes	P2 (unnecessary actions) or P4 (unnecessary logistics)
2	Receiving logbooks from the academic department	20 minutes	Z
3	Returning to the administrative office from the academic department	30 minutes	P2 (unnecessary actions) or P4 (unnecessary logistics)
4	Calling group monitors to get logbooks	15 minutes	Z
5	Handing logbooks over to group monitors	10 minutes	P6 (waiting)
6	Obtaining data from logbooks	1 day	Z
Total		11 days 1 hour 5 minutes	

Each of the mapped out steps should be considered separately:

1. Going to the academic department. In the first stage, the specialist of the Directorate office responsible for attendance tracking visits the academic department to receive paper logbooks. This process requires not only physical movement but also time to commute, which may vary depending on the location of these two offices.

2. Receiving logbooks from the academic department. Upon arrival at the department, the specialist receives the logbooks upon signature. This process includes verifying that the required

logbooks meet the established requirements. It is important to note that there may be delays at this stage due to paperwork or lack of the required number of logbooks.

3. Returning to the administrative office from the academic department. The specialist returns to the workplace. This step also involves commuting, which may further increase the total time required to complete the entire cycle.

4. Calling group monitors to get logbooks. At this stage, the specialist needs to initiate communication with each group monitor. It can be accomplished through phone calls, emails, or other means of communication. The specialist informs the group monitors on the necessity to get the logbooks in the academic depertment.

5. Handing logbooks over to group monitors. The institute specialist gives the logbook to each monitor while informing them of the rules of filling it out and the deadlines. It is important to ensure that monitors clearly understand the requirements for keeping attendance record, which may also require additional time for clarification.

6. Obtaining data from logbooks. The specialist has to scrutinize the records, check their accuracy, and enter the necessary data into the e-record systems. This process takes considerable time, especially if the logbooks are completed inaccurately.

As can be seen from the detailed observation of each stage, keeping paper logbooks implies a lot of time concerns and does not seem to be particularly convenient. Given the current trend for digitalization it is more appropriate to switch to e-logbooks. Such change, for example in Google Tables, can significantly reduce the time spent and minimize the physical burden on employees. This form of record keeping automates the processes of collecting and analyzing attendance data, thereby improving the accuracy and timeliness.

Table 2 depicts the process of keeping the logbooks "before" and "after" transition to the e-version.

Table 2. Students' attendance register "before" and "after" moving to e-logbooks

"BEFORE"	"AFTER"
1. The specialist should receive paper logbooks in the academic department for the number of full-time student groups. 2. Call the group monitors and hand in the logbooks. 3. When necessary, the specialist requests data from the logbook.	1. The specialist starts "logbooks" in Google tables for the number of full-time student groups. 2. Provide access to the e-logbooks to group monitors and, if necessary, to deputy monitors. 3. When necessary, the specialist has the ability to review data from logbooks.

In order to understand the optimized e-journal process, it is necessary to consider the decomposition of the e-logbook implementation process, i.e., the transition from paper to electronic alternative (Figure 2).

Table 3 depicts the measurement of this process flow.

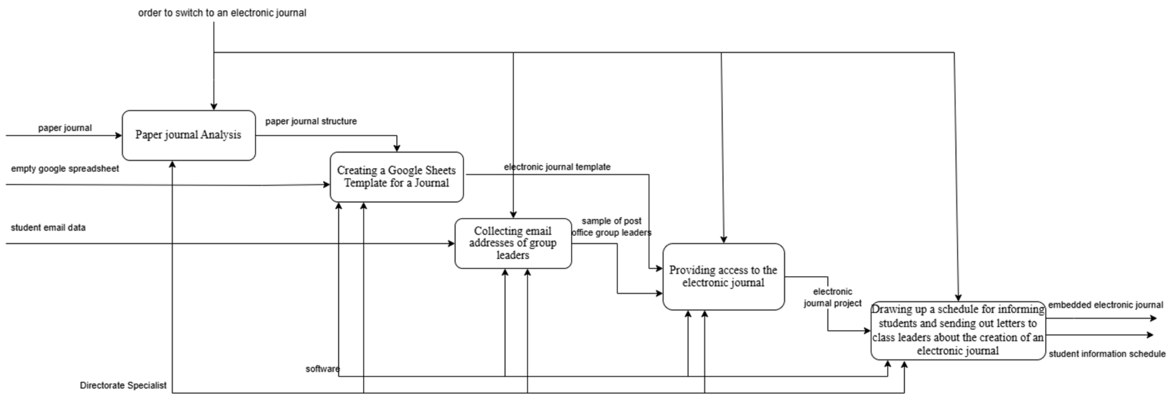

Fig. 2. Moving from traditional logbooks to an electronic alternative: process decomposition.

Table 3. Duration of the "e-logbook" process (designed by the authors)

№	Action	Time
1	Assessment of paper logbook	4 hours
2	Starting a template for the logbook in Google tables	1 hour
3	Collection of monitors' mail addresses	1 day
4	Provision of access to the e-logbook	10 minutes
5	Drawing a schedule for informing students and sending notifications on the creation of an e-logbook	30 minutes
Total		1 day 5 hours 40 minutes

As a result of this shift, the process can be optimized from 11 to 1 day only. In order to understand the specifics of process optimization, it is necessary to consider the data collecting during the transition period. Figure 3 shows the process of keeping the e-logbook.

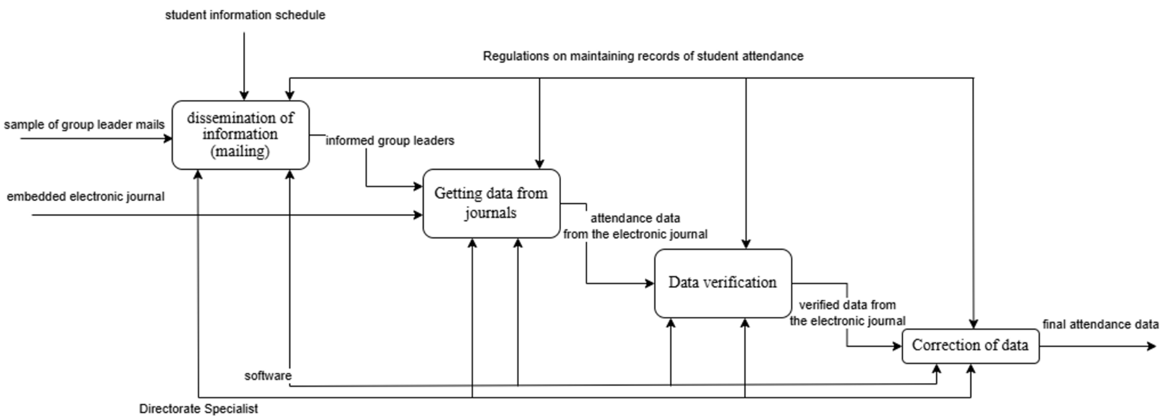

Fig. 3. Specifics of keeping the e-logbook: process decomposition.

As a result, optimization is reduced to 4 stages to be implemented within 1 day only. However, it should be noted that the shortest period is possible if monitors provide data within the deadlines set by the academic office. In order to maintain stability and improve this process, it is recommended to use the PDCA (Plan-Do-Check-Act) cycle on a regular basis. Table 3 summarizes the given cycle in terms of starting and keeping an e-logbook.

Table 4. PDCA cycle for e-logbook implementation

Cycle stage	Actions
1. Plan	- Designing an e-logbook to record student attendance using Google Tables; - Ensuring access for group monitors.
2. Do	*Implementation:* - Create and customize a Google Table template; - Conduct training for monitors on how to fill in the table and work with Google Tables; - Provide monitors with information on the student population of their academic groups; - Monitors start completing the logbook from the beginning of semester.
3. Check	*Monitoring:* - Regular checks of the logbook completion (e.g. once a week) and data quality; - Collecting feedback from monitors on the process of filling in and usability of the table. *Data analysis:* - Evaluation of the e-logbook efficiency compared to the previously used paper version; - Problem detection on the difficulties specified by the monitors.
4. Act	*Adjustments:* - Based on the feedback, changes are made to the table template or filling instructions (e.g., data formats, explanations); - A second updated training is carried out for monitors in case of problems.

The transition from traditional paper logbooks to an electronic alternative demonstrates a significant reduction in the time required to process and analyze data. However, in order to maximize efficiency in data collection and processing, it is necessary to apply the PDCA cycle. According to this model, once the electronic logbooks are implemented the effectiveness of the existing template should be regularly updated. An important aspect of this process boils down to feedback collection from students in order to reveal their suggestions and modernization recommendations.

A comprehensive approach to analyzing and improving the attendance accounting system based on the PDCA cycle can significantly improve performance of the academic department and produce the overall positive impact on the associated processes.

Conclusion

Application of mapping in the process of attendance tracking made it possible to visualize current business processes, identify bottlenecks and inefficiencies, and formulate recommendations for their elimination. Optimization of the existing attendance control showed that the implementation of lean technologies can significantly improve the overall performance. In addition, the developed recommendations for further improvement based on the PDCA (Plan-Do-Check-Act) cycle provide a systematic approach to process management and facilitate regular review and adaptation to changing conditions. According to the results of the study, implementation of lean production tools in higher education opens new horizons for the universities, improves attendance tracking and increases the overall quality of educational services.

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