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ANALYSIS OF METHODS FOR REDUCING HARMFUL EMISSIONS FROM COAL-FIRED POWER STATIONS USING COMPUTATIONAL MODELING TECHNIQUES

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Abstract. The coal-fired power industry is a significant source of environmental pollution. Nowadays, thermal power plants mostly use coal as fuel. As a result, combustion produces nitrogen oxides, leading to stricter requirements for the energy industry. This research is devoted to heat and mass transfer processes during pulverized coal combustion with the use of OFA technology to reduce harmful emissions. The authors developed the geometry and partitioning of the computational domain into control volumes and generated a mathematical model of pulverized coal flame. Based on the results of computational experiments, a graphical interpretation of the obtained results and their verification was carried out, allowing the authors to confirm that the introduction of OFA technology can significantly reduce the amount of nitrogen oxides.

Keywords: coal-fired power station, coal combustion, OFA-technology, energy industry, computational modeling

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АНАЛИЗ СПОСОБОВ СНИЖЕНИЯ ВРЕДНЫХ ВЫБРОСОВ УГОЛЬНЫХ ТЭС С ПРИМЕНЕНИЕМ МЕТОДОВ КОМПЬЮТЕРНОГО МОДЕЛИРОВАНИЯ

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Аннотация. Угольная энергетика представляет собой значительный источник загрязнения окружающей среды. На сегодняшний день, тепловые электростанции по большей части используют в качестве топлива уголь, в результате сжигания которого образуются оксиды азота, что приводит к ужесточению требований к предприятиям энергетической отрасли. Данное исследование посвящено процессам тепломассопереноса при сжигании пылеугольного топлива при использовании OFA-технологии для снижения вредных выбросов. В ходе исследования была разработана геометрия и разбивка на контрольные объемы расчетной области, сформулирована математическая модель горения пылеугольного факела. По результатам вычислительных экспериментов на основе полученных данных была проведена графическая интерпретация полученных результатов и их верификация, подтверждающая, что внедрение технологии OFA позволяет существенно снизить количество образуемых оксидов азота.

Ключевые слова: угольная ТЭС, сжигание угля, OFA-технология, угольная энергетика, компьютерное моделирование

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Introduction

Nitrogen oxides, predominantly NO and NO2, and partly N2O, produce the maximum photochemical smog. For instance, when oxidized to higher oxides, they can provoke acid rain, which is extremely harmful to plants and animals, buildings, and cultural and architectural monuments. Formation of nitrogen oxides occurs during combustion due to oxidation of air nitrogen at high temperatures and nitrogen in the fuel, which is present in complex organic coal compounds. 10—30% of fuel nitrogen is converted into nitrogen oxide (II) NO. Leaving the chimney stack, nitrogen dioxide (NO2) makes 10-15%, while the remaining 85-90% is mainly NO. What is more, the amount of nitrogen dioxide increases to 60—70% as the flue stream moves through the atmosphere (Ol'khovskii, 1996; Mcmullan, 2001; Kulikov, 2009; Messerle, 2021; Askarova et al., 2024).

A two-stage combustion method is considered most efficient in reducing the amount of nitrogen oxides formed directly in the combustion chamber. This method relies on dividing the combustion chamber volume into oxidizing and reducing zones. hereby, part of the air required for complete combustion of the fuel is supplied above the combustion zone. As a result, air depletion results in a temperature reduction in the combustion chamber, ultimately decreasing the thermal oxides (Wilde, 2008). Above the flame area, lower temperatures contribute to reduction of afterburning products of incomplete combustion (CO to CO2) and reconstruction of nitrogen oxide to molecular nitrogen (Askarova, 2021).

It is also important to note that the intensity of the combustion process of a coal particle is largely determined by the rate of oxidizer supply to its surface. The air supply above the combustion area can occur at high speed (depending on the number, size, and arrangement of diluent air nozzles). Thus, the vortex in the combustion chamber makes it possible to intensify the combustion process. The research by (Dyusenova, 2005; Kuang, 2012; Huang, 2006; Liu, 2005; Le Bris, 2007; Cremer, 2002, 2003; Valentine, 2003; Wang, 2015; Askarova, 2012) is focused on specific features of different OFA nozzle layouts and combustion chamber designs. In order to optimize the combustion of energy fuel and minimize harmful emissions, there is a strong need to conduct studies of heat and mass transfer processes. Computational modelling proves to be the most relevant and efficient method of all. Despite the entire variety of challenges associated with computational experiments, it is possible to achieve high accuracy if an adequate physical and mathematical model is designed.

Materials and Methods

This research employed the FLOREAN software package in association with the control volume approach. This strategy implies that the computational domain is divided into a grid, forming a set of finite volumes. The solutions of the basic equations (continuity, motion, energy, and components) are calculated in the centers of these volumes.

The case study is carried out on the basis of the combustion chamber of a PK-39 steam boiler installed at Aksu power plant, operating on Ekibastuz coal. Figure 1 shows the layout of the boiler: a) for traditional pulverized coal combustion, b) with OFA supplementary air nozzles. The main design features are presented in Table 1.

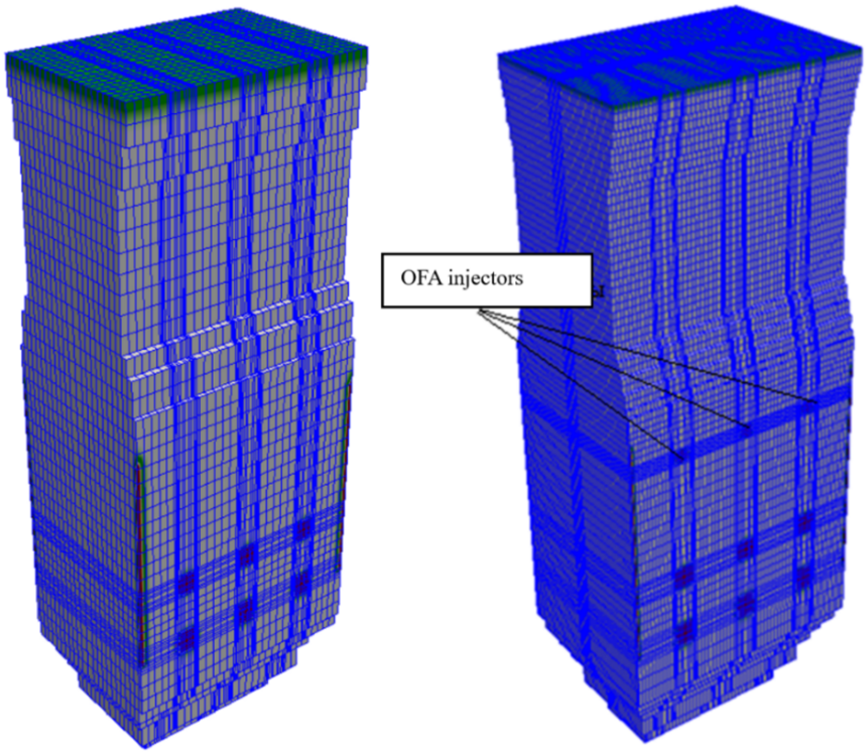


Fig. 1. PK-39 boiler and its layout with control volumes: a) base case, b) with OFA nozzles implemented.

Table 1. Design characteristics of PK-39 boiler with air staging (Aksu TPP)

Design characteristics	Size/number
Elevation of combustor, meters	29.985
Width of combustor, meters	10.76
Depth of combustor, meters	7.762
Number of burners	12
Number of OFA noozles	6
Elevation of the of the lower burner tier, meters	7.315
Elevation of the of the higher burner tier, meters	10.115
Elevation of OFA nozzles tier, meters	15.735
Size of lower burners, meters	1.2
Size of higher burners, meters	1.05
Size of OFA noozles, meters	0.7

A system of differential equations (1-4) is employed for the description of three-dimensional motion of a medium with variable physical properties, velocity, temperature, and concentration. The control volume method is used to derive data on balance correlation.

$$\frac{\partial \rho}{\partial t} = -\frac{\partial}{\partial x_i}(\rho u_i) \quad (1)$$

$$\frac{\partial}{\partial t}(\rho u_i) = -\frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial}{\partial x_j}(\tau_{i,j}) - \frac{\partial \rho}{\partial x_j} + \rho f_i \quad (2)$$

$$\frac{\partial}{\partial t}(\rho h_i) = -\frac{\partial}{\partial x_i}(\rho u_i h) - \frac{\partial q_i}{\partial x_i} + u_i \frac{\partial \rho}{\partial x_i} + \tau_{ij}\frac{\partial u_j}{\partial x_i} + S_q \quad (3)$$

$$\frac{\partial}{\partial t}(\rho c_\beta) = -\frac{\partial}{\partial x_i}(\rho c_\beta u_j) + \frac{\partial}{\partial x_i} + R_\beta \quad (4)$$

where i = 1,2,3; j = 1,2,3; β = 1,2,3,...,N.

The well-known K-ε turbulence model is used to model turbulent viscosity. The given model involves the equation of conservation of turbulence kinetic energy (K), its dissipation rate (ε), and a model relation for turbulent viscosity. It is a standard flow model with forced and natural convection.

A system of differential equations (1-4) is used for three-dimensional motion of a medium with variable physical properties, velocity, temperature, and concentration. The control volume method is used to derive data on balance correlation. (Chikobvu, 2023).

$$\frac{\partial \rho}{\partial t} = -\frac{\partial}{\partial x_i}(\rho u_i) \quad (1)$$

$$\frac{\partial}{\partial t}(\rho u_i) = -\frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial}{\partial x_j}(\tau_{i,j}) - \frac{\partial \rho}{\partial x_j} + \rho f_i \quad (2)$$

$$\frac{\partial}{\partial t}(\rho h_i) = -\frac{\partial}{\partial x_i}(\rho u_i h) - \frac{\partial q_i}{\partial x_i} + u_i \frac{\partial \rho}{\partial x_i} + \tau_{ij}\frac{\partial u_j}{\partial x_i} + S_q \quad (3)$$

$$\frac{\partial}{\partial t}(\rho c_\beta) = -\frac{\partial}{\partial x_i}(\rho c_\beta u_j) + \frac{\partial}{\partial x_i} + R_\beta \qquad (4)$$

where i = 1,2,3; j = 1,2,3; β = 1,2,3,...,N.

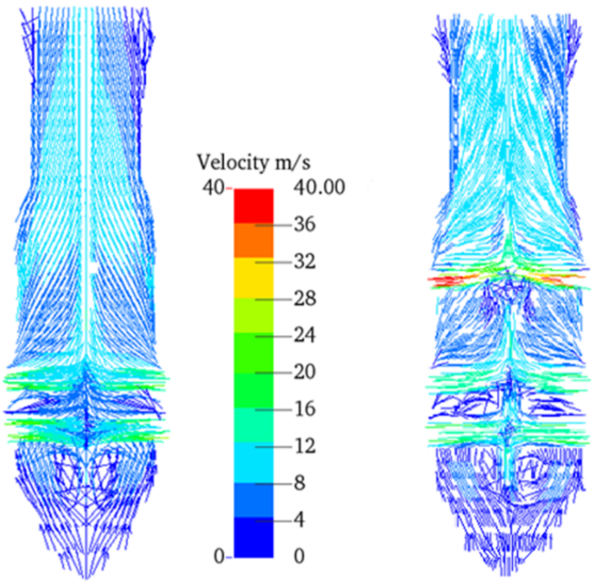
When considering heat transfer processes in technical reacting flows in combustion chambers, heat via radiation makes the largest contribution to the total heat transfer. In the flame zone, the contribution of radiant heat transfer makes up to 90% or more (Saparov, 1990). Consequently, modelling heat transfer by radiation in reacting flows is one of the most important stages in calculations of heat and mass transfer processes in real combustion chambers. The six-flow model in Cartesian coordinates proposed by De Marco and Lockwood is used to describe radiative heat transfer. In this model, the distribution of the radiant energy flux at the corresponding sections is approximated via series and spherical functions.

Results and Discussion

This research considers the cases with the percentage of air supplied through the OFA nozzles equal to 0 (base case), 10 and 20% of the total amount of secondary and tertiary air supplied to the furnace chamber. Aerodynamic, thermal, and concentration features of staged combustion of pulverized coal fuel were investigated on the example of the PK-39 boiler, Aksu TPP.

Comparative analysis on Figures 2-4 shows that the aerodynamic properties of pulverized coal flame combustion differ from the base case when additional OFA nozzles are introduced. Specifically, flame shape and velocity distribution have changed, and turbulization of flows starts to be observed in the area of OFA nozzles.

At the furnace exit (Fig. 4), the vortex flow does not weaken significantly compared to the base case of pulverized coal combustion. Subsequently, combustion products stay in the furnace chamber longer, which results in a greater reduction of nitrogen oxide NO to molecular nitrogen N2.



a) b)

Fig. 2. Distribution of velocity vector in the central section of the furnace chamber, PK-39 boiler:
a) OFA=0%, b) OFA=20%

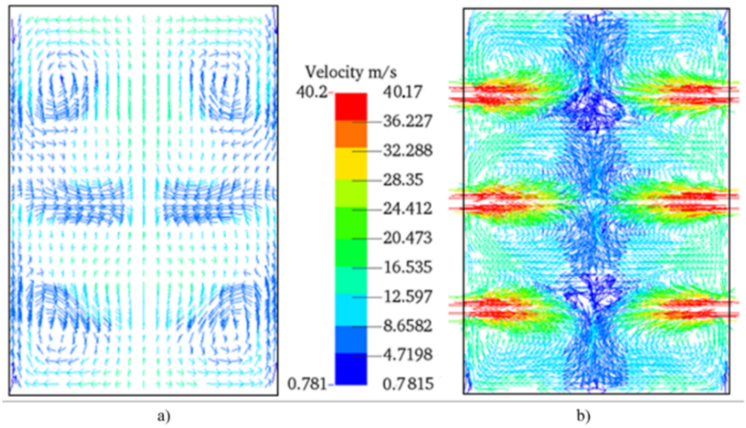


Fig. 3. Distribution of the velocity vector in cross-section of the furnace chamber PK-39 boiler in the area of OFA nozzles: a) OFA=0%, b) OFA=20%

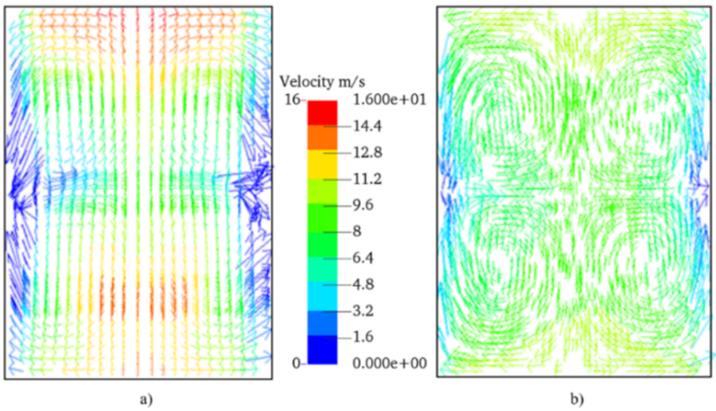


Fig. 4. Distribution of velocity vector at the furnace exit, PK-39 boiler: a) OFA=0%, b) OFA=20%

A number of tendencies are evident from the analysis of temperature distribution in the furnace chamber. According to Figures 5-6, we can see that the excess air ratio around burners reduces when a part of air is supplied from above the zone of active combustion. At the same time, the temperature increases following the growing percentage of tertiary air and, in turn, desrease in the area of OFA nozzles (Fig. 5). Moving towards the furnace exit, the temperature field equalizes and the differences in the values of the average temperature for different cases decrease. At the exit, the difference in the average values amounts to 13.6 °C (Fig. 6).

Verification of the results shows good correspondence between the obtained and experimental data. First of all, the greatest differences are observed in the area of ignition of the pulverized coal mixture. What is more, on the way to the furnace exit, these differences become almost insignificant. Thus, the implemented models prove to be efficient and adequate for the research.

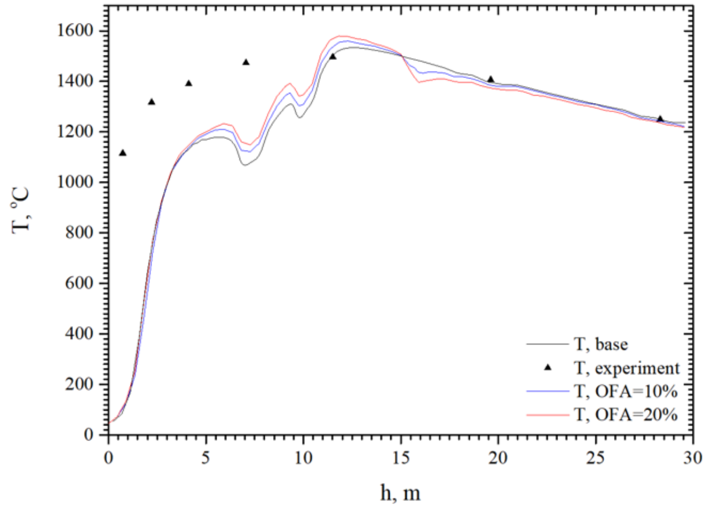


Fig. 5. Temperature distribution along the height of the furnace chamber, PK-39 boiler

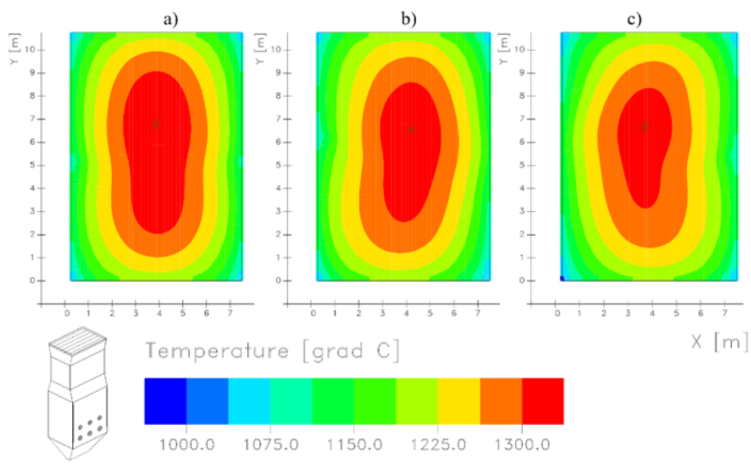


Fig. 6. Temperature distribution at the furnace exit (Z=29,60 m), PK-39 boiler:
a) OFA=0%; b) OFA=10%; c) OFA=20%

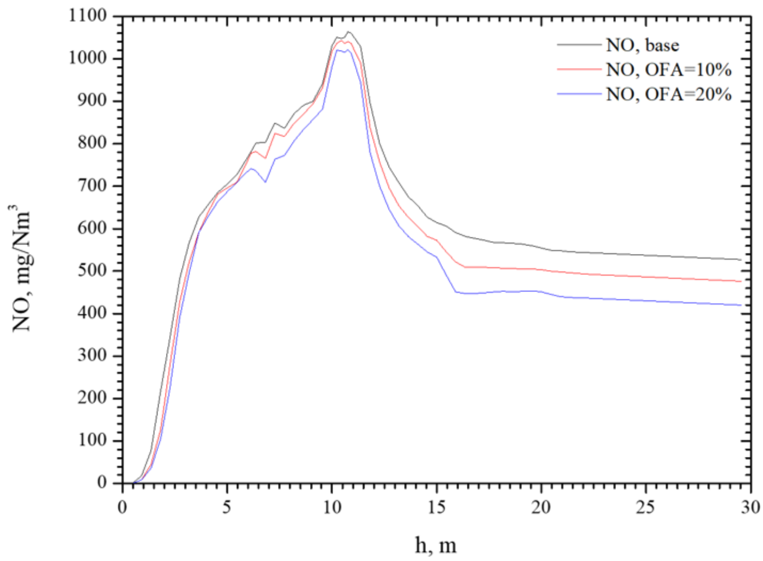


Fig. 7. Distribution of NO concentration over the height of the furnace chamber

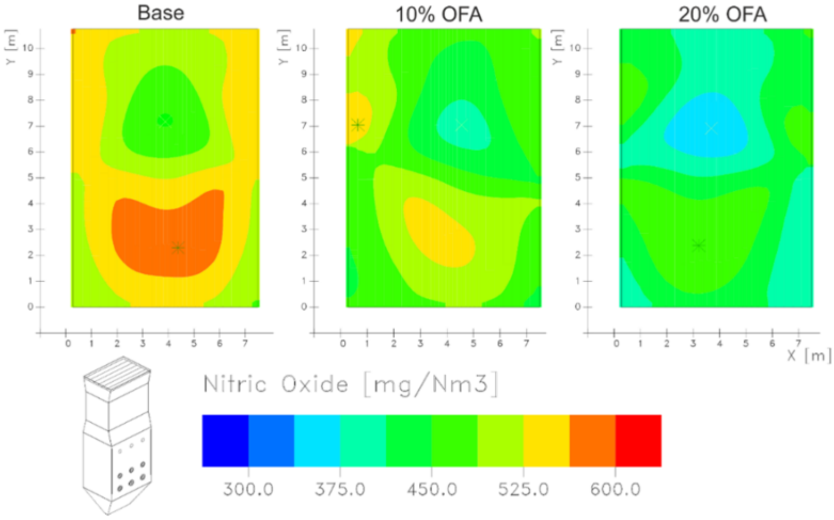


Fig. 8. Distribution of NO concentration at the furnace exit, PK-39 boiler

Analysis of NO concentration and distribution (Fig. 7-8) proves that increasing the air supply via the OFA nozzles allows to significantly reduce the concentration of nitrogen oxide at the furnace exit. It results from the fact that a bigger mass flow rate of air supplied through the OFA nozzles leads to a decrease in NO concentration in the entire volume of the furnace chamber (Fig. 7) and its exit (Fig. 8). This observation is confirmed by the well-known dependence of temperature-produced NO and temperature distribution (Fig. 5-6) in the furnace chamber.

Conclusion

Computational experiments on the OFA technology show that its introduction will lead to changes in the distribution of temperature and concentrations of carbon oxides (CO) and (CO2), as well as nitrogen oxide (NO) in the furnace space (case-based: PK-39 boiler, Aksu TPP). The most important outcome is the reduction of NO concentration at the furnace exit with the OFA amounting to 20%. Overall, OFA technology is one of the most promising ways to reduce harmful emissions (nitrogen oxide and carbon dioxide) into the atmosphere when implemented in the combustion of high-ash fuels in the furnace chambers of coal-burning TPPs.

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CURRENT CHALLENGES IN STATE REGULATION: E-GOVERNMENT AND AGRICULTURAL POLICIES

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Abstract. This article focuses on practical achievements and assessments of the results of e-government measures in the agricultural sector. E-government is based on the application of digital technologies aimed at improving public services and interaction between all stakeholders. As a tool for modernizing agriculture, it plays a crucial role in boosting the living standards of farmers. The study analyzes recent and current e-government tools that provide digital access to markets and data and dissemination of relevant information on agriculture via eMkambo, Agritex Mobile, the EcoFarmer app, etc. The authors examine the effectiveness of the AI application, blockchain, and the Internet of Things and identify the most significant bottlenecks. Based on the obtained results, it became possible to define key development tracks for the agriculture-oriented pilot projects associated with digital technologies. Such an approach proves to be highly relevant due to the fact that agriculture is a key sector ensuring food security and economic development of states.

Keywords: e-government, digital transformation, agricultural policy, digital literacy, smart agriculture, artificial intelligence, block-chain, Internet of Things

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СОВРЕМЕННЫЕ ПРОБЛЕМЫ ГОСУДАРСТВЕННОГО РЕГУЛИРОВАНИЯ: ЭЛЕКТРОННОЕ ПРАВИТЕЛЬСТВО И СЕЛЬСКОХОЗЯЙСТВЕННАЯ ПОЛИТИКА

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Аннотация. Данная статья посвящена практическим достижениям и исследованию результатов работы электронного правительства в сельскохозяйственном секторе. Электронное правительство основано на применении цифровых технологий для улучшения государственных услуг и взаимодействия между заинтересованными сторонами. В качестве инструмента модернизации сельского хозяйства оно играет решающую роль в повышении уровня жизни фермеров. В ходе исследования были проанализированы недавние и текущие инструменты электронного правительства, предоставляющие цифровой доступ к рынкам и данным, распространению актуальной информации о сельском хозяйстве, такие как eMkambo, Agritex Mobile, приложение EcoFarmer и др. Авторами также рассматривается эффективность применения технологии искусственного интеллекта, блокчейна и Интернета вещей с последующим выявлением наиболее проблемных аспектов, связанных с их внедрением. По результатам исследования были определены ключевые траектории развития пилотных проектов, направленных на применение цифровых технологий в сельском хозяйстве — ключевом секторе, обеспечивающем продовольственную безопасность и экономическое развитие государства.

Ключевые слова: электронное правительство, цифровая трансформация, сельскохозяйственная политика, цифровая грамотность, умное сельское хозяйство, искусственный интеллект, блокчейн, Интернет вещей

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Introduction

E-government is a term used to describe how the utilization of digital technologies by government agencies can increase the accessibility, efficiency, and transparency of public services. These consist of a variety of online platforms and digital gadgets that facilitate interactions between the government and residents, simplify government processes, and improve information transmission. E-government initiatives have become crucial in supporting farmers in the agricultural sector through timely provision of information as well as resources and markets. The use of information communication technologies (ICTs) has been employed in these initiatives to address some major problems faced by farmers, for instance market instability, climate change and resource depletion (Bwalya, 2012; Maydanova, Ilin, 2023.).

It is increasingly accepted that digital transformation in agriculture is a powerful engine aimed at boosting productivity, sustainability and economic growth. With digital technologies invited, farming practices are improved via optimization of resources, rise in crop yields and better access to markets. This revolution entails several activities such as policy setting, promotion of research and development projects, financial assistance, putting up infrastructural facilities and many others. Governments can encourage e-Government services to bridge the Digital Divide so that even small scale farmers benefit from IT innovation. This in turn contributes to broader objectives of food security, poverty alleviation and sustainable rural development (Chavhunduka, 2020).

Materials and Methods

This research implements an extensive literature review, encompassing academic papers, government reports, and industry analyses. A descriptive analysis is employed to present a clear picture of current agricultural landscape, highlighting its reliance on information and communication technologies. The main purpose is to assess how e-government influences the agricultural sector in three major areas:

1. Government Initiatives: What government initiatives/policies have been put into place to support the process of digitization? Ultimately, what policy frameworks/programs have been built over time to promote farmers' adoption of IT tools?

2. Impact on Farmers: Assessing implications of e-government services on information dissemination and market accessibility for farmers to evaluate the effectiveness of the government's digital assets and resources on the farming methods, featuring market accessibility, and its economic effect on farmers.

3. Case Studies: Case studies for investigating best practices of e-government in agriculture. In this sort of reviews we aim to discuss all examples of best practices in order to define existing challenges and promising development paths.

Results and Discussion

E-government, or electronic government, aims to apply information and communication technology (ICT) to government activities and practices so as to improve efficiency, transparency, and citizen participation. E-government includes the following constituents:

E-Services – provision of government services via internet, such as online submission of tax returns or applying for a license;

E-Administration – utilization of digital tools to enhance internal government processes by means of better resource management and operational efficiency;

E-Democracy – using electronic platforms, like online consultations or voting systems, in order to facilitate citizen engagement and participation in decision-making processes.

E-government initiatives are focused on bringing public services closer, reducing administrative loads, and promoting more openness as well as accountability. In relation to agriculture, this can enable farmers receive essential data on weather patterns, prevailing market prices, and best practices, hence increasing their productivity levels and boosting resilience (Chikwanha, 2019).

Government interventions aimed at supporting and regulating the agricultural sector are referred to as agricultural policies. They may involve subsidies, trade restrictions, price stabilization or support schemes and research and development programs, etc. Within the context of digitalization, there are a number of policies that stand out:

Development of Digital Infrastructure – policies aimed at connecting rural areas through internet access and ICT infrastructure for farmers;

Subsidies and Incentives – financial provisions towards adoption of new technologies including training programs meant to improve farmers' digital literacy;

Research and Development – funding for research in innovative agricultural technologies that can be transferred digitally to farmers;

Regulatory Frameworks – setting standards and regulations for digital tools and data management in agriculture so as to ensure safety, privacy, and compatibility (Da Silveira, 2021).

These policies are important for promoting widespread adoption of e-government services as well as digital tools within agricultural sector. Effective agricultural policies can play a role in bridging the existing digital divide by providing smallholders with the necessary resources required to catch up with the ongoing technological changes in this field (Kshetri, 2014).

Digital transformation in its widest definition involves the integration of digital technology in all business and social activities that transform the nature and modes of operation and deliver services or value to people. Some of these technologies include precision farming, IoT sensors, drones, and block-chain. They help farmers to:

Optimize Resource Use. With precision agriculture technologies, farmers can use water, fertilizers and pesticides more efficiently thus reducing wastage and increasing yields.

Enhance Decision-Making. It is possible for farmers to access data analytics and AI to identify crop health issues, availability of soil nutrients, market dynamics etc.

Improve Market Access. By using digital platforms farmers can link up with buyers directly, thereby avoiding middlemen, leading to fairer prices.

Increase Resilience. Real-time information on weather patterns and pest outbreaks enables farmers to make timely responses to emerging conditions, thus minimizing associated risks (Revenko, 2019).

Implementation of the above mentioned technologies in agriculture promises three potential benefits – higher production output, sustainable development and profitability. Many traditional problems that were faced by farmers including lack of access to markets and inefficient use of resources can be addressed through the employment of various digital tools.

In order to successfully address existing problems and push for a more progressive form of agriculture, it is necessary for governments to support new agricultural initiatives that have digital elements and modernize the sector to incorporate innovative technologies for the benefit of the farmers. In Zimbabwe, for instance, such initiatives are associated with the push to increase yields and productivity in the agricultural sector, and making agricultural production conform to global market requirements. Government has realized the role of digital technologies in solving some of the pertinent problems including, poor productivity, market access and susceptibility to climate change shocks. Consequently, several policies and programs that support the application of Digital Tools and enhancement of competitiveness have been implemented (Shonhiwa, 2021).

For example, the National ICT Policy envisages how ICT can be used to foster socio economic growth, the sector which includes agriculture. This policy also stresses the necessity of a strong digital platform, technology solutions, innovations and research. Moreover, the Agricultural Policy Framework also includes digital transformation into its ongoing policy that is seeking to enhance agricultural and food system through precision farming, mobile applications, and e-extension services. The above mentioned frameworks provide an institutionalized opportunity to employ Information Technology in Agriculture and make it a systematic process which can follow over a specific program cohesively in tandem with over all development programs.

E-Agriculture is another, perhaps one of the most famous, initiatives in agriculture. Its primary goal is to equip farmers with efficient instrumental and information support to improve their performance and extend markets. It involves development of mobile applications that provide information on weather, markets, and standards on the go. Another exemplary program includes the Smart Agriculture that aims to utilize IoT sensors for resource management resulting in increased crop productivity (Stoces, 2016). These are typically jointly realized with international organizations, as well as with private business.

To a greater extent, all these government trends are aimed at increasing efficiency in the agricultural sector, gaining market access, and sustainable outcome. Coordination of ICT for farming, through incorporating ICT tools into the farming processes is seen by the government as a means of improving yields and cutting input costs, making the business more commercially viable. Market access improvement is another essential outcome, which implies these measures to link farmers' production directly to consumers with fewer intermediaries promoting better pricing. In addition, it also supports sustainable practices that reduce the use and degradation of natural resources for agriculture to support food production adaptation to climate change.

When comprehensively implemented, these measures can contribute to a number of benefits for farmers that are hard to underestimate, such as access to information, market access and economic boost.

1. Access to Information

Considering e-services, the access to important information by farmers is enhanced substantially: weather conditions, prices for crops, as well as production recommendations. Available government websites and smart applications enhance the timeliness of communicated information and weather changes that farmers need in order to make adequate decisions about planting or harvesting their crops. Further on, the market price information helps farmers to sell their produce in a market of their choice at the right time in order to get the fair price for their products. These e-government platforms also provide farmers with educational information and even suggest best practices to incorporate more advanced farming techniques and enhance their yields.

2. Market Access

Online markets make it easier for farmers to get to market because sourcing marketing inputs is done directly with the buyers without intermediaries. Some e-government initiatives present online markets where farmers can offer their produce with related prices for direct agreement with the buyers. It unambiguously benefits farmers by offering better prices and, at the same time, expands their market access beyond immediate regional context. In addition, another advantage of internet-based markets is that they bring efficiency to supply systems by offering logistical aid and monitoring the flow of goods in order to minimize losses (Mashingaidze, 2020).

3. Economic benefits

The positive economic impacts of e-government services include income ethnicity and enable the farmers to get relevant information on the weather and market trends in order to prevent loses in the event of farmers producing crops which are prone to be destroyed by bad weather conditions. Also, digital tools can make efficient use of resources by extending the effective utilization of water, fertilizers, and pesticides. Combined with general market access and direct bargaining with buyers, these tools support the economic viability and expansion of agriculture as a key industry (Sylvester, 2019).

However, several challenges are experienced by the farmers to avail the e-government services even if they have lots of advantages. For instance, digital literacy is still a major modern issue because not all farmers and especially the older generation are knowledgeable when it comes to using digital devices. Another challenge is the infrastructure aspects that limit participation, including lack of reliable Internet connection in rural areas. What is more, accessing the necessary digital devices and using data services to power smart solutions can be very expensive to the smallholder farmers. In order to overcome these challenges, it is necessary to undertake specific action which might include conducting computer training and investments in ICT in the rural regions (Wolfert, 2017).

In order to support the idea of ICT being highly beneficial for farmers, it is important to showcase several platforms successfully employed in agriculture.

Case Study 1: Project A - eMkambo

EMkambo is an e-government project in Zimbabwe trending to offer a virtual platform for farmers to obtain relevant market news and engage in the sale of farming produce. The project intends to provide farmers with opportunities to get closer to the markets and gain an understanding of market prices, as well as streamline and optimize sales (Agricultural solutions; Food and Agriculture Organization of the United Nations. Digital Agriculture: Supporting Digital Transformation in Agriculture).

The eMkambo platform was created by the Ministry of Agriculture and Information Communication Technology, together with the technology stakeholders in Zimbabwe and innovation counterparts from other countries. It encompasses the establishment of a mobile application where farmers can register and list their products; and a web-based portal which will enable them to compare the current market price with those set by major supermarkets and buyers. Educational meetings were organized to make farmers familiar with the use of platform, and rural information centers were established to address the existing issues.

As a result, farmers can now get the latest information on the market and obtain higher income, since they can now bargain for better prices and also cut out several intermediaries. What is more, it has improved market transparency and competition in the agricultural market (Ministry of Agriculture. EMkambo: Transforming Market Access for Farmers).

Case Study 2: Project B - Agritex Mobile

Another practice developed to support the overall mission is Agritex Mobile which focuses on availing extension service through the use of mobile phones. In this project, the Short Message Service, SMSs and Mobile applications are used to convey timely advice on farming, weather and pests to farmers.

Administered by the Ministry of Lands, Agriculture, Water, Climate, and Rural Resettlement, Agritex Mobile encompassed the creation of a tool that alerts subscribers through SMS and avails Agritex information. It also took an evolutionary approach that began with the implementation of pilot projects across a few districts. Introductory training programs and workshops were carried out to familiarize farmers with the technology available.

The Agritex Mobile has enhanced extension services to enable reaching out with improved impacts in Zimbabwe. Farmers are now able to get the permit advice and alarms, hence act on time on the current conditions and other threats such as pests and diseases. The project has been viewed as helpful in enhancing the productivity of yields, as well as a reducing losses potentially brought by unfavorable climate conditions and pest attacks. Furthermore, due to the readily available professional advice, farmers have been able to improve their farming practices and enhance their yields (Ministry of ICT. Postal and Courier Services. E-Agriculture Initiative).

Case Study 3: Project C - EcoFarmer

EcoFarmer is a new online market that was created by the Econet Wireless Company in partnership with the Zimbabwean government. The alarm clock informs the farmers about the prevailing weather conditions and farming advice. This service also provides a sales platform to access and sell agricultural products.

EcoFarmer was delivered through a mobile application interface. The project entailed provision of SIM cards with services already installed by NGOs and other related organizations that provided services through promotional campaigns and partnerships with farmers and companies. The platform also has micro-insurance products, which can be used as a safety net in compensating farmers for losses caused by adverse weather conditions.

EcoFarmer has made a big difference for the agricultural industry within shorter time span by bringing detail information and services handy for the farmers. The weather patterns and advice on farming have also helped farmers arrange themselves in a better way and have higher management performance. The virtual marketplace has enabled easy access to quality inputs and the increased number of market outlets for their produce. In addition, the micro-insurance service offered by the Ministry, has provided a backup for the farmers by affording them an assurance of minimizing risks encountered in farming through an insurance (Government of Zimbabwe. National ICT Policy).

However, there is still a collection of challenges for farmers to deal with. Primarily, they include infrastructure issues, lack of digital literacy and sustainability, policy and regulation barriers.

Infrastructure Issues

Prominent and recurrent factors hindering effective implementation of e-government strategies in the agricultural sector relate to infrastructure. It is worth mentioning that many areas in Zimbabwe, especially in rural zones, still have a poor internet connection that is required to use different digital resources. It is compounded by a scarcity of electricity, meaning farmers cannot charge their devices or engage in internet-supported activities consistently. What is more, considering the capital-intensity of digital devices, and accessibility to data services by the smallholder farmers, they end up locked out from cooperation with e-government. Such infrastructure deficiencies impede digital transformation and prevent its whole-scale application in agriculture (Smart Agriculture in Zimbabwe).

Digital Literacy

Accessibility to digital resources is one of the main difficulties to tackle, especially when it comes to farmers. Up to this day, farming is still being dominated by the elder generations who are not digitally literate enough to properly employ digital enablers in managing their ventures. This defamed literacy results in their inability to access and fully utilize e-government services (World Bank. ICT in Agriculture: Connecting Smallholder Farmers to Knowledge, Networks, and Institutions). In some cases, training programs are needed to overcome this gap. Although, such training is time-consuming and costly, therefore may not reach everyone. In addition, there are still problems of complexity in some digital platforms which hinders the farmers from utilizing the available services (OECD. Digital Opportunities for Better Agricultural Policies).

Policy and Regulatory Barriers

Policy and regulation is yet another factor that is a major concern in adoption of e-government solutions in agriculture, since they present a number of barriers that need to be overcome. In the past, it was also possible to explain constrained use of new technologies by outdated or restrictive policies (Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement. Agricultural Policy Framework). For instance, intricately restricted laws on the stewardship of data and data security may hinder the implementation of e-markets that utilize data collected on agricultural products and markets. Furthermore, there appears to be no definite norms or best practices when it comes to digital agriculture; this leads to incongruity and slows down the manifestation of novel tools as well as solutions. The issue of policies and reforms in advanced technology must undergo significant change in order for the digital transformation to be carried out effectively.

Sustainability and Scalability

Most of the e-projects are first supported by extraneous patrons or through government subsidies, but sustaining most of them ends up in demanding a recurrent funding and support system. Furthermore, there are usually problems in reproducing pilot practices at a national level and such scaling comes with much effort and costs. Factors that come into play include procuring perfect hardware and software with constant training, and installing projects that reflect different regional conditions for sustainability and growth of e-government.

Conclusion

The future of e-government and digital transformation in agricultural forms the new trends effecting the agricultural outlook. An emerging trend is the use of enhanced technologies like artificial intelligence (AI), and machine learning (ML) to develop predictive models that would act as an advisory tool for farmers. It is usually able to pull data from different sources on the health of crops, the right time and manner of planting, as well as resource management. Another trend is block-chain technology, which contributes to increased transparency and accountability of farmers and suppliers during the distribution of products, excluding fraud and guaranteeing fair compensation for intermediaries. Moreover, the rise in demand for mobile and IoT devices promotes smart farming applications that can be used to track and control growth of crops, moisture content in the soil, and meteorological changes.

In order to enhance the effectiveness of e-government initiatives, policymakers should focus on several key areas.

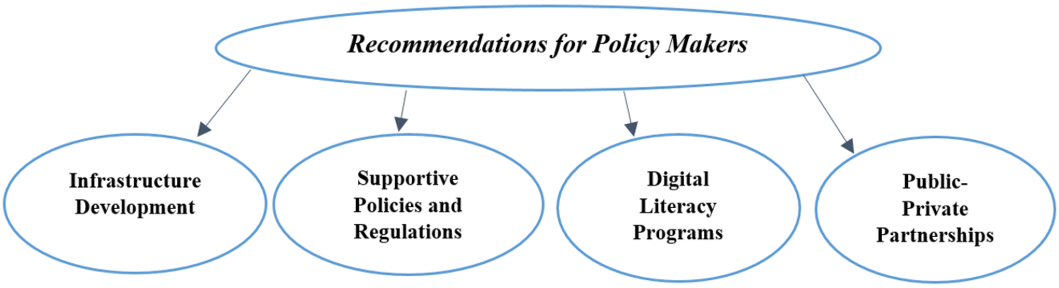

Fig. 1. Efficiency-centered recommendations for policy makers

1. Infrastructure Development – ensure that funding is directed towards strong digital networks such as the Internet; ensure cheap and reliable power source in rural areas;

2. Digital Literacy Programs – extend digital literacy initiatives to help farmers improve their understanding of digital technologies and platforms;

3. Supportive Policies and Regulations – employment of best practices and implementation of polices that will encourage the use of technologies in agriculture; protecting data;

4. Public-Private Partnerships – persuade multi-stakeholder engagement mechanisms that include the government, private and external entities to boost their competence, funding, and technologies for e-government advancement.

Farmers can adopt several strategies to better leverage e-government services:

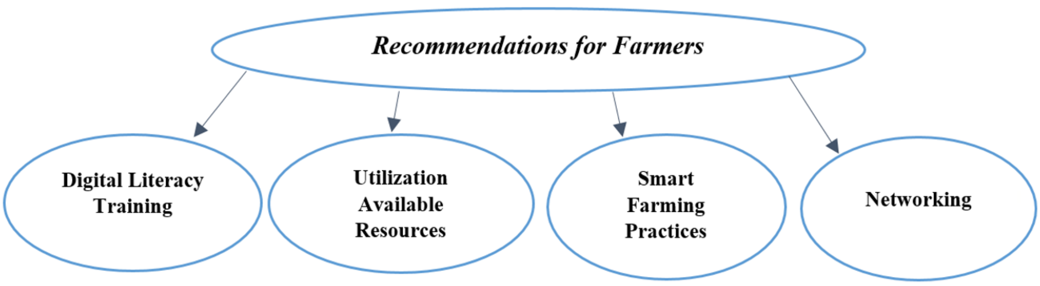

Fig. 2. Efficiency-centered recommendations for farmers

1. Engage in Digital Literacy Training — make sure that employees attend training sessions that would help them become more comfortable with smartphone applications and websites overall;

2. Utilize Available Resources — utilize the social media and other applications offered by the government and other organizations in order get the required information about the market, weather etc.; seek expert's advice on agriculture;

3. Adopt Smart Farming Practices — integrate IoT devices and smart farming solutions to better operate, monitor and manage farms so that productivity enhanced and associated costs cut down.

4. Network with Other Farmers — access the social digital farmer platforms, forums and other relevant online groups for experience and best practice sharing.

Despite significant progress, there are still several gaps in the current research that also need to be addressed.

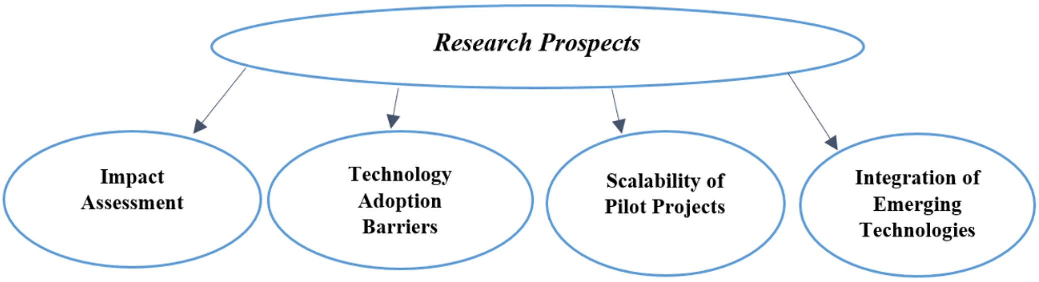

Fig. 3. Research prospects associated with e-government strategies in agriculture

1. Impact Assessment — further research has to evaluate the long-run effects of the adopted e-government strategies on the agriculture performance and farmers' living standards;

2. Technology Adoption Barriers — more literature review is needed to unveil the factors that hinder the farmer to embrace technologies, especially the small scale farmers;

3. Scalability of Pilot Projects — find out the external and internal stimulants and constrains of scalability and sustainability of connected pilot projects in order to transfer them on a national level;

4. Integration of Emerging Technologies — examine the possibility of incorporating emerging technologies that include artificial intelligence, block chain, and IoT into the existing e-government environment to maximize benefits.

All in all, e-government is one of the revolutionary tools that, if efficiently implemented, can bring a shift in the agricultural sector towards high productivity in a short time. The availability of real time information, direct market link and timely extension services enable farmers to make better decisions, enhance production per unit of land, and ultimately raise their income. However, in order to achieve these benefits, there is a need for further investment in digital resources, effective and intensive approach in promoting digital literacy, and development of policies that support investment in ICT projects that are easy to implement. The relevant challenges that still remain require multi-stakeholder approach involving government and other policymakers, private companies, and global institutions to shed adequate light on the existing problems and support the favorable environment for digital transformation in the agriculture sector to take place. The use of e-government initiatives has the potential of improving the lives of farmers, as well as ensuring food security and economic growth in the agricultural sector.

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ENERGY MANAGEMENT IN NETWORK TRADING COMPANIES: CURRENT CHALLENGES AND SOLUTIONS

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Abstract. This study is devoted to the review of modern tools of energy saving management in retail outlets of chain trading companies that provide direct offline sales of products. The research topic is highly relevant due to the digitalization of retail, development of ESG- and eco-friendly approaches to enterprise management. Throughout the research, the authors define the role of energy monitoring in energy management and saving in retail. The main directions of energy monitoring in retail outlets have been identified and characterized. The most widespread monitoring tools in the modern retail market are also distinguished and specified. As a result, the authors define major disadvantages of their application and develop the range of promising solutions.

Keywords: energy management, energy saving, online retail, offline sales, monitoring tools, automation

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УПРАВЛЕНИЕ ЭНЕРГОСБЕРЕЖЕНИЕМ СЕТЕВЫХ ТОРГОВЫХ КОМПАНИЙ: СОВРЕМЕННЫЕ ПРОБЛЕМЫ И ПУТИ РЕШЕНИЯ

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Аннотация. Данное исследование посвящено обзору современных инструментов управления энергосбережением розничных точек продаж сетевых торговых компаний, обеспечивающих непосредственную офлайн-продажу продукции. Актуальность темы исследования определена цифровизацией ритейла, развитием ESG- и экологичного и подходов к управлению предприятиями. В процессе исследования авторами была определена роль энергетического мониторинга в области управления энергопотребления и энергосбережением в ритейле. Определены и охарактеризованы основные направления энергетического мониторинга розничных точек продаж ритейла. Идентифицированы и проанализированы наиболее распространенные в современном ритейле-рынке инструменты мониторинга. Определены ключевые недостатки их применения, предложено их системное решение.

Ключевые слова: логистика, цифровая трансформация, цифровой двойник, архитектура информационных систем, моделирование

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Introduction

With the development of retail, the spread of environmental agendas, and the popularization of ESG policies, the functional area of energy-saving management is becoming more and more important for chain retailers. Society and environment oriented approaches to energy consumption are currently becoming highly relevant. In this regard, the research proposes a review of modern energy monitoring tools in retail (providing the functioning of the digital twin of the retail point of sale) in order to identify and solve the main functional and economic problems of their application.

Materials and Methods

This research is carried out on the grounds of existing research on the topic and author's conclusions on energy saving management perspectives. Theoretical basis for the research is shaped by the international standards on energy and environmental management, as well as studies on digitalization and automation (Kapustina et al., 2019; Barykin et al., 2021; Voronova, 2024; 2019; Krymov, 2016). Another important facet under consideration is development of green and ESG policies in retail (Bakharev, 2020; Kalinina, 2019; Niyazbekova, 2022). The methodology of this paper includes a system of theoretical (analysis, synthesis, classification, deduction, and induction) and practical (description) research. Application of the above mentioned methods allows assessing the theoretical framework and business practice related to energy monitoring in retail. In its turn, the descriptive method ensured the presentation of intermediate and final results of the research.

Results and Discussion

According to the international standard ISO 50001:2018 for energy management systems, energy management rests on the “Energy Performance Based Approach". It implies that energy consumption and management technologies should be based on energy consumption indicators (GOST R ISO). In this case, ISO 14001:2015 states that environmental management systems are obligatory requirements. The application of a systematic approach to energy-saving management as part of environmental management will allow the company to achieve positive dynamics of financial and operational performance as a result of the implementation of environmentally significant solutions (Karakece, 2021; Sizova, 2021). Traditionally, the following directions of energy resource use and energy consumption monitoring are distinguished in retail (Table 1).

Table 1. Characteristics of energy monitoring in retail outlets, FMCG-retail (designed by the authors)

Direction of energy use	Power supply				Central heating	Water supply
Feature	Refrigeration equipment	Lighting	Air-conditioning	Electric heating		
Facilities to be managed and monitored	Cooling chests; Refrigerated displays; Refrigeration units	Lighting units	Industrial air conditioning units	Autonomous heating from electric boilers	Central heating equipment	Sanitary equipment; piping
Facility management tools	Temperature controllers; Lighting controllers (relays)	Switches	Switches	Temperature controllers	Temperature controllers	Water head controllers
Built-in monitoring tools	Temperature sensors Opening sensors (relay); Emergency alarms	–	–	Temperature sensors; Emergency alarms	Heat meters; Alarms	Water meters; Alarms
Additional monitoring tools	Network cards; Smart energy utilization spots; Multi-channel energy meters; Universal energy meters				Pressure sensors; Leak sensors; Temperature sensors	
Monitoring indicators	Electricity consumption; Maintained temperature; Operating mode; Operation failure	Electricity consumption; Operating mode; Operation failure	Electricity consumption; Maintained temperature; Operating mode; Operation failure	Electricity consumption; Maintained temperature; Operating mode; Operation failure	Heat consumption; Maintained temperature; Operating mode; Operating failure	Water consumption; Operation failure (leaks)

According to the table, energy consumption in retail outlets includes a system of tools for monitoring the indicators and mode of operation of engineering equipment (Hasan, 2021; Strielkowski, 2021). Against the background of digitalization of retail, the modern market of IT solutions in management and monitoring of equipment in retail outlets provides business with the possibility of obtaining a unified information system to manage their operational processes and collecting data via the formation of a digital twin (Liu, 2022; Kappertz, 2023). Figure 1 depicts the essence of the digital twin.

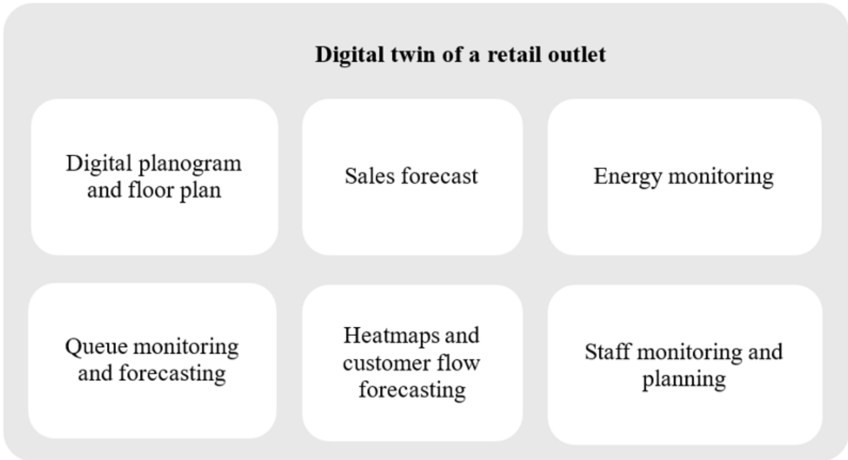

Fig. 1. Digital twin of a retail outlet (developed by the authors)

As already mentioned, the source of data for the digital twin is infrastructure tools, which are part of the engineering complex of retail facilities, as well as retailers' databases. Based on this, the digital twin tools can be generalized as a set of the following three innovative technologies (Fig. 2).

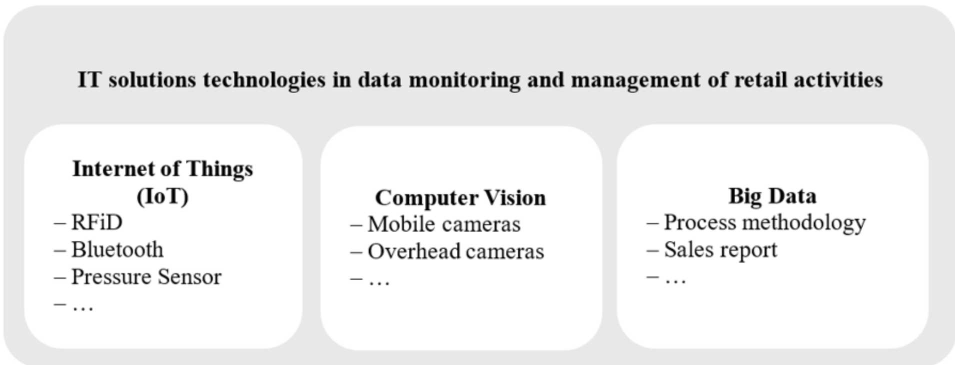

Fig. 1. Typization of modern IT technologies formation and provision of a digital twin

The most common tools for monitoring the activities of retail outlets in chain trading companies include the following:

Sensors. At present days factory sensors and equipment alarms are used in electrical equipment.Vender sensors with the ability to transmit data to a single server ("smart sensors"), installed on individual equipment, areas of the sales floor, or electrical panels. At the same time, in conditions of disparate technological levels of equipment used in retail outlets, network cards based on IoT technology are being actively implemented.

Application of these tools in combination with modern software provides:

1. Regular monitoring of energy consumption indicators of all retail point-of-sale equipment, including those that do not have built-in sensors and meters.
2. Management (including zonal) of equipment and its automation.
3. Visualization of energy consumption data.
4. Automation of energy savings at the retail outlet.

However, in the conditions of mass introduction of such technologies, retail will need a large funds. It is likely to turn out as an uneasy mission due to increasing IT support costs, price index, and dynamic purchase flow.

Cameras. Today, photo and video cameras for retail outlets can have different locations (ceiling cameras, wall cameras, and mobile cameras) depending on the purpose of use and layout solutions. A heat map of the retail outlet can be generated by integrating the camera data collection server with specialized software equipped with computer vision technology and possessing data on the layout.

Heat maps are a tool for visualization (presentation tool) of data on the intensity of customer flows obtained as a result of computer vision technology application. Technically, the heat map is shaped as a result of the identification of buyers and tracking their movement in accordance with the algorithm processing from cameras by specialized software. In addition, computer vision technology accumulates such statistical information as the number of visitors during the day, their average turnover per hour, as well as peak hours.

From a traditional point of view, heat map technology can be used as a tool for evaluating the effectiveness of merchandising, since it contributes to the key indicators of a given operational area of a retailer, including:

- Main routes of shoppers.
- Demand for specific goods.
- Efficiency of promotion campaigns.
- Ergonomics of the planogram.

At the same time, it is important to note that a number of the obtained data in conjunction with the register of retail equipment can be applied by retailers in order to find sources of increasing energy-saving indicators.

Electronic Shelf Labeling. These are e-ink screens equipped with RFID tags, which allow to automatically update the prices of products presented at the retail outlet according to the planogram by synchronizing the price data from the central server. Based on the description, the following key functions of Electronic Shelf Labeling are evident:

Automation of the price update.

Formation of a digital planogram of the retail outlet.

Thereby, introduction of this tool enables retailers to acquire an instrument for managing and monitoring the display of goods in real time in the digital planogram (Osheyor Gidiagba, 2023; Madsen, 2003). It is also important to note the strategic role of this tool for retail companies because the effectiveness of offline sales management depends on the fulfillment of its principles.

Conclusion

Overall, in order to effectively manage energy in chain retail companies, IT tools for monitoring energy consumption indicators should be used only with an integrated approach in association with the technologies of heat maps and Electronic Shelf Labeling. This approach will allow making informed management decisions based on the dynamics of energy consumption indicators, taking into account the data of planograms and the intensity of customer flows in dynamics.

In order to form an effective integrated solution of energy-saving management, the authors suggest structuring the main elements of optimization in energy consumption (Table 2).

Table 2. Elements of optimization of energy consumption management (designed by the authors)

Direction of energy use / Feature	Digital planogram	Heat map	Monitoring module of power consumption	Remote control module
Implementation tool	Electronic shelf labels	Cameras	Sensors, network cards	Network cards
Technology behind IT solutions	IoT	Computer vision	IoT	IoT
Objectives of IT solutions	Price management; Planogram management; Assessment of intensity of customer interaction with products; Evaluation of merchandising effectiveness; Targeted advertising placement	Analyzing traffic intensity; Tracking demand for products; Detecting flaws in design and/ or organization of merchandise in the store; Defining key points of the customer's routes	Monitoring energy utilization rates; Automation of data collection on equipment operation	Automation of engineering equipment management
Results of using IT solutions	Digital planogram of the outlet	Data on customer traffic intensity	Energy consumption indicators	Function of remote (including zone) control of equipment
Business process	Energy management in retail outlet			

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PROJECT MANAGEMENT TECHNOLOGIES IN B2C AND B2G

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Abstract. At present day project methodologies are used to arrange and systematize business processes based on project management. In addition to being used in the B2B segment, they can also be employed in other business areas. This article examines the fundamental differences between these segments compared to B2B as well as identifies the problems that can be solved using specific elements of project management methodologies. Based on theoretical aspects of project management and fundamental differences between B2C and B2G business sectors, this research aims to provide possible solutions for IT market. In accordance with the obtained results, the authors suggest a range of project methodology-based solutions for each of the prospective challenges.

Keywords: B2C, B2G, project management, agile, project technologies

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ТЕХНОЛОГИИ УПРАВЛЕНИЯ ПРОЕКТАМИ В B2C И B2G

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Аннотация. На сегодняшний день проектные методологии используются для структурирования и систематизации управления бизнесом на основе проектного менеджмента. Помимо использования в B2B, они также могут быть использованы в других сегментах бизнеса. В данной статье рассматриваются фундаментальные различия между сегментами по сравнению с B2B, а также выявляются проблемы каждого сегмента, которые могут быть решены с использованием элементов методологий проектного управления. Основываясь на теоретических аспектах и фундаментальных различиях между ведением бизнеса в B2C и B2G сегментах, данное исследование нацелено на предоставление возможных решений для рынка IT. В результате, авторами были предложены элементы методологий проектного управления, предоставляющие возможность наиболее эффективно решить самые актуальные проблемы B2C и B2G сегментов.

Ключевые слова: B2C, B2G, проектный менеджмент, гибкие методологии, проектные технологии

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Introduction

Unlike the B2B, the emotional component plays a major role in the B2C, meaning that divergence in the key principles of business is shaped depending on the specifics of each segment. Thereby, one long-term project with established distribution channels for products in the B2C spills over into multiple sales, while a singular purchase makes the outcome of a B2B project. What is more, the nature of connections formed during different projects also varies: B2C relies on short-term connections between the company and the buyer, while the connection in the B2B segment is often long-term (Cooper, 2009).

The barriers for the B2G segment to overcome also differ from B2B and B2C. The purchase of a product or service offered by a company is determined by the choice of the consumer, while in the B2G segment a tender system is common. Before starting cooperation with a government organization, it is necessary to undergo verification, collect the necessary documents, and apply for a competition, where the government selects the most suitable option according to the requirements. On the one hand, the procedure involves more red tape compared to other market segments, while on the other, winning a tender results in a corresponding benefit. No matter how lucrative cooperation with government organizations may seem, the number of problems that arise on the way is also impressive. The key challenge is the payment procedure when cooperating with the government. The company is supposed to possess large funds since the B2G uses a post-payment system, meaning that the company receives funds only upon closing the project. Another impediment is that the legislation that regulates participation in competitions is changeable. Tenders require competence in the current legislation and the ability to monitor changes in application procedures. These necessities often discourage many companies from cooperating with government agencies (Cooper, Edgett, 2012).

Existing scientific research on the topic highlights problems associated with implementing project management technologies as tools to control product development. It can be explained by the inability of manufacturers to stop the project despite having discovered problems during one of the cycles (Denisova, 2022).

The main goal of this research is to distinguish possible solutions to streamlining project management in B2C and B2G of an IT market. In order to hit this goal, it is necessary to pay specific attention to:

1. Finding elements of project management technologies that are capable of evaluating control over different aspects of IT projects in B2C and B2G.
2. Tailoring such elements based on differences between B2C and B2G business sectors.
3. Providing justification of efficiency for each solution.

Materials and Methods

The methodological basis of this research rests on collection and assessment of data, comparison, description, and mapping. Analysis includes general business structure comparison as well as project structure description, with project cycle processes, project team, and project risks for each of the corresponding business segments. The authors also map out specific elements of project management technologies that may contribute to more efficient problem-solving.

Results and Discussion

B2C (business-to-consumer) is a business model where the recipient of goods or services is the end consumer. Unlike the B2B model, the company seeks to satisfy not one client but all at once, which results in demand for the products offered by the company. The key feature of the B2C segment is that the buyer and the consumer are the same person.

In the current market conditions, the "high risk, high reward" system is in function, but the degree of risk can be reduced if a project to create and release a new product to the consumer market is structured properly. In order to achieve this, the project itself is supposed to be well structured and managed in accordance with the suitable methodology. Nowadays, methodologies have migrated from different areas and can be used everywhere. Thus, for example, Agile, developed for the IT sector, can now be implemented in retail as well (Edgett, Cooper, 2008).

B2G (business-to-government) is a business model where a manufacturer provides goods and services to government agencies. Relations in the B2G market are characterized by their long-term nature, since it is easier for the government to buy from one manufacturer rather than change manufacturers after a certain period. The scale of orders from the government is typically large, with the purchases being made via the tender system.

Although B2G projects are similar in general structure to B2B projects except for the client, they still differ significantly. Thus, B2G projects also need a project methodology to simplify the procedure for participating in competitions for obtaining government orders (Trachuk, 2013; Umyarova, 2022). It is assumed that the general structure of the project processes and teams is similar to the B2B segment, but the risks may differ due to the specifics of working with the public sector. A general comparison of business models is presented in Table 1.

Table 1. Business model comparison

	Clients	Promotion tools	Transaction speed
B2C	Individuals	Contextual and targeted advertising, SMM, promotions, sales	Fast
B2B	Companies (legal entities)	Contextual advertising, SEO, email marketing, PR, event management	Slow
B2G	Government	Tenders	Slower than B2B

According to stage-funnel model, a project to develop a new software product includes the following processes:

- Selecting an idea.
- Scaling.
- Calculating financial indicators.
- Implementation.
- Prototype testing.
- Product launch.
- Post-project analysis.

The main advantage of this model is the presence of funnels between processes, when the company can revisit the feasibility of implementing the project. Upon completion of all stages of the project, the new product enters the market.

However, Cooper's research proves that this model of managing a project to develop a new product is poorly suited to companies, since the funnels that exist to implement strict control over the project rarely lead to the closure of the project; most companies implement the project despite possible negative indicators in the funnels.

Accordingly, even with clearly defined processes and boundaries established between them, during the implementation of projects there is no project management tool, that is, a methodology capable of monitoring the progress of the project. This statement explains why many companies do not achieve the desired indicators.

Project teams are formed depending on the specifics of the project; accordingly, knowing the procedures that are carried out during the project, one can select a set of specialists in different fields necessary and sufficient for the successful implementation of the project. However, the selection of a project team is a responsible procedure since the success of the project directly depends on who is assigned to the project (Gryaznov, 2020). There are several requirements for selecting a project team. The principles of selecting a project team include validity, multi-criteria selection, scientific nature, and a combination of strategy and tactics of management.

A typical project team for developing a new product in the B2C segment includes:

- Product manager.
- Project manager.
- Designers:
- Developers.
- Marketers.
- Sales department.
- Manager.

It should be noted that many companies practice involving consumers in product development, but they are not direct participants in the project team.

At different stages of project implementation, the degree of involvement of each project team member differs, which also needs to be regulated (Glukhov, Ilin, 2014). Without proper control, there is a risk of stagnation and low quality performance, which may potentially lead to freezing or even closure of the project and financial losses. In this regard, the project methodology will allow to regulate the work of project participants at each stage.

Each project has a set of risks that the company faces during the project implementation. The occurrence of a risk event during the project may have a negative impact on the success of the project, so it is in the interests of the company to prepare for risks before they occur. The risk management procedure is a complex event (Maydanova, Ilin, 2023). The key tool for dealing with risks is the risk register, which contains not only the risks themselves but also risk planning, analysis (both quantitative and qualitative), possible responses, and monitoring methods.

Unlike B2B projects, there is no risk of non-satisfaction of the customer's terms since the products developed for the consumer are mostly aimed at a mass audience, so the design of the product is based on the preferences of the majority but not on the requirements put forward by them (Pavlov, 2019). However, the consumer still has a strong influence on what the product will be like: the demand for the product manufactured by the company directly depends on what the future consumer wants to receive.

The main risks of a B2C project may include:

- Data security.
- Communication problems.
- Delays in project deadlines.
- Force majeure (unplanned work, natural disasters, etc.).
- Budget problems.

The structure of an IT project in the B2G segment is similar to the B2B segment, except for the bureaucratic component: before a company can start implementing a project, it is necessary to go through a long procedure leading to the company receiving an order.

The process of receiving an order begins with placing it on a specialized portal.

After completing the stated procedure, the company receives a government order, after which it can start implementing the project. Since the structure of project implementation in the B2G segment is similar to the implementation of a B2B project, the use of a project methodology is justified. However, it is worth noting the differences that arise from the specifics of working with the state:

- During the implementation of the project, there is no financing from the state. As noted earlier, the company receives money only after the project is closed, while in B2B projects, funds are distributed among financial flows coming from the customer during the implementation of the project phases. This feature limits the number of companies able to enter the B2G market.
- Rigid project structure. B2B projects allow for unplanned changes in the event of budget re-evaluation or revision of product functionality, but the probability of any unplanned changes in a B2G project is minimal. Each decision is agreed upon with the customer in advance, and no changes after approval are possible.
- Probability of working at a loss. Since the tender is based on the system of the lowest price offer, there is a possibility that during the project implementation it will turn out that the cost of implementing the project is higher than the price agreed with the customer. If in a B2B project there is an opportunity to re-agree with the customer for a different price, then in the case of a B2G project, an underestimated price in the tender will only lead to inevitable losses.

The decision to enter the B2G market has many strict frameworks, so the order analysis procedure is extremely important when putting forward an offer from the company (Kravari, 2016). The use of project management methodologies with sufficiently strict frameworks can facilitate the task of ensuring financial benefits because of project closure.

The implementation of a project in the B2G segment implies a high degree of involvement of the company's manager in interaction with the customer, i.e., with a government agency. Also, the specifics of project approval include work with legislation; therefore, a mandatory component of the project team is a lawyer who will be responsible for fulfilling the requirements from the legislative side of the project, as well as settling all requirements for registration for the competition (Nemtseva, 2022). The full composition of the B2G segment project team includes:

- Manager.
- Business analyst.
- Lawyer.
- Developer.
- Tester.
- Project manager.
- Product manager.
- Support specialist.

Unlike B2C projects, in the case of working with government agencies, there is no need to include a marketer in the project team since the product developed by the company can be considered sold. Accordingly, there is no need to focus on the "salability" of the product; the main tool for attracting the customer's attention is the price offered by the company for the execution of the order.

Like any project, a B2G project has its own risks, which are more specific than similar projects implemented in the B2B and B2C segments. A distinctive feature is cooperation with government agencies during the project implementation, while clients of other segments are individuals and legal entities. The following risks have been identified for projects implemented in the B2G sphere (Nandankar, Sachan, Adhikari, Mukherjee, 2023):

- Risk of the company being included in the register of unscrupulous suppliers (in case of evasion of concluding a contract or failure to fulfill a contract).
- Risks of incorrect electronic document management.
- Risk of delay in contract fulfillment.
- Risk of using outdated technologies.
- Risk of failure of equipment containing critical data.
- Risk of lack of communication between project participants.
- Risk of decreased financial stability.
- Risk of decreased liquidity and solvency.
- Risks of increased financial burden during the execution of a government contract.
- Risk of refusal to renew licenses for the use of foreign software.
- Risk of restrictions or prohibition on updating and servicing software that has no analogues in Russia.

The consequences of the risks described above also differ from the risks that occur during the implementation of B2B and B2C projects, the key ones of which may be the accrual of fines and penalties as well as a ban on participation in a tender for government contracts for up to 2 years, as well as the insolvency of the company up to and including bankruptcy.

Summary of project structure analysis is given in Table 2.

Table 1. Project structure comparison

	Project team	Risks	Budget
B2C	Product Manager Marketing Manager Designer Developers Data Analyst Customer Service Specialist	Data security; Communication issues; Project delays; Force majeure (unplanned work, natural disasters, etc.); Budget issues	Determined by the amount of funds that the company has
B2B	Business Analyst Systems Analyst Technical Team Implementation Team Product Manager Project Manager	Technical risks; Data security; Dependence on suppliers; Changing customer requirements; Financial risks; Communication problems	Discussed with the customer at the stage of concluding the agreement and can be revised during the project in the event of unforeseen circumstances
B2G	Manager Business Analyst Lawyer Developer Tester Project Manager Product Manager Support Specialist	Risk of the company being included in the register of unscrupulous suppliers; Risks of incorrect electronic document management; Risk of delay in contract performance; Risk of using outdated technologies; Risk of failure of equipment on which critical data is located; Risk of lack of communication between project participants; Risk of reduced financial stability; Risk of reduced liquidity and solvency; Risks of increased financial burden during the execution of a government contract; Risk of refusal to renew licenses for the use of foreign software; Risk of restriction or ban on updating and servicing software that has no analogues in Russia	Proposed by the contractor at the stage of participation in the competition and is not revised after winning the tender

The B2C segment is characterized by variability, caused by the end consumer of any business in this segment—the general population. Each consumer has their own preferences and tastes, their own triggers to attract attention: a catchy label, technology, a large advertising campaign, and so on. Therefore, the main point that ruins new companies is a superficial analysis of their target market. Many of them neglect such indicators as market saturation, market leaders, as well as the average price for goods in a similar category.

In addition to pre-project planning, during their activities, many companies neglect a competent financial apparatus as well as effective promotion (Morcov, 2023). The latter parameter proves to be the most important, since the key goal of any business in the B2C segment is to build a brand in such a way that would encourage the buyer to purchase it, or even more — impose a feeling of inability to function without it.

For small organizations, lack of flexibility leads to a decrease in customers, who logically tend to prefer companies capable of innovation in products and services they provide. A gradual decrease in the customer base leads to devaluation of the brand, which has often been built up over a long period of time. In pursuit of customers, B2C companies turn to price reduction, which in most situations results in the opposite outcome. Not all companies are capable of adaptation, having an organizational structure that quite strictly defines the responsibilities of employees and the order of actions in the company (Rudenko, 2015).

The first tool useful for B2C companies is the Scrumban board. Depending on the scale of the company, its practicality may vary, but it allows to visualize the process of the product production cycle and, if necessary, make changes related to innovations and changing individual operations. Kanban is also suitable due to its short-term nature — there is no need for long-term planning for B2C companies; therefore, the Kanban board can be a useful tool for monitoring the implementation of the production cycle.

Flexible methodologies such as Scrum and Agile would also come in handy for B2C companies. Both methodologies have a high degree of adaptability, allowing companies to adjust to the preferences of the target audience quickly. Maintaining close communication with the customer can greatly contribute to the company's success (Ilin, Frolov, Lepekhin, 2020; Wong, 2018). Since the consumer and customer are the buyers, communication with them can be maintained in the form of surveys, marketing campaigns, and focus groups, etc. All the listed measures provide a clearer picture of the customer's opinion and increase brand awareness.

Scrum would be useful for companies that frequently deliver new products. In this case, dividing the work into sprints will increase the efficiency of producing a specific unit, while sprints can be changed if necessary. A trigger for such a change can be, for example, a drop in product sales. Regular meetings, typical of Scrum, will be useful in such cases. During the meetings, it is possible to brainstorm ideas for new products. They can be recorded and go from the Scrum Master up to the management, who then considers the received ideas for the feasibility of implementation.

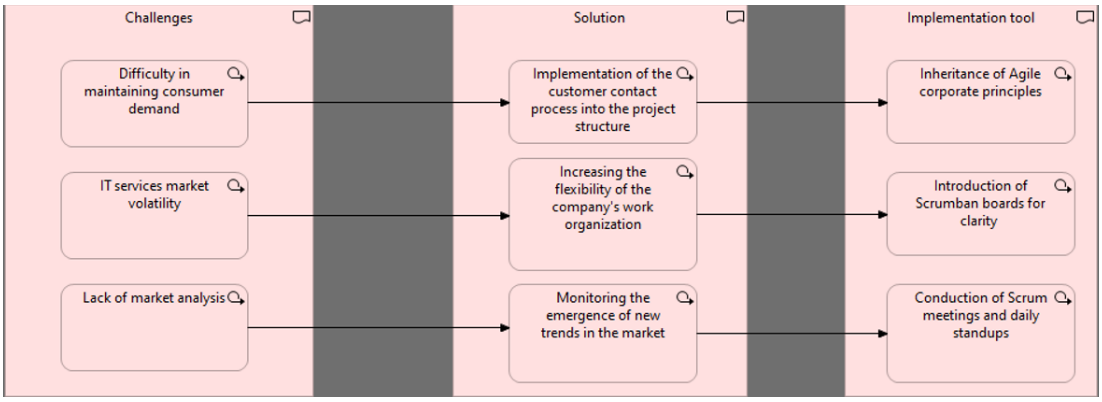

Fig. 1. Visualization of proposed solutions for the B2C segment

Key problems of business in the B2G segment are:

Compliance with regulatory requirements. Unlike the B2B segment, B2G regulates contracts concluded within the public sector according to a strict framework. Therefore, proposals made by the contractor to the customer must comply with data confidentiality standards, legal requirements, and ethical standards.

Long sales cycles. Efficiency cannot be called a characteristic feature of business operations within the public sector. Decisions, as a rule, are made quite slowly and consider all possible factors. Bureaucracy also plays a large role, including work with documentation, budget cycles, and consultations with stakeholders, which negatively affect the duration of the sales process. A long duration can cause financial damage to the contractor, who is in a state of inactivity (Zaitsev, 2022).

Transparency and accountability. Documentation generated when interacting with government agencies should be detailed and transparent, including positive aspects of the contractor to gain the customer's trust and convince him of the benefits of cooperation with a specific enterprise rather than with others.

Based on the above-described problems and challenges, it is possible to suggest a specific set of strategies that can increase the share of success for an organization entering the B2G market. They include:

Segmentation. Although different organizations belong to the public sector, each has different requests and requirements. For instance, the healthcare and military sectors function in completely different ways, and therefore the approach to each specific case is unique. The ability to adapt on the part of the organization would be a plus that can open new opportunities in completely different areas of the public sector. However, the ability to adapt, as described above, differs from the adaptation of the B2C segment.

Intellectual leadership. Public sector organizations pay attention to companies that occupy leadership positions in the field of knowledge. A huge benefit for the organization would be the presence of regular articles, webinars, and seminars held by the company. As in the case of B2C, a B2G company is supposed to have an image, since B2G, like no other segment, is subject to giving preference to a company that is on everyone's lips. Therefore, the structure of the organization is supposed to have a division engaged in methodological work. To some extent this type of work is another branch of marketing aimed at attracting the attention of government agencies. The effect of such marketing, however, becomes visible only during the competition, where this type of recognition will positively affect the outcome of the tender.

Examples of use. State organizations also appreciate the practicality of solutions offered by the supplier of goods or services. Instead of promoting a product based on its technological advancement, attention should be focused on its practical benefits. Cost reduction when using new software, reduction in the length of product routes because of implementing a transport information system – such examples attract a customer who has put forward an offer based on some need. Thus, focusing on the fact that the customer's product or service can satisfy this need will enable the organization to attract the customer.

Cooperation. Bureaucracy, of course, has a negative impact on the implementation of a project at the initial stage, but it allows to accurately determine the needs of the customer, get into closer contact with them and expand the horizon of knowledge about what is required of the contractor. Thus, the likelihood of canceling the project and ending cooperation will decrease, so attending meetings with stakeholders and communication with officials will have a positive impact on the course of the project.

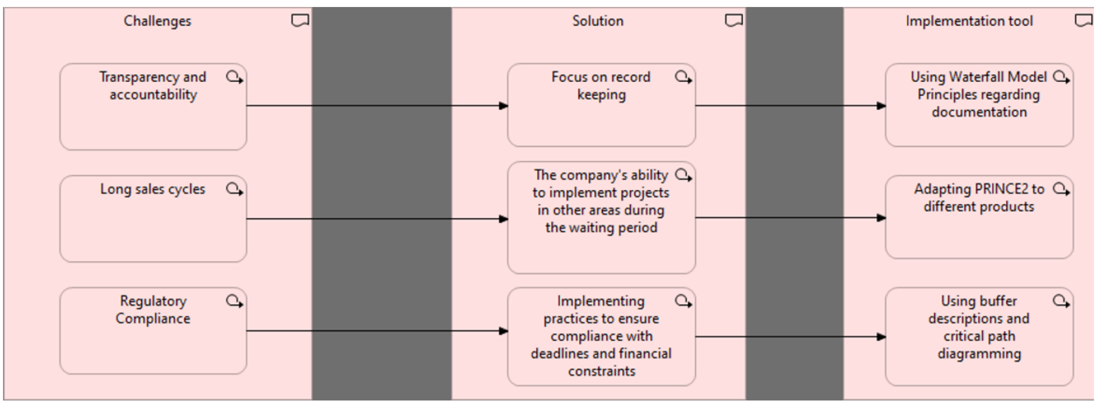

Fig. 2. Visualization of proposed solutions for the B2G segment

Conclusion

In this study, possible solutions to streamlining project management in B2C and B2G sectors of an IT market are shown. These solutions have been tailored based on unique aspects of the stated sectors. According to the results of the research, elements of flexible methodologies have practical benefits for B2C companies, while more rigid methodologies are expected to have a positive effect on the activities of companies operating in the B2G segment. The most unexpected result is the highlighted division between possible solutions. Unlike B2B, which works well with both flexible and rigid methodologies, B2C and B2G favour either one or another.

Thus, Scrum, Agile, and Scrumban methodologies would allow B2C companies to increase the flexibility of their activities, which is necessary for the company's ability to adapt to the changing preferences of the target audience. Kanban boards would allow visualizing the process of implementing goods by tasks and, if necessary, simplify the perception of information about changes in one or a group of production processes. Agile and Scrum, implying close communications within the team and communication with the customer, provide tools to more accurately capture the desires of potential customers and implement the necessary changes quickly enough.

For the B2G segment, methodologies with a rigid structure are more suitable, such as PRINCE2, Waterfall, and Critical Chain Project Management. This is due to the unambiguous requirements from the customer, which become clear at the pre-project planning stage. The above methodologies pay special attention to monitoring compliance with financial and time constraints, as well as strict adherence to quality standards of the product being developed.

Stated solutions are based on theoretical study; therefore, their practicality may differ from predictions suggested in the paper. These solutions have been tailored to IT market demands and might not be useful for other areas. Other markets haven't been reviewed because of a large number of differences in priorities and business structures.

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DIGITAL TRANSFORMATION IN LOGISTICS USING DIGITAL TWIN TECHNOLOGY

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Abstract. This article explores the possibilities of digital transformation, including definitions of relevant notions and current trends in logistics. The authors focus on key technological trend: digital twins. This research is highly relevant due to the growing significance of digital transformation in logistics and its influence on competitive advantage. Automation of information and physical processes is a major achievement, with the potential for long-term impact on strategic, tactical, and operational planning and control in logistics systems. Therefore, exploring digital transformation in logistics is a crucial area for research and further practical application. The authors aim to explore the potential of using a digital twin in logistics, as well as to model the architecture of information systems using this approach.

Keywords: logistics, digital transformation, digital twin, architecture of information systems, modelling

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ЦИФРОВАЯ ТРАНСФОРМАЦИЯ В ЛОГИСТИКЕ: ТЕХНОЛОГИЯ ЦИФРОВОГО ДВОЙНИКА

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Аннотация. В данной статье рассматриваются возможности цифровой трансформации в логистике, включая определение терминологии, существующие тренды и применение технологий. Особое внимание в данном исследовании уделяется одному из ключевых технологических трендов — цифровым двойникам. Актуальность данной технологии обусловлена важностью цифровой трансформации в отрасли логистики и ее влиянием на конкурентные преимущества перед другими предприятиями. Развитие компаний в данном направлении представляет огромные возможности для достижения конкурентных преимуществ на различных уровнях. Автоматизация информационных и физических процессов представляет собой одно из наиболее значительных достижений, поскольку оно потенциально может оказать долгосрочное влияние на планирование и контроль логистических систем на стратегическом, тактическом и оперативном уровнях. В этой связи, изучение возможностей цифровой трансформации в логистике является важным направлением исследования и последующего практического применения. В рамках данной статьи авторами были определены возможности использования цифрового двойника в логистике и моделировании архитектуры информационных систем.

Ключевые слова: логистика, цифровая трансформация, цифровой двойник, архитектура информационных систем, моделирование

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Introduction

The origin of logistics as a scientific subject began in the United States during wartime. Its creation was encouraged by the need to ensure military transportation and delivery. Precisely in the late 1970s, the concept of logistics spilled over from industry and the military sphere into the civilian application. Currently, logistics proves to be one of the most defining facets of a company's sustainability.

Logistics is an integral management tool that hits both operational and strategic goals and satisfies the end user more by improving the quality of products and services. What is more, the organization shows higher performance in managing all material and information flows (Levkin, 2019; Sergeev, 2023; Jesus, 2024). Thus, the effectiveness of logistics lies in ensuring accurate and timely delivery of products in the required volume and appropriate quality while minimizing costs.

"Digital transformation in logistics" is a compound structure that requires scrutinized observation due to the fact that the term combines definitions of such notions as digitalization, digital transformation, and logistics. Consequently, it is important to figure out the specifics of several approaches to the concept of "digital logistics" in order to see the bigger picture.

The notion primarily rests on the term “digitalization”. A collection of the most comprehensive and versatile interpretations of this definition is given in Table 1.

Table 1. Definitions of the term “digitalization”

Author	Definition	Promotion tools
J. Scott Brennen and Daniel Kreiss	“Digitalization is the restructuring power for many areas of social life in terms of the digital infrastructure of communica-tions and media” (Brennen, Kreiss, 2014).	This definition is based on connecting people via innovative digital commu-nication channels.
Gartner IT Glossary, 2022	“Digitalization implies the use of technology to change the business model and create additional ways to generate revenue and create value” (Glossary Gartner).	Gartner focuses on changing business models that bring value through the use of digital technologies.
Khalin V. G., Cher-nova G. V.	“Digitalization in a narrow sense refers to the transformation of information into digital form, leading to lower costs, and the emergence of new opportunities, etc. Meanwhile, in a broader sense digitalization can be considered as a trend of effective global development only if it meets the following require-ments: it affects production, business, science, the social life; the result of digitalization bring in new development prospects; its results are available to users, and not only specialists, but also ordinary citizens” (Khalin, Chernova, 2018).	This definition observes the concept as digitization of data within a specific framework.
Vartanova E. L.	“The translation of information into numbers and at the same time the infrastructural, managerial, behavioral, cultural com-ponents of the content of education – this is what makes digi-talization” (Vartanova, 2017).	The transformation of information into a digital format that affects various aspects of public life is considered digitalization.
Shestak Ksenia	“Digitalization is the use and implementation of technologies in the company's processes to improve their quality and effi-ciency” (Digital business transformation and digitalization).	

Having examined the essence of digitalization from various perspectives, it is evident that the concept does not boil down to technological transformation only, but also to a multifaceted cultural and societal phenomenon. According to the definitions provided in Table 1, digitalization extends beyond the realm of business operations and internal company processes, permeating into the fabric of society as a means of enhancing its overall standard. Most scholars concur that digitalization entails the integration and application of digital technologies with the aim of enhancing various sectors and aspects of human existence (Botнn-Sanabria et. al., 2022).

If we consider digital transformation and digitalization, it is possible to see that digital transformation has a broader purpose, representing a strategic transformation of business (Digitization and digital transformation). In fact, digital transformation has more to do with changing the organization comprehensively. At a time when the company is becoming customer-oriented from top to bottom and its activities are becoming increasingly important, making changes becomes its core competence. Such adaptability contributes to those initiatives that are aimed at digitalization but does not replace them completely (Zhang, Guo, Sun, 2022; Lyamin, Voronova, 2023.).

In their research, Afanasenko I.D. and Borisova V.V. coin two definitions of digital logistics. “In a broad sense, digital logistics is a supporting subsystem. The object of its study is digital flows that accompany or replace the economic flow. The main goal is to ensure the required environment for the logistics system (sustainability, efficiency, etc.).

In a narrow sense, digital logistics itself is a system that ensures the digitalization of the projected object. Digital logistics studies the patterns of digital flows in economic systems" (Alekseev, 2019).

Digital technological trends in logistics are associated with the following factors:

- development of robotics;
- development and use of AI (artificial intelligence);
- automation of logistics processes.

All these factors are aimed at reducing the workforce. One of the most efficient technologies that reduce the number of operations performed by humans is digital twin technology. This trend encompasses virtual models that accurately reflect the conditions and behaviour of the physical objects or processes they represent in real time. For enterprises, the digital twin is valuable because, it ensures diagnostics and analysis of equipment, forecasting and modelling new scenarios, and process optimization without interacting with a physical real twin (Jeong, Baek, Kim, 2022).

Over the past few years, the application and diversification of various sensor technologies, the growth of cloud computing, and the development of artificial intelligence have allowed expanding the functionality. Thus, AI-based digital twin technology creates more accurate digital models for both the asset and component, as well as the entire process, depending on the application level. Between 2021 and 2027, the market, which was estimated at more than $5 billion in 2020, is projected to grow by more than 35% due to the introduction of new digital counterparts (Afanasenko, 2019).

The introduction of a digital twin into an enterprise is not enough to ensure maximum efficiency and safety of the process. In addition to the introduction of this technology, the company should also consider such technological trends (Afanasenko, 2019) as blockchain, cloud computing, artificial intelligence, as well as big data. The combination and adaptation of all these technologies will allow companies to have competitive advantages, transparent logistics processes, information about all failures, inconsistencies, problems, as well as forecasting and modelling possible process optimization scenarios at all their control points. Each of these technological trends should be considered in detail.

The blockchain. Blockchain technology is used to create secure, reliable and transparent systems that store and process data without centralized control. In this case, it is assumed that security is achieved through the use of blocks containing information, as well as hash sums. This structure creates a complex chain of blocks that ensure data security (Gillespie, Tarleton, 2014).

Interactive artificial intelligence. Interactive artificial intelligence is an extension of AI algorithms capable of processing text, speech, voice, handwriting for analysis and giving reasonable response. Advanced versions of this technology are able to conduct complex conversations, simulate a sense of empathy for users, etc.

Cloud technologies. Cloud technologies and APIs are models that can be used to provide users with remote access to hardware resources via Internet. Cloud technologies allow running applications on remote servers, working with data online, as well as storing and processing information.

Big data. "Big Data is structured or unstructured arrays of large amounts of data. They are processed using special automated tools for statistics, analysis, forecasts and decision-making" (Afanasenko, 2019).

The digital twin in supply chain management, known as DSCT (Digital Supply Chain Twins), is a virtual replica of a physical system that encompasses all the components, assets, and processes within a logistics network. This digital twin serves as a comprehensive representation, displaying the data, statuses, interactions, and behaviours of the logistics system. It stores and analyzes data through specialized repositories, providing a detailed overview of the system's operations (Bimber, Flanagin, Stohl, 2012).

Moreover, the digital twin enables simulation experiments, modelling novel scenarios and system behaviors. This capability empowers companies to meticulously test new strategies and concepts prior to their implementation, ensuring a smoother and more efficient operational process.

Scientific community studies the digital twin in the supply chain in terms of its diverse functions. It can be a tool for better visibility, traceability, and product authentication (The Logistics Trend Reader 6.0), a decision support system for managing failure risks, or a means to effectively manage long-term supply chains (Park, Son, Noh, 2020).

Materials and Methods

Various research methods were employed in this article, such as literary analysis, synthesis, induction, generalization, a systems and process approach, and graphical interpretations of the research data. ArchiMate was used in data processing.

Results and Discussion

As previously defined, a digital twin in logistics is the same version of a physical process in a virtual state; one can imagine that this is the same process, but performed by a computer. This model is able to change by processing information received from various sources; for example, data from a real object obtained from a repository or through the use of various IoT technologies such as sensors, or data provided by specialists for forecasting and modelling a new, improved process. Thanks to this abilities management can draw conclusions and make decisions on the feasibility of suggested innovations.

Based on the information analyzed earlier, an automation model for the logistics process should be assessed in the context of digital twin technology. Figure 1 depicts the relevant model.

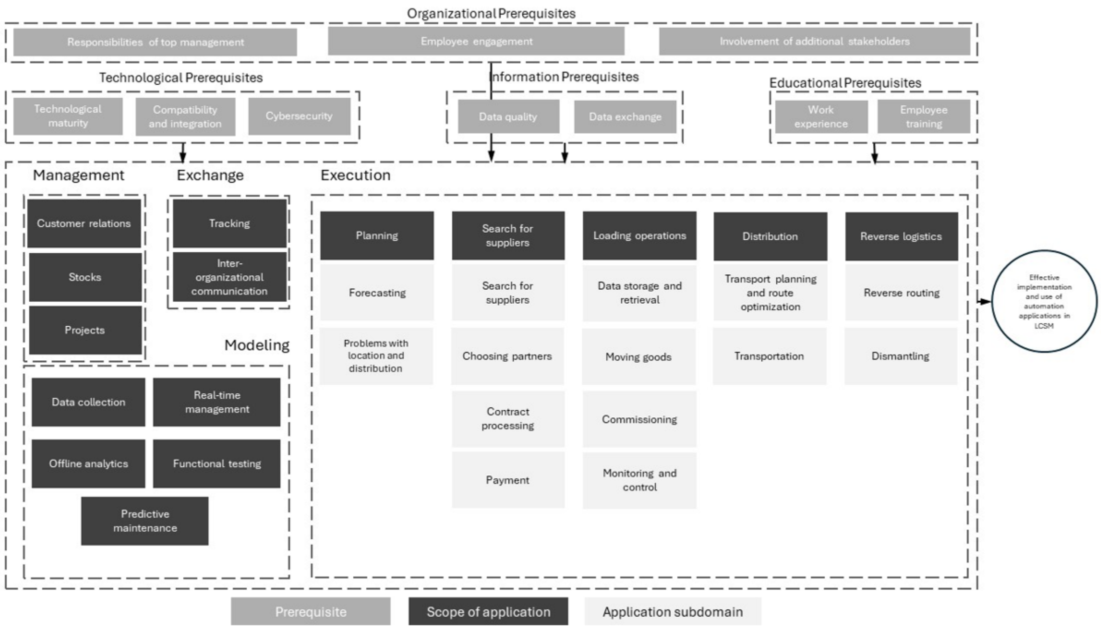

Fig. 1. Conceptual bases of automation in logistics and supply chain management using digital twin technology

The classical model of the logistics process consists of three main blocks: management, exchange, and execution. When using a digital twin, another aspect is added — modelling. It is aimed at supporting the execution of the main customer order using a digital twin (Jensen, 2013). This includes data collection, real-time management, offline analytics, health checks, and forecasting.

Considering the conceptual foundations of automation in logistics and supply chain management using digital twin technology (Bhandal, Meriton, Kavanagh, Brown, 2022), a model of information systems architecture within a single enterprise is proposed. The model presented in Figure too takes into account all the previously described trends in logistics.

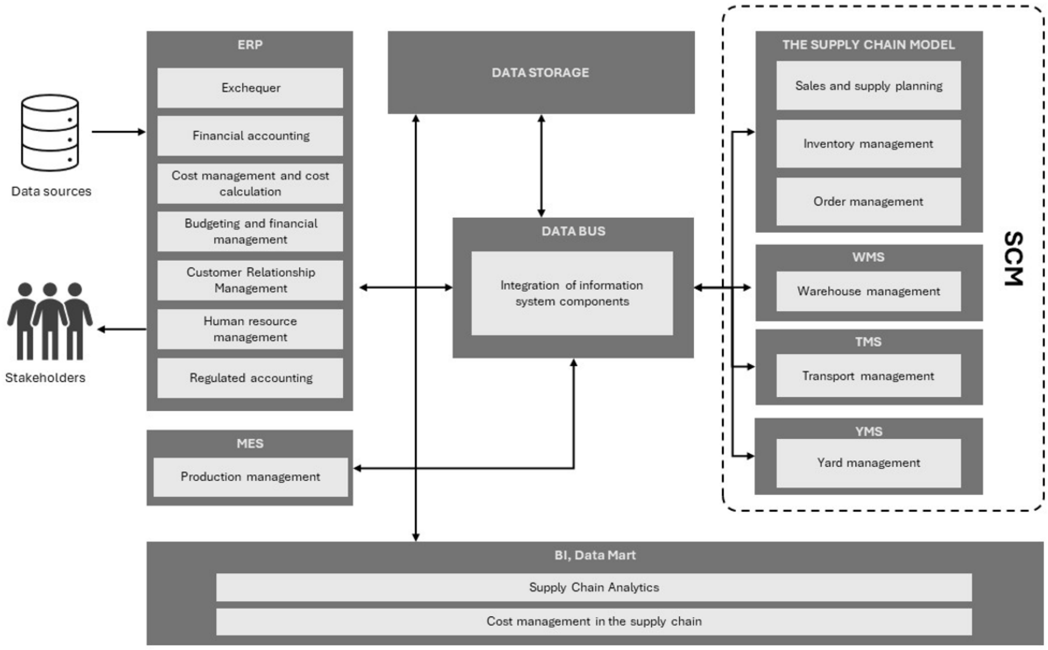

Fig. 2. Architecture of information systems within a single enterprise

The main system in this scenario is a supply chain management model that collects and analyzes data between other logistics systems, such as WMS, TMS, and YMS, while also supporting the planning of the entire enterprise's supply chain (Kabanov, Fedorov, 2022). Digital twin technology shapes the ground for this model. By inputting data collected from actual objects or parameterized by experts, it's possible to simulate processes, improve them, and identify bottlenecks. This also helps describe the accurate and current state of the process within the company. Each component of the SCM can interact with other parts of the system.

Thus, the virtual model is supposed to have the ability to adapt to changes, which implies changing parameters in accordance with technological progress, new trends, and improvements in the industry. It is also necessary to convert and transform information from various sources related to a physical object into a usable format. Cloud computing and APIs can be used to collect and store data. Artificial intelligence (AI) can be used to work with simulation models and arrays of unstructured data. Cloud technologies can be employed to ensure data confidentiality and security, while blockchain can verify and preserve the integrity and authenticity of data. Strategic planning, including scenario modelling, can be carried out via artificial intelligence (AI) capable of analyzing various scenarios and potential consequences in the long run.

Conclusion

Digital twin in logistics allows enterprises to improve processes, adapt to new approaches, improve the quality of services provided to customers, and also gain an advantage in the market. In order to boost the reliability and accuracy, as well as increase the technological advantage, blockchain, cloud computing, AI, and big data should also be implemented.

Overall, the model of the enterprise information system architecture presented in this research is based on the concept of digital logistics, which defines the purpose and objectives of the logistics system. This model is aimed at the successful implementation and application of digital twin technologies in logistics.

Further research on the topic is required in order to comprehensively assess the interaction of digital twins of several enterprises with each other, measure the economic efficiency of this innovation, and define what equipment is necessary for the whole-scale implementation of digital twins.

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POLYNOMIAL NETWORKS INSTEAD OF NEURAL NETWORKS

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Abstract. Neural networks are widely used in various scientific fields and practical research. They are sometimes implemented in the modeling of nonlinear economic dynamics. However, neural networks are often not suitable for modeling nonlinear economics. An effective alternative to neural networks in economics is the Elementary image of the Kolmogorov-Gabor polynomial. It has proven to have a more powerful ability to model nonlinearity than the artificial neural network. At the same time, the coefficients of this polynomial are estimated much simpler and faster than the coefficients of the artificial neural network. This observation provides grounds for the idea to replace neurons in the network by the Elementary images of the Kolmogorov-Gabor polynomial, thus creating an alternative polynomial network. This network is trained in just a few steps, while a neural network is trained over several tens of thousands of steps. Additionally, a Bayesian approach can be applied to polynomial networks, while it is not possible with neural networks. What is more, polynomial networks describe nonlinear processes no worse, and some-times even better, than neural networks. Therefore, when modeling nonlinear economic processes, polynomial networks not only prove to be simpler and faster in calculations, but also are capable of Bayesian parameter re-estimation with significant accuracy.

Keywords: neural networks, polynomial networks, Kolmogorov-Gabor polynomial, elementary image KGp, nonlinear economic dynamics

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ПОЛИНОМИАЛЬНЫЕ СЕТИ ВМЕСТО НЕЙРОННЫХ СЕТЕЙ

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Аннотация. Нейронные сети активно используются в самых разных областях науки и в практических исследованиях. Встречаются случаи использования нейронных сетей в моделировании нелинейной экономической динамики. Но чаще всего нейронные сети оказываются малопригодными для моделирования нелинейной экономики. Эффективной альтернативой применению нейронных сетей в экономике может служить элементарный образ полинома Колмогорова-Габора. Показано, что элементарный образ полинома Колмогорова-Габора обладает более мощной способностью моделирования нелинейности, нежели модель искусственного нейрона. При этом коэффициенты этого полинома оцениваются значительно проще и быстрее, чем коэффициенты искусственного нейрона. Данное утверждение позволяет предложить замену нейронным сетям — вместо нейронов в сеть подставляются элементарные образы полинома Колмогорова-Габора и получается альтернативная полиномиальная сеть. Эта сеть обучается за несколько шагов в то время как нейронная сеть обучается за несколько десятков тысяч шагов. К тому же к полиномиальной сети применим байесовский подход, в то время как к нейронным сетям его использовать не удаётся. Показано также, что полиномиальные сети описывают нелинейные процессы не хуже, а иногда даже лучше, чем нейронные сети. В этой связи, при моделировании нелинейных экономических процессов предлагается использовать полиномиальные сети как более простые и быстродействующие в вычислениях, способные к байесовской переоценке параметров и не менее точные, чем нейронные сети.

Ключевые слова: нейронные сети, полиномиальные сети, полином Колмогорова-Габора, элементарный образ KGp, нелинейная экономическая динамика

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Introduction

The successful use of neural networks in natural and engineering sciences has prompted economists to search for opportunities to apply them to solve various tasks, including economic forecasting. However, attempts to use them for this purpose have not been very successful so far; after all, neural networks were created to solve image recognition tasks, and their application to modelling dynamic systems has been unsuccessful yet.

Since objects of economic forecasting often possess some inertia in their dynamics, it became possible to take this property into account in neural networks by using feedback connections. Such connections in neural networks are called "recurrent". Therefore, neural networks with such connections are also called recurrent (RNN). If in simple neural networks the input data is considered unordered, in recurrent networks, the presence of feedback connections models the order of the data sequence, making them more suitable for modelling dynamic processes.

Materials and Methods

Currently, the scientific community is increasingly publishing results of successful applications of RNN in economic modelling and forecasting. There are some successful examples of economic forecasting using RNN. For instance, Hansika Hewamalage, Christoph Bergmeir, and Kasun Bandara (Hewamalage, Bergmeir, and Bandara, 2021) showed that RNN can be more accurate than such popular forecasting models as exponential smoothing (ETS) and autoregressive integrated moving average (ARIMA). However, unlike RNN, ETS and ARIMA models are reliable, efficient, convenient, and easily formalized. RNN, on the other hand, still represents poorly formalized models that need to be tailored for each case, with the success or failure depending on the qualifications of the researcher using them.

When considering the possibility of applying artificial intelligence and machine learning to economic forecasting, Stephan Kolassa wrote about the three major issues: scarce, opaque, and brittle data (Kolassa, 2020). And yet, the main tool of artificial intelligence and machine learning is neural networks! If we also consider that building RNN requires not only advanced programming skills but also knowledge of complex mathematical optimization methods that are a significant part of machine learning, it becomes clear why RNN in modelling nonlinear economic dynamics and economic forecasting are still relatively rare.

What needs to be done to make neural networks a usable tool in economic modelling and economic forecasting? How can we make them simpler so that any researcher applying mathematical methods in economic modelling but not possessing perfect forecasting skills could use them? How can we make the process of building and evaluating such a model simple and universal?

The answers to these questions can be found by turning our attention to alternative models. Pursuing this goal, the research focuses specifically on a mathematical model of an artificial neuron, the Kolmogorov-Gabor polynomial and the Wiener series, an elementary image of the Kolmogorov-Gabor polynomial, neural networks, and polynomial networks.

Results and Discussion

Mathematical Model of an Artificial Neuron

A neural network represents a set of j interconnected neurons. Each individual neuron has one or more inputs and one (and only one) output. Its mathematical model is a superposition of a linear multifactorial function and a non-linear function:

$$\hat{y}_j = f(a_0 + \sum_{i=1}^{n} a_i x_i) = f(y') \quad (1)$$

where:

$\hat{y}_j$ – output signal of the j-th neuron;

f – transfer function;

a_i – weight of the i-th signal (factor);

x_i – i- th component of the input signal (factor);

i = 1, ..., n – neuron input number;

n - number of neuron inputs;

a_0 – free coefficient;

y' – the result of the sum of the weighted input signals.

To avoid problems that may arise with data scales when working with neural networks, all variables are pre-normalized.

Artificial neuron models (1) differ from each other in the type of transfer function f(y'). Depending on the tasks that the researcher sets when forming a neural network, this transfer function can be a simple activation function, where the output signal takes a value of 0 or 1, or a more complex function that converts the sum of weighted input signals into a numerical output. This conversion can be performed using a linear or nonlinear function.

One of the simplest variants of an artificial neuron model is when the transfer function is written as:

$$\begin{cases} f(y') = 0, & y'_b \geq y', \\ f(y') = by', & y'_b < y' < y'_e, \\ f(y') = 1, & y'_e \leq y'. \end{cases} \tag{2}$$

Here, y'_b and y'_e are some predetermined constants of the minimum (base) and maximum (final) values of the output changes, and b is the proportionality coefficient.

At the output of the neuron, a signal is obtained that represents a superposition of two linear functions, and the coefficients ai and b can be easily estimated using statistical methods. But how can a nonlinear dependence between input factors and output be described using a linear neuron model? In order to do this, it is necessary to connect many linear neuron models to each other. And the more complex the configuration of such a neural network, the more accurately it will describe non-linearity. This process is reminiscent of the well-known piecewise-linear approximation method (Leenaerts, van Bokhoven, 2013). Since such networks represent a superposition of linear functions, their coefficients can be estimated using standard statistical methods, for example, the least squares method (LSM). However, since there are many coefficients in the neural network model, it is easier to solve this learning task using one of the numerical methods. Such simple neural networks are suitable for describing weak nonlinearities. The more complex the nonlinear phenomena being described, the more cumbersome the neural networks with piecewise-linear transfer functions become. Therefore, neural networks of this type are rarely used in practice.

Most often, an S-shaped nonlinear function, called a sigmoid, is used as a transfer function. Networks with such transfer functions excellently describe nonlinearities and are less cumbersome than networks with piecewise-linear transfer functions.

Among many possible functions with S-shaped forms, the most convenient ones are logistic:

$$\hat{y}_j = \frac{b_0}{b_1 + e^{-b_2 y'}} \tag{3}$$

and the hyperbolic tangent

$$\hat{y}_j = \frac{e^{y'} - b_0 e^{-y'}}{b_1 e^{y'} + b_2 e^{-y'}} \tag{4}$$

However, in practice, these transfer functions are often simplified by setting all their coefficients bi equal to one. Direct application of well-known statistical methods, such as the method of least squares, to estimate the coefficients of an artificial neuron (1) turns out to be impossible, since the mathematical model of an artificial neural network in this case represents a superposition of many nonlinear functions of parameters. Therefore, to estimate the coefficients of an artificial neuron and a neural network, one of the numerical methods is used, most often the gradient method. In the gradient method, as is known, the value of the first derivative (gradient in the multifactor case) is calculated. Functions (3) and (4) differ from many other sigmoidal functions in their derivatives that are expressed through the function itself, with the gradient method easily applicable to them. It is precisely for this reason that the logistic function and the hyperbolic tangent have become the most popular types of transfer functions in neural networks.

Hereinafter, when considering an artificial neuron model, we will assume that its transfer function is represented in the form of (3) or (4). We will not consider the transfer function in linear form.

Kolmogorov-Gabor polynomial and Wiener series

In the work "Theory of Functionals, Integral, and Integro-Differential Equations" from 1930, V. Volterra derived series that allow studying systems with soft inertial nonlinearities (Volterra, 1930). In 1958, N. Wiener, in his monograph "Nonlinear Problems in the Theory of Random Processes", presented a modification of Volterra's series for the discrete case (Wiener, 1958). This same problem for continuous processes was solved in 1956 by A.N. Kolmogorov (Kolmogorov, 1956), and in 1961, D. Gabor proposed a discrete variant of the "extended prediction operator" based on it (Gabor, Wilby, Woodcock, 1961).

It turns out that the same scientific research tool was developed independently by two groups of researchers: V. Volterra and N. Wiener, as well as A.N. Kolmogorov and D. Gabor. This mathematical tool can be referred to as "Wiener series" or the "Kolmogorov-Gabor polynomial".

In published scientific works, results of forecasting obtained via the "Kolmogorov-Gabor polynomial" are encountered. For example, Hamidreza Marateb and other authors use this polynomial to predict COVID-19 hospital stays (Marateb, Norouzirad, Tavakolian, et. al., 2023), and Wei Liu and colleagues use this polynomial to forecast electrical load (Liu, Dou, Wang, 2018). The term "Wiener Series" is not found in applied works but is used in published articles and monographs of mathematicians. For example, in the work of Wim van Drongelen, where the differences between the Wiener and Volterra series are discussed, which is helpful to derive the expressions for the zero-, first-, and second-order Wiener kernels (Wim, 2010). There are many other publications on solving practical problems where authors use not the concept of "Wiener series" but "Kolmogorov-Gabor polynomial" (Anjorin, Ricks, 2023; McElroy, Ghosh, Lahiri, 2024; Nelles, 2020; Razif, Shabri, 2023).

Since we are not considering the theoretical properties of this mathematical tool but are studying its practical applicability, we will adhere to the term that is commonly used in practical research, namely "Kolmogorov-Gabor polynomial" (hereinafter, KGp).

This polynomial can be represented in general form as:

$$y = a_0 + \sum_{i=1}^{m} a_i x_i + \sum_{i=1}^{m}\sum_{j=1}^{m} a_{ij} x_i x_j + \sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{k=1}^{m} a_{ijk} x_i x_j x_k + \ldots \tag{5}$$

For example, for two factors, it will take the following form:

$$y = a_0 + a_1 x_1 + a_2 x_2 + a_{11} x_1^2 + a_{12} x_1 x_2 + a_{22} x_2^2 \tag{6}$$

It is obvious that estimating the values of 6 coefficients of such a model from statistical data does not present any difficulties. However, for three factors, the KGp will become significantly more complex and cumbersome, containing 20 unknown coefficients:

$$\begin{aligned} \hat{y} = {} & a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_1^2 + a_5 x_2^2 + a_6 x_3^2 + a_7 x_1 x_2 + a_8 x_1 x_3 + \\ & a_9 x_2 x_3 + a_{10} x_1^3 + a_{11} x_2^3 + a_{12} x_3^3 + a_{13} x_1^2 x_2 + a_{14} x_1^2 x_3 + a_{15} x_1 x_2^2 + a_{16} x_2^2 x_3 + \\ & a_{17} x_1 x_3^2 + a_{18} x_2 x_3^2 + a_{19} x_1 x_2 x_3 \end{aligned} \tag{7}$$

If the number of factors increases to i = 4, then the number of KGp coefficients will grow to N = 70, and for i = 5, the number of coefficients to be estimated becomes equal to N = 252.

In general, the number of KGp coefficients grows nonlinearly with the increase in the number of factors i. This number is calculated using a well-known formula from combinatorics.

The enormous dimensionality of the KGp construction task with many original variables limits the practical application of this tool for modeling nonlinear dependencies. Therefore, "It may be mentioned that parameter-saving approximations to KG polynomials have interested researchers for a long time" (Terasvirta, Kock, 2010). The prominent Ukrainian scientist A.G. Ivakhnenko proposed a method of step-by-step decomposition of the KGp model construction process, which he called a "multi-level system" (Ivakhnenko, 1963). He repeatedly used this method to solve practical problems and tried to popularize it (Ivakhnenko, 1971;1975). Frankly speaking, most scientific research using KGp employs the approach proposed by Ivakhnenko. Although it simplifies the method of estimating KGp coefficients, it remains cumbersome and is only suitable for cases with a small number of variables xi. The work (Svetunkov, 2024) shows that A.G. Ivakhnenko's method leads to the construction of a different polynomial, not KGp. For example, when i = 3, the polynomial constructed by Ivakhnenko's method contains 80 terms, while KGp in this case should consist of 20 terms. This means that Ivakhnenko's "multi-level system" represents a different model than the KGp model, and its scientific significance becomes unclear.

Elementary image of the Kolmogorov-Gabor polynomial

The fact that scientists have not been able to propose a method for constructing KGp that could overcome the "curse of dimensionality" (Ivakhnenko, 1963) has deprived science of such a powerful modeling tool as KGp for many years. However, instead of the full KGp, its simplified analog (Svetunkov, 2024) can be used, which excellently handles modeling nonlinearities. Let's consider this possibility in more detail. For any number of variables xi, i=1, 2, ..., m, affecting the variable y, a simple linear multifactorial model can be easily constructed:

$$\widehat{y'} = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_m x_m \tag{8}$$

The coefficients of this model are estimated by any statistical method, for example, LSM.

Then, the calculated values of the modeled variable need to be used in a polynomial of degree m:

$$\hat{y} = b_0 + b_1 \widehat{y'} + b_2 (\widehat{y'})^2 + \ldots + b_m (\widehat{y'})^m \tag{9}$$

The coefficients of such a polynomial can also be estimated using one of the statistical methods. As can be seen, it is necessary to estimate 2·(m+1) unknown coefficients, where (m+1) coefficients from model (8) are estimated first, and then, based on these estimates and the calculated values of the variable y, the other (m+1) coefficients from the model (9) are estimated. Both models (8) and (9) are linear in parameters, and the coefficients of these models can be easily found for sufficiently large m.

If we now substitute model (8) into equation (9) and expand the brackets, we can group the terms to obtain a structure and several terms that fully correspond to the structure and number of terms in KGp, thus deriving the desired polynomial model.

The system (8) – (9) can be represented in a more compact mathematical form:

$$\hat{y} = b_0 + \sum_{j=1}^{m} b_j (a_0 + \sum_{i=1}^{m} a_i x_i)^j \tag{10}$$

Models (8) – (9) or (10) do not represent KGp, but rather an approximate model of it. Indeed, it can be observed that a significantly smaller number of coefficients is estimated than would be necessary if constructing a KGp. For example, for m=3, the proposed method estimates 4+4=8 unknown coefficients, whereas the complete KGp, as indicated in (7), consists of 20 terms, requiring the estimation of 20 unknown coefficients. The smaller number of coefficients implies that model (10) provides approximate estimates of the KGp coefficients. Essentially, this means that a complete KGp is not constructed, but rather its simplified model, which has been proposed to be referred to as the "Elementary image of KGp" (Svetunkov, 2024).

The advantages of the elementary image of KGp over the KGp itself rest on the fact that the elementary image can be constructed for any number of variables, while the original KGp can only be constructed for a small number of variables. However, this does mean that the simplified representation of KGp captures nonlinearities less effectively than the original KGp. Nevertheless, previous studies have shown that, even though the elementary image of KGp is a simplified model, it possesses excellent approximation properties and describes various nonlinear relationships very well (Svetunkov, 2024).

Comparison of the Artificial Neuron Model and the Elementary image of KGp

If we compare the artificial neuron model (1) with the elementary KGp model (10), certain similarities can be observed. Firstly, both the neuron model and the polynomial model are unstructured statistical models. In regression analysis within mathematical statistics, it is assumed that the form of the relationship between input and output factors is explicitly represented by some function. It is presumed that the identified regression relationship is the model of the expected value of the modelled process, which evolves according to the properties of this model. The diversity of modelled processes significantly exceeds the forms of regression relationships used in mathematical statistics (Izonin et. al., 2024). Therefore, in econometrics, when selecting an econometric model, the researcher aims not to choose the best model but to select an acceptable model based on the principle: "Since I do not have other forms of functions for the econometric model, I will use this one as the best of a bad lot." Both the neuron model and the polynomial model do not require knowledge of the practical use since the form is automatically selected during the estimation of the neuron and polynomial coefficients, and the researcher is not familiar with this form. Therefore, both models are "blackbox" models, where the structure of the model is of no interest. The second similarity between the neuron and polynomial models will be even more apparent if we represent the artificial neuron model (1) as follows:

$$\begin{cases} y' = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_m x_m, \\ \hat{y} = f(y'), \end{cases} \tag{11}$$

and the model of the elementary image KGp can be represented as follows:

$$\begin{aligned} \widehat{y'} &= a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_m x_m, \\ \hat{y} &= f(\widehat{y'}) \end{aligned} \tag{12}$$

It is evident that in both cases (11) and (12), the first equation in the system represents a multi-factor linear model of the same type, while the second equation in both (11) and (12) represents a transformation of the obtained result. Thus, the structural similarity between the artificial neuron model and the elementary KGp model is apparent.

However, in the artificial neuron model, the coefficients of the linear transformation and the transfer function are estimated simultaneously. Therefore, (11) is presented as a system of two equations. In contrast, in the elementary KGp model, the coefficients of the first equation are estimated first, and then the obtained results are substituted into the second equation. Thus, this is not a system of two equations but rather two sequential equations.

Aside from the obvious similarities between these two models, there are also several significant differences. The first obvious difference lies in the methods of estimating the coefficients of the neuron and the elementary KGp model. In the artificial neuron model (11), all its coefficients (for both the first and second equations) are estimated simultaneously, and due to the nonlinearity of the transfer function parameters, one of the numerical methods is used for this purpose. In the elementary KGp model (12), the coefficients are estimated in two stages: first, the coefficients of the first linear equation are estimated, and then the second polynomial equation is evaluated. Both equations are linear in their parameters, and coefficient estimation can be performed using straightforward statistical methods (Chen et. al., 2021).

Considering the difference in estimation methods, it should be noted that the process of estimating the coefficients in the elementary KGp model is significantly simpler and faster than estimating the coefficients of the artificial neuron model.

The second difference between them is that the artificial neuron is consistently nonlinear regardless of the number of input variables (signals), whereas the elementary KGp model increases its level of nonlinearity and its approximation power with the number of input variables. As shown in (Liu, Lu, Luo, 2020), artificial neurons with a sigmoid transfer function are well described by third-degree polynomials. This means that the elementary KGp model may describe nonlinear processes somewhat worse than the artificial neuron if the number of inputs $m < 3$. However, if the number of input factors $m > 3$, the elementary KGp model may be more accurate than the artificial neuron model. For $m = 3$, both models are expected to provide approximately the same level of approximation accuracy.

Example. We will use data on the Gross Domestic Product (GDP) of the United Kingdom (yt), gross capital accumulation (x1), and the economically active population of the country (x2) from 1990 to 2016. We aim to find the dependence of GDP on these two other factors. Based on this data, we will construct both an artificial neuron model and an elementary KGp model, first normalizing all data. We will minimize the sum of the squared deviations between the actual and calculated values.

As expected, the artificial neuron model approximated the original data slightly better. The mean squared error of approximation for the neuron model was 0.0189, while for the elementary KGp model, it was 0.0228.

Now, we will add a third factor (x3) to this data, namely, the expenditure on research and development in the UK for the same period. For the artificial neuron model, the mean squared error of approximation is 0.01753, and for the elementary KGp model, it is 0.01734. Apparently, the elementary KGp model provided a slightly more accurate description of the data compared to the artificial neuron model.

Of course, different results may be observed in various cases, but generally, it should be assumed that as the number of input factors increases in these two models, the elementary KGp model has a greater capability to describe nonlinearity compared to the neuron model.

Neural networks and polynomial networks

In practice, no one uses a mathematical neuron model as a standalone model for describing some nonlinear dependency. The true power of this modelling tool becomes apparent when connecting elementary neurons together, where the outputs from preceding neurons serve as inputs to subsequent neurons. Such an interconnected network of artificial neurons can describe very complex nonlinearities between input and output variables. Therefore, well-constructed neural networks prove to be so accurate in approximation that other known modelling methods cannot compete with them, including regression-correlation analysis methods.

Since we have just seen that the elementary KGp model can successfully compete with the neuron model, it is natural to assume that a network connecting such polynomials with each other might also serve as an alternative to neural networks.

Let us compare two networks of the same structure: a neural network and a polynomial network. But first, let's revisit the methods of estimating the coefficients of these networks. In neural network theory, this process is called “training,” and we will use this term along with “estimation.”

If a multilayer neural network is subjected to one of the numerical training methods (most commonly, the gradient method), all coefficients of the network are estimated simultaneously. In this process, the coefficients of the output layer play a major role — they are estimated more extensively, while the coefficients of preceding layers are either not trained at all or are poorly estimated. This happens because the error at the output is completely addressed during the training of the output layer. To mitigate this issue, Rumelhart, Hinton, and Williams proposed the backpropagation algorithm in 1986. This procedure involves “distributing” the training error across all estimated coefficients of the neural network and adjusting the gradient method so that the training of the coefficients in the last layer proceeds more slowly than the training of the coefficients in preceding layers. This is achieved using both the model's coefficient values and the gradient method parameters, which are adjusted depending on how far the coefficient is from the network output.

As the simple explanation of neural network construction shows, using them in applied research requires a good understanding of mathematics and programming skills, as training a neural network is an iterative process with many simultaneously estimated parameters. Often, in practice, researchers use standard template networks and software products with pre-embedded training procedures for neural networks of a given structure. In other words, researchers do not design the structure of the neural network for their specific tasks but use a ready-made template developed by someone else for different tasks. In such cases, the advantages of neural networks are not fully realized, and their application becomes less effective.

The complexity of training neural networks is the main drawback hindering their widespread practical application in modelling complex economic processes. In contrast, polynomial networks are straightforward to train. In polynomial networks, not all coefficients are estimated simultaneously but sequentially — from the coefficients of the input layer to those of the output layer. The results from one layer's estimation serve as the basis for estimating the subsequent layer. Once all the coefficients of the polynomial network have been estimated in stages, the training is complete. There is no need to re-estimate the model coefficients in search of a better solution — the best solution has already been found. This means that training a polynomial network does not require recurrent methods; in general, the well-known least squares method is quite sufficient for this task.

Thus, training neural networks requires significant time and the use of complex computational methods. In contrast, training polynomial networks takes negligible time and employs basic statistical methods. However, it should be clarified whether the simplicity of training polynomial networks leads to a loss of accuracy in modeling.

To address this question, let us build a two-layer neural network and an equivalent two-layer polynomial network using data on the UK's GDP (y) in relation to gross capital accumulation (x1), the size of the economically active population (x3), spending on research and development (x3), and the size of social benefits in the UK (x4).

We will test how these two networks perform in three cases using the given data:

1. From 1990 to 2020,
2. From 1990 to 2021,
3. From 1990 to 2022.

Since the influence of the first three factors on the GDP is approximately the same — they are factors that generate GDP — and the influence of social benefits (x4) is somewhat different — they consume funds from the state budget and social funds — we will construct the neural network and the polynomial network in the following manner:

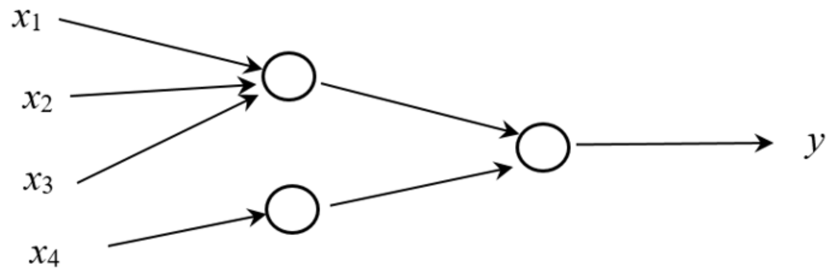

Fig. 1. Graphical model of a neural network and a polynomial network

For the neural network, each circle represents an artificial neuron, while for the polynomial network, each circle represents an elementary Kolmogorov-Gabor polynomial. A total of three neurons and three polynomials are used.

Since, after normalizing the initial data, it becomes both negative and positive, the transfer functions of the first two neurons are represented as logistic functions, while the transfer function of the last neuron is represented as a hyperbolic tangent function.

Alongside these two networks, we will also assess the accuracy of modelling this dependency separately with an artificial neuron model (using a hyperbolic tangent transfer function) and a Kolmogorov-Gabor polynomial model. The comparison results are presented in Table 1.

Table 1. Results of approximation of UK data by different models for specific periods of time

Model type	Neural network	Polynomial network	Artificial neuron model	Elementary image of the Kolmogorov-Gabor polynomial
1. 1990 – 2020				
Average sum of squares of approximation error	0.0077	0.0062	0.0310	0.0057
Standard deviation in %	11.14	10.02	15.47	9.60
Number of passes when evaluating coefficients	85 864	5	3 729	2
2. 1990 – 2021				
Average sum of squares of approximation error	0.0087	0.0075	0.0416	0.0068
Standard deviation in %	9.18	8.09	17.12	6.86
Number of passes when evaluating coefficients	34 252	5	15 011	2
3. 1990 – 2022				
Average sum of squares of approximation error	0.0216	0.0237	0.0745	0.0275
Standard deviation in %	17.31	18.12	32.15	19.55
Number of passes when evaluating coefficients	36 111	5	19 136	2

It is crucial to compare two models: the neural network model and the polynomial network model. The results show that in two out of three cases, the polynomial network was more accurate in approximation than the neural network. This does not necessarily mean that this ratio will hold in all cases; it only indicates that the polynomial network used in this example performed as well as the neural network. Both networks work with similar accuracy — their approximation standard errors differ by about one percent. However, the advantages of the polynomial network over the neural network become evident when considering the time required for training each network.

It is also worth noting that the elementary Kolmogorov-Gabor polynomial (the last column in Table 1) was the best model in terms of approximation accuracy in the first two cases and only 2.24% worse than the leader in the third case. This further confirms that the elementary Kolmogorov-Gabor polynomial can serve as an alternative to neural networks in modelling economic dynamics (Svetunkov, 2024).

Bayesian approach

Neural networks have a significant drawback. During the training process, the computational algorithm adjusts the network parameters to achieve the best output. However, it is impossible to understand how each neuron and each input factor influence the result based on the computed parameters. This limitation severely restricts the application of neural networks in modelling economic processes and, particularly, economic dynamics, as the meaning of the evaluated model parameters remains unclear.

Today, one of the actively developing approaches in economic modelling is the Bayesian approach. Generally, the Bayesian approach involves updating prior (a priori) conclusions based on new (posterior) data. In a narrower sense, Bayesian methods refer to statistical methods that use Bayes' theorem to compute conditional prior and posterior probabilities based on probabilistic distributions.

The Bayesian approach, both in its broad and narrow senses, is used by researchers in solving various econometric problems and economic forecasting tasks. One would expect the emergence of Bayesian methods applied to neural networks, but "neuro-Bayesian methods" currently exist only in theory. Applying the Bayesian approach to neural networks has proven to be impossible due to the neural network being a "blackbox" with an unknown structure to the researcher. Attempts to mathematically describe this network using multi-stage superposition of functions have been unsuccessful due to the complexity of the final mathematical model. Of course, the researcher knows the number of neurons, the connections between them, the number of "synapses," etc. But what is still impossible to trace is how the transformation of the input signal into the output signal occurs and how the factors and coefficients of the neural network influence the result.

Dynamic processes in economic systems can be classified into reversible and irreversible processes. Reversible processes are such that when returned to their initial condition, they will proceed in the same manner as before. In contrast, in economic systems where irreversible processes occur, there are not only quantitative but also qualitative changes. The latter means that the relationships between elements, the set of elements, and even the structure of the systems change — new elements emerge during evolution, and some old elements disappear. If a statistical model is constructed for such processes that adequately describes the past on average, then for it to be used as a forecasting model, its parameters need to be updated based on new posterior information for the model, i.e., the Bayesian approach must be employed.

Methods of model adaptation and adaptive models developed in forecasting serve as one of the tools for the Bayesian approach in its broad sense. Practice shows that their application significantly improves the accuracy of economic forecasts made using regression models. The widely known exponential smoothing method in short-term forecasting is one such method.

Unlike neural networks, in polynomial networks, the influence of each coefficient and factor on the result is known. This means that the Bayesian approach can be applied to polynomial networks, making them suitable for forecasting economic dynamics. To demonstrate this possibility, we will use one of the methods for adapting econometric models based on stochastic approximation.

We will use the same neural network and polynomial network models that were constructed using GDP data from the UK with four factors for the years 1990 to 2020. The subsequent years, 2021 and 2022, will be used as a validation period to test the suitability of the models for forecasting.

Polynomial network adaptation was performed on this data, while the neural network, as mentioned earlier, is not suitable for Bayesian evaluation and thus remained unchanged. In contrast, the adapted polynomial network, the original polynomial network, and the neural network were used. The results of forecasting the UK GDP using each of these three models for 2021 and 2022 are presented in Table 2.

Table 2. Comparative accuracy results, the UK GDP forecast by three models

Year	Factual data, y_t	Adapted polynomial network		Original polynomial network		Neural network	
		forecast	% error	forecast	% error	forecast	% error
2021	1.580226	1.39129	12.7	1.376194	13.80	1.375751	13.83
2022	2.001742	1.89455	5.5	1.559506	24.84	1.375753	37.07

As expected, the Bayesian approach to adapting the polynomial network improved its forecasting capabilities — the adapted polynomial network predicted the UK GDP more accurately than both the non-adapted original polynomial network and the neural network.

Conclusion

When modelling many economic processes, scientists and practitioners often face situations where none of the statistical models provide the necessary accuracy. In such cases, there is a desire to use some unstructured model like neural networks, but they are complex to apply, and examples of their successful use in economic practice are few.

The Kolmogorov-Gabor polynomial is a powerful tool for modelling nonlinearities, but as the number of influencing factors increases, the polynomial's structure becomes significantly more complex, which limits its applicability. Results of using KGp are limited to polynomials with a small number of explanatory variables — between three and five. The multi-stage procedure for constructing KGp proposed by A.G. Ivakhnenko in the 1970s turned out to be quite inefficient.

The method for constructing a simplified KGp model suggested in this research avoids these drawbacks — it is easy to construct, its parameters are easily estimated, and its size can be arbitrary. This method provides an approximate estimate of the actual KGp, which is why the model is referred to as the "elementary image of KGp."

Research has shown that the elementary image of KGp describes nonlinear economic processes well and can itself serve as an important tool for economic-mathematical modelling.

Structurally and functionally, the elementary image of KGp is very similar to an artificial neuron model. This means it can be used as a basis for developing another type of unstructured (sometimes referred to as non-parametric) models that describe complex nonlinear processes — polynomial networks.

Polynomial networks can have the same structure as neural networks. They can be single-layered or multi-layered, feedforward or recurrent — essentially, they can be like neural networks, but instead of artificial neuron models, they use elementary images of KGp.

It should be noted that specialists in neural networks have already used power polynomials instead of sigmoids in the transfer function of neural network models. These networks are reported to train faster and have very good approximate properties. However, it is not clear what degree these polynomials should be. Since there is no answer to this question, researchers use polynomials of small degrees or linear forms, referring to KGp. Moreover, unlike the polynomial networks discussed in this article, all coefficients of such neural networks with polynomial transfer functions are trained simultaneously, which implies a multi-iterative evaluation procedure. In the proposed polynomial networks, each elementary image of KGp is trained separately, which ensures quick and efficient estimation of all polynomial network coefficients.

As demonstrated with simple examples, training a simple two-layer feedforward neural network required several tens of thousands of passes, while a polynomial network of the same structure needed only a few simple iterations. The accuracy of describing economic nonlinearity is approximately the same for both neural networks and polynomial networks.

A significant advantage of polynomial networks is the possibility of applying the Bayesian approach — reassessing the parameters of the polynomial network based on new posterior data. This possibility was demonstrated through the adaptation of a polynomial network using the stochastic approximation method. The Bayesian approach to neural networks is currently impossible, and neuro-Bayesian methods are still in the stage of unsuccessful development.

Of course, the proposed polynomial networks based on the elementary image of KGp require additional and extensive research. However, it is already clear that they can serve as an alternative to neural networks in modelling complex economic processes.

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APPLICATION OF DATA MANAGEMENT TOOLS TO IMPROVE EFFICIENCY OF A BIOTECHNOLOGY COMPANY

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Abstract. Most companies in today's economy tend to use information technologies both to execute their activities and to support the core business processes of the organization. There are many tools available in the IT market that can meet the needs of organizations and their customers. However, an important requirement for realizing the possibilities of optimal digitalization of production is the high quality of the data used in the organization, as well as the proper data management, which is one of the assets of the organization. A data management approach is important for any company that wants to be competitive in its industry. This paper analyzes the current architecture of data management in a biotechnology company and its disadvantages and proposes a new architecture, taking into account the implementation of integration tools between services to improve data quality and more efficient data management.

Keywords: enterprise service bus, system integration, data management, data architecture, ETL

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ПРИМЕНЕНИЕ ИНСТРУМЕНТОВ УПРАВЛЕНИЯ ДАННЫМИ ДЛЯ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ БИОТЕХНОЛОГИЧЕСКОЙ КОМПАНИИ

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Аннотация. Большинство компаний в современной экономике в ходе ведения своей деятельности прибегают к использованию информационных технологий как для реализации своей деятельности, так и для поддержки основных бизнес-процессов организации. На рынке информационных технологий существует масса инструментов, которые могут отвечать на ту или иную потребность организаций и их клиентов. Однако важным условием для реализации возможностей оптимальной цифровизации производства является высокое качество используемых данных в организации, а также грамотное управление данными, которые являются одним из активов организации. Подход к работе с данными важен для любой компании, которая хочет являться конкурентоспособной в своей отрасли. В данной работе путем анализа рассмотрена текущая архитектура работы с данными в биотехнологической компании и ее недостатки, а также предложена новая архитектура с учетом внедрения инструментов интеграции между сервисами для повышения качества данных и работы с ними.

Ключевые слова: сервисная шина, интеграция систем, управление данными, архитектура данных, ETL

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Introduction

Most corporations in various business sectors are actively employing information technology for the efficient operation of their employees and production. The more efficiently an organization works internally and delivers a high-quality product, the higher its position in the marketplace, compared to direct competitors and companies producing substitute goods. A high level of competitiveness allows companies to boost their profits, which is the main goal of any business.

The introduction of digital technology into manufacturing began back in the 20th century and has continued to develop rapidly since then. Thus, almost every business or technological process is accompanied by the use of specific information technology tools, from the use of various devices and sensors to planning and production systems (by levels of computer automation) (Giyosidinov et. al., 2023). Accordingly, the use of information services and tools leads to the generation of constantly growing data.

As previously mentioned, the primary goal of using digital solutions in production is the ability to enhance efficiency and quality of all processes associated with the company. To be more precise, these processes involve:

Process automation: simplification and acceleration of production processes via robotic mechanisms and automated systems.

Data management: collecting, processing, and analyzing quality data to optimize and improve the efficiency of production.

Internet of Things (IoT): connecting equipment and other machines to a single network for real-time monitoring and control from anywhere with the appropriate access.

Quality and production control: implementing quality control systems to reduce errors in production using sensors, data analysis, and artificial intelligence technologies such as machine learning.

Production planning: optimizing logistics and inventory management, adapting quickly to market needs, and planning resource use efficiently using digital platforms.

Cost reduction: optimize resources and reduce operating costs by improving efficiency.

Modelling and simulation: using software to model processes and test changes without the need for actual implementation.

These options have huge potential and are already used in many modern companies. The market for Industry 4.0 technologies is actively developing, and the growth forecast is almost 20% in the next 10 years (IMARC Group).

An important condition for realizing the possibilities of optimal digitalization is the high quality of data used in an organization, as well as the competent management of data, which is one of the organization's assets. Data management is the process related to collecting, accumulating, organizing, remembering, updating, and storing data and using it to improve a company's performance and increase its profits. Since organizational data quality is one of the fundamental criteria for an organization's high level of data maturity, organizations must ensure that the required level of data quality is supported through activities to automate data quality rules, setting up data quality checks, and so on.

Low-quality data can lead to significant financial losses. Gartner estimates that each year poor data quality costs organizations an average of $12.9 million (Gartner). In 2022, Unity Software reported a loss of $110 million in revenue and $4.2 billion in market capitalization due to poor data quality from a major business partner. Similarly, bad data led Equifax, a publicly traded credit agency, to send lenders inaccurate credit ratings for millions of customers (Equifax). Poor data quality is also found in the medical industry. For example, due to data quality issues during the manufacturing process, Zoll Medical's defibrillators were found to display error messages and even fail during use (Get Right Data). The company had to conduct a Class 1 recall, the most serious type of recall for situations in which there is a reasonable likelihood that the use of these products will result in serious injury or death to a person. The recall resulted in a loss of trust and $5.4 million in fines.

The main purpose of this article is to present an improved data architecture in a biotechnology company to make the data management more efficient and to minimize the occurring data errors. The authors carried out the following tasks in order to achieve this goal:

– analyzed the data processing tools available on the market;

– assessed the ways to improve the data management approach;

– examined the current data architecture of a biotechnology company and suggested an improved structure using integration tools.

Materials and Methods

This research invites the following methods: collection and analysis of information, comparison, description, and modeling. Analytics involves gathering information on data technologies, assessing information on the company and its data architecture, and selecting the best data architecture option that will address the identified specifics of data management in the systems.

Results and Discussion

According to the DIKW pyramid (Gordon, 2024), data makes the basis for the information and knowledge that companies use in their operations. Various data management tools are implemented to ensure higher performance:

Data Integration. Data integration technologies allow data from different sources (databases, applications, IoT devices) to be combined to create a single information model. Using ETL (Extract, Transform, Load) or ELT (Extract, Load, Transform) processes and tools for data integration ensures integrity and relevance of information.

Machine Learning (ML) and Artificial Intelligence (AI). The application of machine learning (ML) and artificial intelligence (AI) algorithms can automate data analysis processes, identify hidden patterns, and build predictions. Machine learning technologies can be used to create personalized recommendations, optimize production processes, and predict demand or any business scenarios.

Blockchain. Blockchain provides secure and transparent storage of data by distributing information across a chain of blocks. Blockchain can be used to ensure data integrity, validate transactions, and manage access to sensitive information.

Data quality management. Using tools to clean data, check for duplicates, and ensure data integrity. Compliance with regulations and standards to maintain high data quality.

Data Analytics Tools. Data analytics platforms (e.g., Tableau, Power BI, Looker) allow visualizing data and creating interactive reports to extract information from the collection of data to make strategic decisions in the organization (Ivanov et. al., 2023). What is more, programming languages (Python and R) are used for statistical analysis and machine learning for the same purpose and even for production, automation, and monitoring.

Not every company is mature enough to utilize all these technologies at once. To use analytics tools, an organization is supposed to possess high-quality data and develop analytics tools gradually to take full advantage of the technological capabilities. The maturity levels of data analytics in an organization are described by Gartner's analytics evolution model (Rowley, 2007). Each of the 4 stages of data analytics evolution in a company answers a specific question: descriptive analytics (What happened?), diagnostic analytics (Why did it happen?), predictive analytics (What will happen?), and (How can we implement it?). It turns out to be impossible to forecast what will happen in the future if the awareness over what is happening now is scarce. Organizations have to meet certain requirements in order to evolve and increase the application of analytics in their operations. Some of them are presented below:

Access to quality data. The availability of reliable and relevant data makes the foundation for the development of data analytics.

Analytical culture. The organization should encourage the use of data in decision-making and support the development of an analytical culture among employees.

Technology infrastructure. Availability of appropriate tools and technologies to collect, store, process, and analyze data.

Staff competence. Availability of skilled data analytics professionals, including analysts, data scientists, and developers.

Thus, in order to develop high-quality analytics and obtain reliable and valuable information from data, organizations have to take care of the data quality. It makes the one and only prerequisite for efficient strategic decisions and improved competitiveness.

It is important to bear in mind that manufacturing organizations not only own data on the processes of production but also on entities that support this very production: product, employees who work on the production line, the raw material suppliers, contractors, and so on. The more complex the production line, the more data is generated, stored, and used.

With the current development of technology and economy, the biotechnology industry has become one of the fastest-growing industries in the world. Biotechnology combines the principles of biology, chemistry, and engineering to create innovative products and processes that can solve complex problems in medicine and healthcare. The biotechnology industry is in constant advancement in genetic research technologies, DNA sequencing, and the analysis of proteins and other biomolecules. Studies, discoveries, and innovations in this industry allow scientists and researchers to gain more and more data about living systems and their functions.

Processing data in biotechnology manufacturing can be divided into several aspects based on the specifics of this industry:

Collecting data on production processes: real-time data on temperature, pH, pressure, nutrient concentration, and other parameters allow controlling the necessary conditions for microorganisms or cells to be cultured.

Data analysis: bioinformatics is used to process and analyze genomic data to identify genes responsible for specific functions. Statistical methods are used to analyze experimental data and identify patterns, for example, in tests for the efficacy of new drugs.

Quality control: data on each stage of production helps to monitor compliance with quality and safety standards (e.g., GxP and ISO 9000). Another test is deviation analysis, which consists of collecting and analyzing data on non-conformances to identify potential problems and prevent their recurrence.

Process Optimization: using data to create mathematical models that help to optimize production conditions and improve efficiency. Machine learning algorithms help forecasting the results of experiments based on statistical data (Dubgorn, 2020).

Collecting and analyzing data on the safety and efficacy of new drugs at various stages of clinical trials.

Use of Industry 4.0 technologies: sensors to collect real-time process data and improve monitoring and control; cloud technologies to store and analyze large amounts of data and share them across multiple devices.

Data security: the importance of complying with regulations to protect personal data and intellectual property, especially when dealing with genetic information (Ilin, Iliashenko, 2022).

Data in the biotechnology not only contributes to process efficiency but also opens up new opportunities for research and innovative product development. The large amount of data generated, however, presents a significant challenge. The data resides in various sources, such as laboratory instruments, databases, and others. Integration of these data becomes a necessity to obtain a comprehensive perspective on complex biological processes and to develop new technologies (Iliashenko et. al., 2018).

The use of data integration tools also improves the efficiency of any company. Such technology automates the processes of data collection, storage, and analysis, which reduces the time and effort spent on searching and processing information. Moreover, data integration improves the accuracy of results and reduces the possibility of errors, which is a critical factor in sensitive areas such as drug development or genetic research.

The biotechnology company combines research centres, pharmaceutical and biotechnological production, and preclinical and clinical research systems. It covers the full cycle of drug development: from molecule search and genetic engineering to mass production and marketing support. Thus, the activities in the organization are divided into three components: management, core, and supporting activities.

Supporting activities involve information and technological support, like most modern companies. In this regard, the IT direction is well developed in terms of resources and technologies.

The IT area is structured according to the principle of support provided to the core business: process production automation, infrastructure and systems, and information technology architecture. Each branch is supported by corresponding systems that form the microservice architecture of software. This includes interprise solutions such as 1C: Enterprise, ERP and ECM platforms, automated process control systems, equipment monitoring systems for production and warehouses, tools for BI-analytics, and advanced analytics (e.g., a system for forecasting performance in bioreactors based on real-time data from sensors). Only a small fraction of systems are mentioned, but in total more than 50 systems are collected.

The presence of a large number of services leads to the fact that a huge amount of data is generated as a result of the company's activities. Given that the vector of development of modern companies is aimed at digitalization in order to increase their competitiveness in the biotechnology market, data on business processes and their products is also used for analytics. The organization under consideration claims a high level of analytics development, according to Gartner, as the following advanced analytical tools are used:

– Power BI for reports and dashboards (Iliashenko et. al., 2020);
– Computer vision tools for tracking production and process flows;
– Monitoring platform for instant detection and prevention of IT failures and comprehensive IT infrastructure management;
– Assessment of process data and deviations via identifying anomalies and interrelationships of parameter readings;
– A system for planning clinical trials and control of monitoring activity;
– Monitoring sensors on production equipment to prevent breakdowns and accidents.

However, even with advanced data tools, the company faces data errors, inappropriate formats, and a lack of digitalization. Unfortunately, such problems in working with data not only affect the competitiveness of the organization but also lead to additional expenditure of IT specialists' resources (Dubgorn et. al., 2020).

No regulations were prescribed for describing the organizational structure of the company, updating this information, and transferring it to other systems. These data on the structure were transferred daily to the ESM platform with some errors, in which they were already used to build the logic of business processes for the company's documentation. Further, reports in Power BI on KPIs of these processes displayed distorted information about the activities of the departments that directly work with documentation and are responsible for it. Thus, data errors in one system caused the following problems:

– Errors in other systems where the data was passed up the chain;
– Burden on technical support services, as these errors were found by the departments whose KPIs are based on documentation processes;
– Developer's labour costs to refine the integration so that data is transmitted without distortions and errors.

This case in the company's practice indicates what problems arise due to the large number of unregulated data flows and why it is necessary to develop/implement a new approach to data transfer between systems and the formation of a common data warehouse that could be used for analytics (Ilin et. al., 2018; 2019; 2020).

Integrating systems separately between each other is technically difficult and does not provide for a common repository of information from the units being integrated. Based on the problems in handling data from different systems, it is suggested to resort to implementing an ESB tool and a common ETL system with which the existing systems will be integrated.

Let's consider the recommended data architecture for the company, taking into account the implementation of ESB and ETL (Fig. 1).

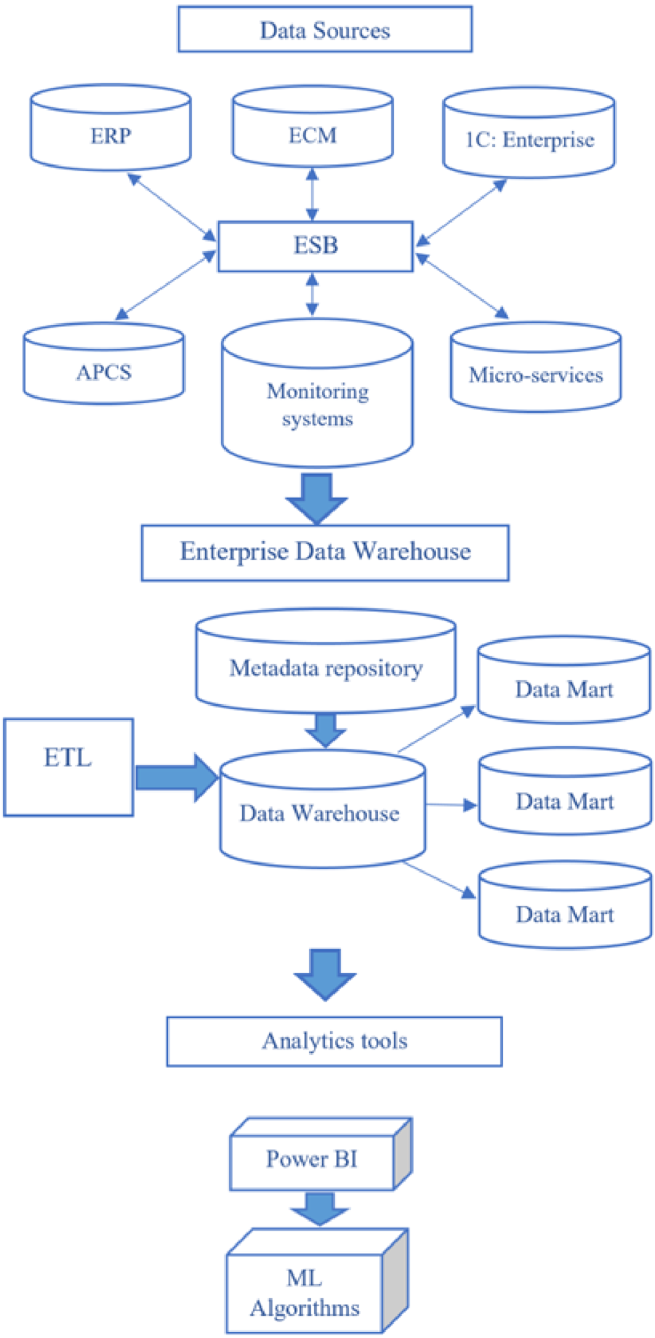

Fig. 1. TO-BE data architecture

As mapped in the TO-BE architecture, it is proposed to integrate the company's services with an ESB tool to exchange data between each other, as well as an ETL system to form a common data warehouse from these services, which in turn will be used for analytics. The following is a closer look at these two technologies.

The ESB (Enterprise Service Bus) is software that provides connectivity and integration between the various applications, systems, and services in the corporate IT landscape. It acts as a central messaging platform that allows applications to communicate with each other without the need for direct integration. The enterprise service bus plays an important role in data integration as it enables applications and systems to communicate with each other in real time (Robin et. al., 2017; Dong et. al., 2011). It provides reliable and efficient messaging, data conversion, and routing.

The advantages of ESB are:

Simplified integration: it allows new applications and systems to be integrated into existing IT infrastructure quickly and easily;

Improved productivity: automates messaging and eliminates the need for manual integration, which increases efficiency;

Flexibility and scalability: provides a flexible and scalable architecture that can adapt to changing business needs;

Improved data quality: provides message conversion and routing services, which improve data quality and consistency between systems;

Improved security: establishes centralized access and security controls, which improves the overall security of IT systems.

ESB functionality implies:

Messaging: provides mechanisms for reliable and efficient messaging between applications and services;

Data conversion: converts data from one format to another, enabling interoperability between systems with different data structures.

Message Routing: routes messages to appropriate recipients based on defined rules;

Process management: coordinates the sequence of tasks and actions required to execute business processes;

Data management: provides data management functions such as data integration, synchronization, and data quality.

ETL (extract, transform, load) is the process of moving data from various sources into a target data system for analysis and reporting. It involves three main steps:

Extraction: extracting data from source systems such as databases, files, or web services.

Conversion: Converting the extracted data into a format compatible with the target system. This may include changing the data structure, data cleansing, and applying business rules.

Loading: Loading the transformed data into the target system, which may be a data warehouse, database, or other repository.

An ETL system is critical to ensuring consistency, accuracy, and completeness of data for analysis. It allows organizations to combine data from different sources, improve data quality, and create a single version of the truth. By implementing a common ETL system, organizations can benefit from centralized data management and simplified integration processes (Mhon, Kham, 2020; Bengeri, Goje, 2022).

The benefits of a common ETL system are:

Centralized data management: provides a single source of consistent data.

Simplified integration processes reduce the time and effort required to integrate new systems.

Improved efficiency: automates data conversion and loading processes, freeing up resources for other tasks.

Data Quality Assurance applies data transformation rules to ensure accuracy and consistency.

Improved analytics: provides quality data for accurate analysis and informed decision-making.

Conclusion

The implementation of ETL in the case study is a solution to the problem of data analysis and other types of analytics available in the company. Since any analytics involves working with a large amount of data obtained from different sources, the proposed solution will make it easier to work with them. The company's employees will be able to compare the received information, analyze it, and make forecasts based on it much easier and more efficiently.

Integration of existing systems with ETL facilitates the formation of MDM—data containing key information about the business and industry, including customers, products, employees, technologies, and materials. Each of these groups can be divided into several subject areas: the people category includes customer, salesperson, and supplier. So we can have a set of validation rules that the data must satisfy.

ETL and ESB are used together to create a comprehensive data management and integration solution. ETL is responsible for extracting, transforming, and loading data into a data warehouse or other target system, while ESB provides real-time data exchange between applications and systems.

Integrating ETL and ESB will allow a company to:

- Automate the exchange of data between different systems;
- Improve data quality and consistency;
- Reduce the time required to deliver data for analysis and reporting;
- Increase the flexibility and scalability of IT systems.

Implementing ETL and ESB requires careful planning and implementation. Organizations must define their integration requirements, select appropriate technologies, and develop an architecture that meets their business needs. All of the recommendations presented for changing a company's data architecture with the addition of ETL and ESB will help to sustain a high level of company analytics development, as keeping data in one environment in a structured manner promotes quality analytics that can continually evolve.

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