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Digital Transformation of Kazakhstan's Industry: Designing a Management Mechanism Based on DEA and a Digital Platform

Abstract. In this research we focuse on developing an organizational and technical mechanism for managing industrial enterprises in the context of digital transformation in the Republic of Kazakhstan. The quantitative analysis is based on the Data Envelopment Analysis (DEA) method, which assesses the relative efficiency of enterprises based on digital transformation input indicators and economic output results. The main digital factors influencing profit growth and production volumes were identified. The results demonstrate significant differences in efficiency due to the quality of digital infrastructure and the level of business process automation.

Based on an analysis of the practices of the Kazakh-German enterprise Boehmer Armatura LLP and the principles of system design, a digital platform structure has been proposed that uses the TOGAF architectural model to remotely manage the operation of an industrial enterprise.

An organizational and technical mechanism of industrial enterprise management in the context of digital transformation has been developed based on theoretical analysis, empirical data obtained from studying Boehmer Armatura LLP's activities, and the results of a quantitative assessment. This mechanism focuses on effectively integrating digital technologies into production and management processes. It includes a set of technical and organizational levers that ensure feedback availability and contribute to continuously improving processes and increasing the effectiveness of applying digital resources.

Keywords: Digital Economy; Digital Transformation; Organizational and Technical Mechanism; Digital Ecosystem; Digital Platform; Industry 4.0; Industrial Enterprise; Transformation of an Industrial Enterprise
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1. Introduction

In recent years, digital transformation has gradually become the primary strategic focus of global technological change, aiming to create a favorable business environment, transform business models, and gain a competitive advantage.

The digital economy can increase companies' productivity, reduce economic costs, and accelerate the flow of production factors (Nanxu et al., 2022).

The application of digital technologies enables companies to be more flexible and efficient, optimize production processes, develop value propositions for innovative ecosystems, respond to market needs promptly, and enhance competitiveness (Alcocer & Cruz-Machado, 2019).

Digital transformation involves using digital technologies in many areas of business strategy, including digital platforms, digital services, digital ecosystems, and artificial intelligence (Luo, 2022).

Using digital infrastructures, such as Internet of Things (IoT) and artificial intelligence (AI) platforms, companies can collect and analyze large-scale, detailed data in real time for forecasting purposes. Digital transformation enables the development, testing, and analysis of multiple production flow scenarios in the early stages in the form of digital models or simulations and digital twins with the introduction of new or significantly different process parameters, production methods, or technologies (Koteshwar Ch., 2021).

Hundreds of sensors record all parameters important for the process, and predictive models developed using AI technologies can predict optimal settings. This ensures improved quality, reduced production costs, and process flexibility throughout the industrial production chain (Sokolov et al., 2018).

To overcome organizational inertia and improve operations, conglomerate enterprises are implementing integration technologies and cloud data management solutions offered by industrial Internet platforms. These technologies enable effective communication, collaboration, and coordination between entities in the manufacturing ecosystem. Integration increases productivity, reduces costs, and improves competitiveness overall in relevant industries.

A digital industrial platform facilitates the interaction of manufacturing enterprises by integrating data from production sites and remote equipment operation and maintenance with software and equipment management platforms (Wang et al., 2018).

Technical support from an industrial Internet platform enables enterprises to reduce unplanned downtime, quickly eliminate malfunctions, and improve equipment setup speed to minimize downtime. It also mitigates equipment and short-term downtime and ensures production and operational efficiency (Liua et al., 2024).

The advantages that digital transformation brings to industrial enterprises, as well as the need to increase their competitiveness, determine the importance of creating an organizational and technical mechanism for their development within the economic conditions of the Republic of Kazakhstan.

This article aims to develop such a mechanism for industrial enterprises in the context of digital transformation in Kazakhstan.

This scientific article addresses the following research questions:

1. What is the relative efficiency of industrial enterprises in Kazakhstan in the context of digital transformation (based on the DEA method)?
2. What theoretical principles and practical tools should be used when developing an organizational and technical mechanism for developing industrial enterprises in the context of Kazakhstan's digital transformation?

Research Hypothesis: In the context of digital transformation, the following factors positively impact on the efficiency of industrial enterprises, as expressed by an improvement in production volumes and profits:

- The number of enterprises with automated internal business processes;
- The number of ICT specialists;
- The cost of information and communication technologies;
- The number of employees who use a computer with internet access for work.

2. Brief Literature Review

Research by Western scholars offers in-depth analysis of various aspects of digital transformation. Ni & Sun (2025) examines the relationship between digital transformation and the development of service production models, taking into account the specifics of the Chinese economy.

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Using empirical data and considering the problem in the context of asset specificity, the authors conclude that digital transformation is not a one-time act, but a continuous evolutionary process. In this process, companies systematically implement and adapt digital tools, which leads to fundamental changes in their technologies and operations, laying the foundation for the transition from traditional manufacturing to service-oriented business models.

The digital transformation process involves more than just introducing new technologies. It also promotes technical innovation and business development, redesigns operational processes, expands iteration capabilities, and revises business models (Warner & Wager, 2019). Paul et al. (2024) conducted a large-scale interdisciplinary synthesis of existing knowledge on digital transformation. Having analyzed a large body of literature from various fields (management, marketing, information systems, etc.), they proposed an integrative definition of this phenomenon. According to their study, digital transformation is the strategic application of modern information technologies (such as cloud computing, IoT, AI, Big Data) not just to automate simple operations, but to launch deep transformations: updating technology, business processes, reengineering operational flows and changing organizational structures. The authors see the ultimate goal of this process as a complete digital modernization of the entire production system of the enterprise.

Thus, integrating digital technologies affects corporate governance, innovation, and efficiency (Hakim et al., 2022; Wang et al., 2024). In their critical review, Jiao et al. (2025) examined the relationship between digital technologies and firms' innovation performance. The authors not only systematized and classified the key emerging technologies that are the driving forces of transformation and innovation, but also identified the key ones: cloud computing, the Internet of Things (IoT), artificial intelligence (AI), virtual and augmented reality (VR/AR), and big data. They identified significant contradictions and gaps in the scientific literature regarding the mechanisms of their influence on innovation results. Based on this analysis, they formulated clear directions for future research.

Saeed, et al. (2025) analyzed the practices of implementing digital transformation in various industries using the multiple case study method. Their study empirically revealed one of the main difficulties that companies face when developing a digital transformation strategy: management's lack of understanding of the real competitive advantages that digital technologies can provide, as well as the uncertainty of their long-term development prospects. The authors convincingly showed that the success of digital initiatives critically depends on management's fundamental understanding of not only the technical aspects, but also the conceptual foundations of digitalization, as well as the specifics of their application in specific business cases. The result of their work was the development of practical recommendations for planning and implementing digital transformation projects.

In their study, Xiong et al. (2025) examine in detail the essence of digital transformation at the enterprise level. They argue that digital transformation is not only a micro-level support for the rapid development of the digital economy at the enterprise level, but also one of the high-quality core elements of the architecture of economic development strategy. It promotes the deep interaction of the digital and real economies, stimulating the growth potential of the total productivity of enterprises, which is of great significance.

Digital transformation of enterprises involves the introduction of innovations into traditional production and operation models, as well as business models, in particular, production processes, transaction models and operations management, using digital technologies such as data, information and algorithms.

The key tool for such transformations, as the researchers found, is modern digital technologies, in particular, working with large amounts of data, their processing and interpretation and the use of complex computational methods. The main conclusion of their work was the confirmation of the important role of human-machine cooperation in the process of influencing digital transformation on the growth of enterprise productivity.

Qiao & Chen (2025) in their empirical study based on the analysis of data from Chinese companies examined the impact of digital transformation on managerial performance and internal socio-economic indicators, such as intra-firm equality («company prosperity»). Their work provides evidence that the implementation of digital technologies in the activities of enterprises differs significantly from simple optimization within the framework of traditional economic models. The authors substantiated that digital transformation can cause qualitative changes in business processes, leading not only to an increase in operational efficiency and productivity, but also having a positive impact on the social aspects of the company's functioning and the development of the entire industry as a whole.

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The study by Taoa & Chaob (2024) aimed to examine the critical role of digital technologies of Industry 4.0 (cyber-physical systems, IoT, Big Data, AI) in achieving the goals of sustainable development by industrial enterprises. The study paid special attention to the practices of «green» supply chain management (GSCM). Using econometric modeling, the authors demonstrated that these technologies offer manufacturing companies many significant benefits: from the creation of innovative and profitable business models and increased operational efficiency to improved product quality and working conditions for personnel. The key mechanism identified in the study is the ability of Industry 4.0 technologies to ensure continuous communication between physical objects (equipment, products) and their digital versions, creating a single system of interacting objects. This integration opens up opportunities for the implementation of advanced technologies such as additive manufacturing, adaptive robotics and flexible automated lines. Taken together, the implementation of Industry 4.0 technologies, realized through effective GSCM practices, significantly increases the resilience of industrial systems to external influences.

Corporate digital transformation positively impacts various business operations, including financial management, production efficiency, and customer engagement strategies (Adner et al., 2019).

Digital technologies aim to increase process flexibility and reliability, maximize output, and improve product quality and service methods through continuous online adjustment and optimization of processes in industry (Branca et al., 2020).

Murawski (2019) described how AI capabilities, such as deep learning and neural networks, can help manage a smart, self-learning factory based on data collected from thousands of sensors. This data can be useful for identifying unknown problems and planning production.

Kuo and Kusiak (2019) point out that new business models may increase production efficiency and optimize resource allocation. Digital transformation can be integrated into various processes, such as production and sales, thus increasing efficiency.

Usman et al. (2021) argue that digital transformation positively impacts corporate sustainability by promoting enterprises' green evolution.

María et al. (2023) claim that digital transformation provides companies, regardless of their geographical location, with new opportunities to interact with external organizations and gain access to their production capabilities.

Babkin et al. (2022) point out that industrial production projects with high digital potential are increasing every year, primarily due to the use of various information and communication technologies and companies' desire to be competitive in domestic and foreign markets.

However, digital transformation requires a radical restructuring of industrial enterprise activities.

Gao et al. (2019) argue that companies seeking digital maturity must focus on resources, information systems, organizational culture, and structure. Companies must be prepared for fundamental restructuring of their resources, structures, infrastructure, and culture, which is crucial in the context of digital transformation.

Sandkuhl et al. (2019) state that factors influencing the success of digital transformation projects include a defined strategy, management, employee engagement, products or services that align with changing customer needs, corporate culture, digital governance structures that control the transformation, and appropriate technologies.

Industrial enterprises use various development mechanisms in the context of digital transformation. Kapustina and Kondratenko (2020) argue that smart manufacturing, or Factories of the Future, involves producing smart products by digitizing production processes while minimizing human involvement. Factories of the Future can increase labor productivity, create jobs for highly skilled employees, and organize production that focuses on cooperation and improving environmental safety.

Kulzhambekova et al. (2023) emphasize that digital factories have many advantages over traditional factories. They minimize errors in product design and reduce production waste and defects. They also shorten the time required for product design and market launch.

According to Zvereva and Deputatova (2019), the digital transformation of an industrial enterprise is a continuous process that transforms the entire company ecosystem, including employees, customers, suppliers, and partners. This transformation is based on advanced business technologies and is aimed at either optimizing existing business models and processes to generate additional profits or replacing business models with more advanced ones.

Enterprises develop the mechanism of digital transformation through entrepreneurial initiatives, which affect the following systemic components: business processes, management methods,

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organizational structure, and competencies. These ultimately result in new, innovative products that determine a digital enterprise's competitiveness (Mugutdinov, 2021).

Babkin et al. (2017, 2019, 2022) point out that the Fourth Industrial Revolution has contributed to the reorientation of the manufacturing industry (within the Industry 4.0 framework) toward implementing and adapting digital tools, such as big data, the Industrial Internet of Things, and blockchain, to its own needs and those of the market. These technologies provide the basis for digital platforms. Industry 4.0, which aims to implement cyber-physical systems globally, has defined further paths for developing cluster systems. One way is digitizing business processes, which significantly reduces costs and enables the production of high-tech, innovative products. It also decreases communication time between all participants in the industrial cluster and promotes the sustainable development of enterprises.

According to Liua et al. (2024), industrial Internet platforms facilitate digital transformation by offering a comprehensive digital ecosystem that combines advanced technologies, such as cloud computing, big data analytics, the Internet of Things (IoT), artificial intelligence, and blockchain.

Gnatyshina (2023) states that digital transformation involves creating and developing digital platforms and ecosystems that contribute to the industrial sector's enhanced efficiency and competitiveness. These platforms and ecosystems consist of enterprises, suppliers, consumers, and other participants in the industrial complex that collaborate on joint developments and innovative projects.

Digital technologies contribute to companies' profit growth. As Ayaganova et al. (2023) noted, a key element of a profitable business model is the use of accessible information technologies and inexpensive resources.

A literature review has confirmed that digital transformation is a promising direction for industrial enterprise development, ensuring production flexibility and economic competitiveness.

3. Methodology and Methods

This study uses a comprehensive approach that incorporates quantitative and qualitative methods to ensure reproducible results. The study was carried out using a phased approach consisting of two consecutive key stages.

1. Quantitative analysis using Data Envelopment Analysis (DEA), a method for assessing the relative efficiency of entities (decision-making units, DMU) based on multidimensional inputs and outputs. In the context of digital transformation, the creation of an organizational and technical mechanism for an industrial enterprise aims to increase production volumes and profits while minimizing costs. Thus, the study employed the output-oriented CCR (Charnes, Cooper, and Rhodes) model. To determine the factors with the greatest impact on production volumes and profits, a correlation analysis was performed on indicators characterizing the digital transformation of industry. Based on the correlation analysis, parameters were selected as input and output variables and normalized:

Inputs:

- X_1 - the number of ICT professionals;
- X_2 - the ICT expenditures;
- X_3 - the number of employees out of the total number of employees who use a computer with Internet access for work;
- X_4 - the number of enterprises with automated internal business processes.

Outputs:

- Y_1 - the volume of industrial production (goods, services) in value terms;
- Y_2 - profit (loss) before taxation.

The data have been normalized. The DEA model has been solved for each region of Kazakhstan using OpenSolver.

The DEA model has been used to determine:

- θ - efficiency;
- v, u - input and output weights.

For each DMU, individual optimal weights of inputs and outputs have been determined to maximize its efficiency provided that no other DMU demonstrates greater efficiency with the same weights.

2. An organizational and technical mechanism has been developed based on the principles of systematic and integrative design.

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The following methods have been used as a starting point:

- The Case Study method: for the qualitative analysis of the joint Kazakh-German enterprise Boehmer Armatura LLP organizational, technical, and managerial features which actually involve digital technologies and international experience;
- The structural-functional approach: for formalizing the relationships between the elements of the organizational and technical mechanism.

4. Results

4.1. Assessment of the Impact of Digital Transformation on Industrial Enterprise Activities Using the DEA Method

In the context of digital transformation, the creation of an organizational and technical mechanism for industrial enterprises is aimed at enhancing production volumes and profits with a minimal cost increase, which is made possible by the introduction of digital technologies.

Let us introduce some symbols. We have designated the indicators characterizing digital transformation of industry in accordance with Table 1 using VAR00001, VAR00002, ... VAR000011. The DEA method does not require unconditional correlation of parameters. However, to determine the factors that have the greatest impact, a correlation analysis was performed for the indicators characterizing digital transformation of industry (Table 1) (Table 2). Of the 11 variables, only 4 variables VAR00002, VAR00005, VAR00006, VAR00007 lead in terms of the number of strong connections (6 each). At the same time, the variables VAR00005, VAR00006, and VAR00007 have the maximum correlation strength of 1.000, which indicates potential multicollinearity and loss of stability of the DEA model due to duplication of information. Therefore, the VAR00002 indicator has been selected for further analysis.

The VAR00002 indicator correlates significantly with the VAR00004, VAR00005, VAR00006, VAR00007, VAR00008, and VAR00011 indicators.

Table 1:
Indicators Characterizing Kazakhstan's Industry Digitization in 2023

Region	Volume of industrial production (goods, services) in value terms, thousand USD	Number of ICT professionals, thousand people	Actual number of employees in industry, thousand people	Number of enterprises with automated internal business processes, units	Availability of ICT equipment connected to the Internet, units	Number of enterprises using computers, units	Number of enterprises using the Internet, units	Information and communication technology costs, million USD	Investments in fixed capital in industry, million USD	Profit (loss) before taxation, million USD	Number of employees out of the total number of employees who use a computer with Internet access for work, people
Symbolic indicator designation	VAR00001	VAR00002	VAR00003	VAR00004	VAR00005	VAR00006	VAR00007	VAR00008	VAR00009	VAR00010	VAR00011
Republic of Kazakhstan	103114925	45008	630700	25441	1023625	124305	121439	2040.778	17642.733	32810.38	1137136
Abai	3491750.7	274	21900	231	17520	1528	1474	10.402	436.622	243.529	20720
Akmola	3874680.4	529	28900	1067	29102	4363	4280	11.198	553.416	1074.349	33258
Aktobe	5569310.6	655	44200	233	32657	4182	4023	24.632	1325.982	1200.329	38680
Almaty	3814937.9	338	20700	242	32629	3679	3624	27.698	572.378	630.091	37630
Atyrau	24212597	2545	29600	958	50416	3122	3025	244.385	5222.371	10490.713	53723
West Kazakhstan	7690327.7	635	17000	175	27709	2767	2697	40.047	878.327	3.171	32189
Zhambyl	1883792.5	489	21500	515	20567	2530	2409	8.206	593.378	180.087	24278
Zhetisu	712501.74	351	11200	285	11653	1472	1450	6.607	231.353	72.036	14903
Karaganda	7688442	1407	82100	2360	65015	8147	8105	38.162	1156.273	137.264	76137
Kostanay	5894725.7	737	40100	1295	39437	4482	4393	20.511	601.856	410.202	43417
Kyzylorda	2275334	398	17800	288	18839	1732	1592	10.046	482.609	540.08	22907
Mangistau	6643068.1	471	46600	409	31702	3002	3000	16.394	1359.213	895.362	34558
Pavlodar	6878051.3	1071	60000	1073	41519	4217	4007	52.134	1087.449	679.804	43585
North Kazakhstan	1439037.9	586	12100	354	20466	3202	3149	5.436	138.833	218.198	24175
Turkestan	2224393.7	234	21500	165	25410	3850	3805	11.679	823.453	1881.036	31510
Ulytau	2370830.3	392	28700	128	11828	612	602	14.731	383.756	25.28	12665
East Kazakhstan	5313130.6	856	45300	165	39972	4078	3976	53.812	625.289	584.064	44159
Astana	4308888.1	14284	20800	2922	161113	26392	25942	992.898	571.524	5855.324	175252
Almaty	4493639.7	18106	41300	11538	307429	35302	34464	442.160	341.713	7331.053	330273
Shymkent	2335484.4	650	19400	1038	38642	5646	5422	9.637	256.938	358.404	43117

Source: Compiled based on data from the National Statistics Bureau of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan

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Table 2:
Correlation Analysis Results

Indicator	VAR00001	VAR00002	VAR00003	VAR00004	VAR00005	VAR00006	VAR00007	VAR00008	VAR00009	VAR00010	VAR00011
VAR00001	1	0.047	0.289	0.03	0.07	-0.018	-0.018	0.163	0.961	0.679	0.063
VAR00002	0.047	1	0.059	0.877	0.965	0.983	0.983	0.858	-0.045	0.668	0.964
VAR00003	0.289	0.059	1	0.24	0.198	0.144	0.145	-0.046	0.193	0.005	0.201
VAR00004	0.03	0.877	0.240	1	0.963	0.903	0.901	0.522	-0.081	0.547	0.963
VAR00005	0.07	0.965	0.198	0.963	1	0.977	0.976	0.713	-0.042	0.633	1
VAR00006	-0.018	0.983	0.144	0.903	0.977	1	1	0.808	-0.122	0.59	0.979
VAR00007	-0.018	0.983	0.145	0.901	0.976	1	1	0.81	-0.122	0.589	0.978
VAR00008	0.163	0.858	-0.046	0.522	0.713	0.808	0.81	1	0.101	0.669	0.713
VAR00009	0.961	-0.045	0.193	-0.081	-0.042	-0.122	-0.122	0.101	1	0.672	-0.047
VAR00010	0.679	0.668	0.005	0.547	0.633	0.590	0.589	0.669	0.672	1	0.627
VAR00011	0.063	0.964	0.201	0.963	1	0.979	0.978	0.713	-0.047	0.627	1

Source: Compiled by the authors based on the conducted analysis

When applying the DEA method, it is advisable to use indicators with a high correlation coefficient that reflect key aspects of enterprise digital transformation as input indicators: «Number of ICT professionals»; «Information and communication technology costs»; «Number of employees out of the total number of employees who use a computer with Internet access for work»; «Number of enterprises with automated internal business processes.» We have defined the following as output indicators: «Profit (loss) before taxation»; «Volume of industrial production (goods, services) in value terms.» The number of observations corresponds to the Charns and Cooper empirical criterion:

$$n \geq \max\{m \times s, 3 \times (m+s)\}, \quad (1)$$

where:
n - the number of DMUs;
m - the number of inputs;
s - the number of outputs.

The analysis covers 20 regions of Kazakhstan. With 2 outputs, the number of inputs should not exceed 4. Let us bring the selected indicators to a normalized form relative to the maximum (Table 3).

The impact of input indicators on performance indicators («Volume of industrial production (goods, services) in value terms,» «Profit (loss) before taxation») has been verified using the DEA method with Open Solver.

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Table 3:
Normalized Form of the Selected Evaluation Parameters using the DEA Method

No.	Region	Inputs (X1, X2, X3, X4)				Outputs (Y1, Y2)	
		Number of ICT professionals, people	Information and communication technology costs, million USD	Number of employees out of the total number of employees who use a computer with Internet access for work, people	Number of enterprises with automated internal business processes, units	Volume of industrial production (goods, services) in value terms, thousand USD	Profit (loss) before taxation of enterprises, million USD
1	Abai	0.015133	0.010476175	0.062736	0.144212149	0.023213759	0.0200208
2	Akmola	0.029217	0.01127854	0.100699	0.160027456	0.102409517	0.09247703
3	Aktobe	0.036176	0.024808624	0.117115	0.230017068	0.114418234	0.02019414
4	Almaty	0.018668	0.027895882	0.113936	0.157560043	0.060061799	0.02097417
5	Atyrau	0.140561	0.246133262	0.162662	1	1	0.08302999
6	West Kazakhstan	0.035071	0.040333542	0.097462	0.3176168	0.000302278	0.01516727
7	Zhambyl	0.027008	0.008264692	0.073509	0.077802166	0.017166294	0.04463512
8	Zhetisu	0.019386	0.006654144	0.045123	0.029426903	0.006866602	0.02470099
9	Karaganda	0.077709	0.038435172	0.230527	0.317538921	0.013084377	0.20454151
10	Kostanay	0.040705	0.020657814	0.131458	0.243456977	0.039101461	0.11223782
11	Kyzylorda	0.021982	0.0101183	0.069358	0.093973149	0.051481723	0.024961
12	Mangistau	0.026013	0.016511032	0.104635	0.274364125	0.085348078	0.03544808
13	Pavlodar	0.059152	0.052506657	0.131967	0.284069125	0.064800593	0.09299705
14	North Kazakhstan	0.032365	0.005475328	0.073197	0.059433438	0.020799136	0.03068123
15	Turkestan	0.012924	0.011762644	0.095406	0.091869274	0.179304829	0.01430057
16	Ulytau	0.02165	0.014836697	0.038347	0.097917225	0.00240975	0.01109378
17	East Kazakhstan	0.047277	0.05419733	0.133705	0.219436626	0.055674426	0.01430057
18	Astana	0.78891	1	0.530628	0.177960589	0.558143594	0.25325013
19	Almaty	1	0.445322259	1	0.18559098	0.698813617	1
20	Shymkent	0.0359	0.009705815	0.13055	0.09645741	0.034163973	0.0899636

Source: Compiled by the authors based on the conducted analysis

After normalizing the selected parameters, the weight coefficients for input and output indicators have been optimized (Table 4).

The results in Table 4 demonstrate significant variability in the contribution of factors:

1. The most significant factor for efficiency is process automation (v_4): in 16 out of 20 DMUs, this indicator has a non-zero weight, which indicates its decisive influence on the formation of results.
2. Polarization of output indicators:
   - Profit (loss) before taxation (u_2) is the leading indicator for DMU2 (10.808) and DMU10 (8.910);
   - Volume of industrial production (goods, services) in value terms (u_1) is significant only for DMU9 (76.387) and DMU17 (17.962).
3. Zero weights indicate low effectiveness of spending on information and communication technologies v_2.

The weights given in Table 4 provide the highest θ-efficiency (Table 5).

Table 4:
Results of Weight Determination Based on the Open Solver Software

DMU	v_1 (Number of ICT professionals, people)	v_2 (Information and communication technology costs, million USD)	v_3 (Number of employees out of the total number of employees who use a computer with Internet access for work, people)	v_4 (Number of enterprises with automated internal business processes, units)	u_1 (Volume of industrial production (goods, services) in value terms, thousand USD)	u_2 (Profit (loss) before taxation of enterprises, million USD)
1	0	0	0	6.934	0	0
2	0	0	0	6.249	0	10.808
3	0	0	0	4.348	0	0
4	0	0	0	6.346	0	0
5	0	0	0	1	1	0
6	0	0	0	3.148	0	0
7	0	0	13.626	0	0	0
8	0	0	22.224	0	0	0
9	0	0	0	0	76.387	0
10	0	0	0	4.108	0	8.91
11	0	0	0	10.641	0	0
12	0	0	0	3.644	0	0
13	0	0	0	1	0	9.298
14	0	0	0	16.824	0	0
15	0	0	10.48	0	5.577	0
16	0	0	26.099	0	1	0
17	0	0	0	0	17.962	0
18	1.267	0	0	0	0	0
19	1	0	0	0	0	1
20	0	0	0	10.368	0	0

Note: *- A zero weight may indicate that when optimizing the efficiency of a specific DMU this indicator does not contribute to the result, which does not mean that it is completely irrelevant for the entire sample.

Source: Compiled by the authors based on the conducted analysis

Table 5:
θ-efficiency and Status

DMU	θ-efficiency	Status
1	0.148	Significant growth potential
2	1	Optimal result
3	0.217	Needs optimization
4	0.305	Needs optimization
5	1	Optimal result
6	0.001	Significant growth potential
7	0.092	Significant growth potential
8	0.038	Significant growth potential
9	1	Optimal result
10	0.852	Acceptable level
11	0.478	Average level
12	0.312	Needs optimization
13	1	Optimal result
14	0.586	Moderate level
15	1	Optimal result
16	0.023	Significant growth potential
17	1	Optimal result
18	1	Optimal result
19	1	Optimal result
20	0.401	Average level

Source: Compiled by the authors based on the conducted analysis

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Table 5 shows that there is a polarization of efficiency: 40% of DMUs (8 out of 20) operate optimally; 25% (5 out of 20) demonstrate low efficiency (DMU1, DMU6, DMU7, DMU8, DMU16). DMUs with $\theta < 0.5$ need immediate optimization.

A systemic problem for all regions is the low return on ICT costs. High ICT costs combined with unprofitable production indicate that the mechanisms used for digital transformation of enterprises are ineffective. It is necessary to develop an organizational and technical mechanism for the development of industrial enterprises that would effectively use ICT infrastructure and automation and ensure an increase in production volumes and profits.

4.2. Examples of Digital Transformation of Kazakhstani Industrial Enterprises

The digital transformation of industry is a strategically important direction for developing Kazakhstan's economy, aimed at enhancing enterprise efficiency and competitiveness. From 2019 to 2023, the number of enterprises using computers increased by 13.8% (growing from 109.172 to 124.305), and the number of enterprises with internet access increased by 15% (growing from 105.531 to 121.439). Notably, enterprises' expenditure on information and communication technologies grew more than 24-fold during this period (Bureau of National Statistics, 2023).

Enterprises must develop their own information technologies, automate internal business processes, and implement RFID technologies. Nevertheless, many industrial enterprises in the Republic of Kazakhstan are already successfully adapting digital solutions to their activities. Examples include model digital factories such as AK Altynalmas JSC, a gold mining enterprise. Its enterprises are in the Karaganda, Akmola, and Zhambyl regions. AK Altynalmas JSC has implemented a production management system based on the Internet of Things platform, which collects production data available to company divisions in real time. The platform creates digital applications and system diagnostics and is integrated with ERP, SCADA, and the company's information systems. These digital solutions allow for better production management, reduced costs, and a faster response to changes in the production process.

Another example is Himfarm JSC (Shymkent). The company has implemented a digital Smart Maintenance system that predicts possible breakdowns in the technological process and plans to repair work accordingly. Their digital solutions plan the technical and financial aspects.

The KARLSKRONA LC AB machine-building plant in Uralsk has implemented a system that facilitates work with customers digitally, from order acceptance to completion of all operations. This digital format allows for operation and customer base analysis, as well as the optimization of customer relations. The plant also uses a 3D modeling system for its manufactured equipment and products, reducing design time, increasing accuracy, diminishing costs, and taking customers' individual needs into account (Ministry of Transport of the Republic of Kazakhstan, 2021).

Bal Textile LLP (Shymkent) has optimized its business processes using new technologies such as cloud services and the Internet of Things. The Almaty Fan Plant LLP has implemented a digital line for high-precision metal processing. Eurasian Foods JSC adopted the SAP ERP enterprise management system to reduce costs.

Kentau Transformer Plant JSC uses a robotic complex and augmented reality technologies for staff training (Kulzhambekova et al., 2023, p. 138). At the Kachar site of the Sokolovsk-Sarbai Mining and Processing Production Association, JSC, implementing digital technologies has automated industrial processes and the monitoring system, minimized failures and downtime while decreased electricity consumption and increasing labor productivity (Aubakirova et al., 2020).

4.3. A Study of an Existing Enterprise Management Mechanism in the Context of Digital Transformation: The Case of the Kazakh-German Joint Venture Boehmer Armatura LLP

The digital transformation of industrial enterprises is particularly important for improving competitiveness and achieving sustainable development. Introducing digital technologies and modern organizational and technical mechanisms through joint ventures with advanced technology and access to international experience and knowledge bases is significant. In this regard, analyzing an existing management mechanism using the Kazakh-German joint venture Boehmer Armatura LLP as an example is particularly interesting. This will enable us to identify successful management and technological solutions that can be replicated in other Kazakhstani industrial enterprises.

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It is important to note that creating joint ventures is common in the Republic of Kazakhstan. Typically, they are equipped with advanced technologies and equipment and use modern information technologies. The parent company applies its established corporate connections and relationships with suppliers and contractors to newly created enterprises in Kazakhstan. Proven, successful German technologies, for example, can be replicated in other countries. This allows for the standardization of services and equipment, reduction of costs and parts, and simplification of operations.

Joint ventures utilize the parent company's well-developed training and professional development systems to adapt personnel to new industries and technologies. The parent company supplies high-quality, complex materials from Germany. Less critical materials can be produced locally from local raw materials. It should be noted that these production facilities already use Industry 4.0 technologies and are prepared for further development and transition to Industry 5.0 technologies. These technologies can be adapted based on German experience or developed jointly in Kazakhstan. Using foreign equipment that meets the highest environmental standards improves the environment and investment climate and creates export-oriented products.

One example of such a production company is Boehmer Armatura LLP, a ball valve manufacturing company. Its headquarters are in Germany. Boehmer Armatura LLP is the sole official representative of BÖHMER GmbH and Boehmer Armatura LLP in the Republic of Kazakhstan and the countries of the Eurasian Economic Union. The company employs over 20 professionals and has four branches in Kazakhstan's largest cities. In its 11 years of operation, the company has sold over 4,500 ball valves in Kazakhstan (Vasiliev, 2025).

Taking into account such a high level of quality provided by Bemer Armatura LLC in the production of shut-off valves, the company has no competitors either in the territory of the Republic of Kazakhstan or within the Eurasian Economic Union. The share of Bemer Armatura LLC products in the shut-off valves market of the Republic of Kazakhstan is 5%.

Table 6 shows that the company's revenue is growing. From 2021 to 2024, revenue increased by 8709.61 thousand USD, net profit increased by 2334.05 thousand USD.

Table 6:
Dynamics of income and net profit of Bemer Armatura LLC, thousand USD

Year	Income	Net profit
2021	6133.96	1641.98
2022	7171.83	1342.92
2023	11648.28	2148.26
2024	14843.57	3976.03

Source: Compiled by the authors based on the data of the enterprises

At Boehmer Armatura LLP, the design and engineering stages are digitized, but the organizational stages are not. Currently, there is no need to implement the expensive plant management system used by the parent company in Germany.

To improve management efficiency, a digital platform that provides centralized control over equipment and production processes, regardless of their geographical location, could be used (Figure 1). The digital ecosystem is based on a digital platform that connects different categories of users (e.g., managers, executors, contractors, and customers) with digital services. The platform's structural components are presented in TOGAF style: Business architecture; Applied Architecture; Data Architecture; Technology Architecture.

Within the business roles of the digital ecosystem, management implements the strategic level through decision-making based on analytical information presented in KPI dashboards. Operational employees who perform production functions directly interact with the digital platform through mobile applications. External contractors connect to the processes via a specialized order portal. Customers access digital services through a web portal and notification system. Business processes on the digital platform include forecasting market demand using the platform's analytical tools; monitoring the product life cycle at all stages; analyzing and optimizing chains based on the platform's data and algorithms; managing orders based on business services integrated into the platform. Business roles interact with business services, and the necessary requirements are transferred to the application architecture.

The application architecture illustrates the operational modules of the digital platform. Management from BÖHMER GmbH's head office in Germany is carried out via a remote management

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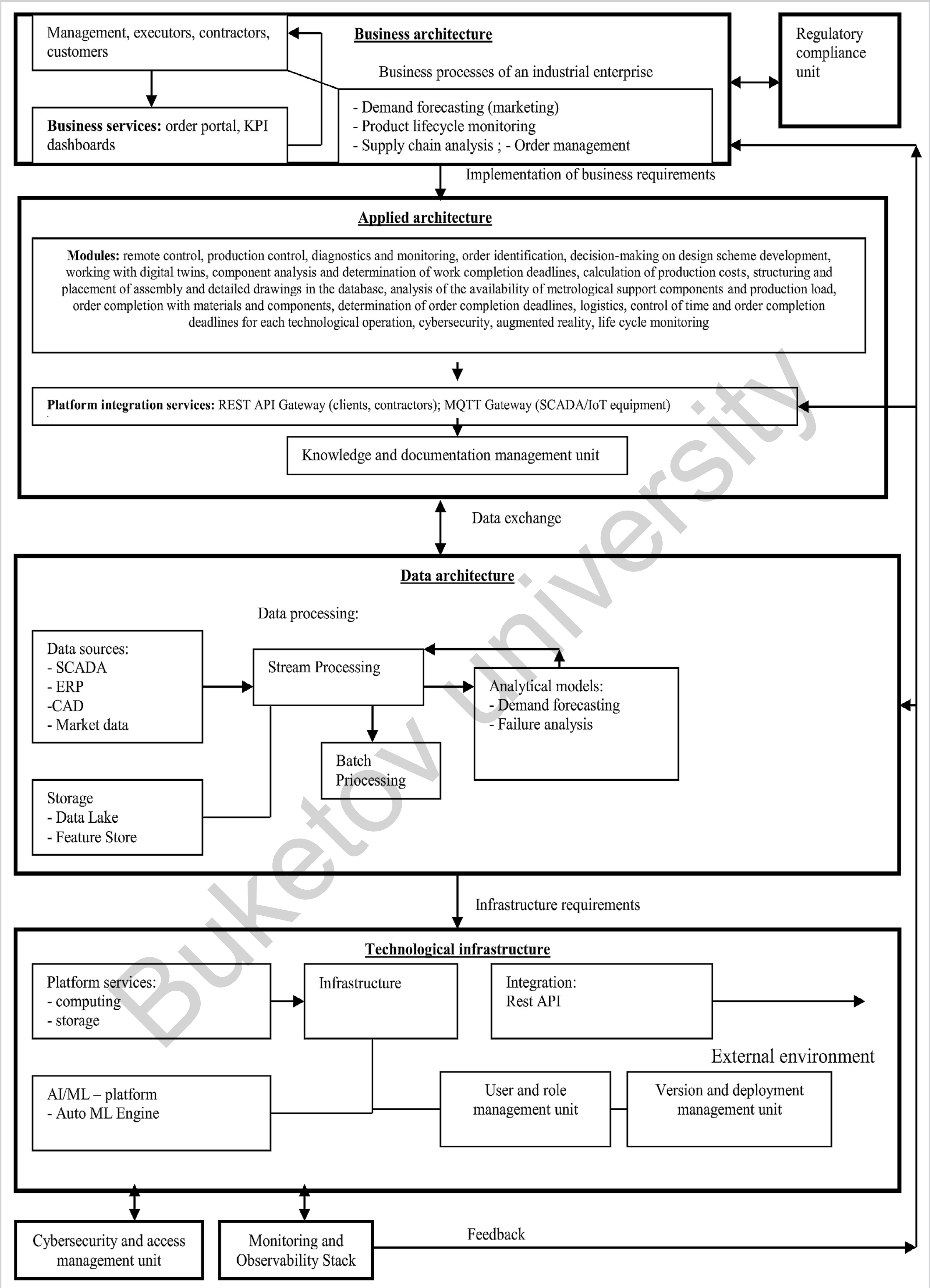

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Figure 1:
Diagram of the Digital Ecosystem Remotely Controlling the Operations of Boehmer Companies located in Germany, the USA, and Kazakhstan
Source: Developed by the authors

module. The following integration services are used: The REST API Gateway interacts with customers and contractors, and the MQTT Gateway connects industrial equipment (SCADA/IoT).

These modules transfer results to the data level. Data architecture comprises industrial systems (SCADA, MES, and ERP), design systems (CAD/CAM), and market data as data sources. Data processing takes place in stream processing (current data processing) and batch processing (long-term data processing).

Stream processing and storage are linked via a central processor. Operational data is stored in the data lake, while data for machine learning is stored in the feature store. Processed data goes to analytical models for demand forecasting and production process optimization.

Technological architecture provides the technical foundation for the digital platform to function. This architecture includes the infrastructure that supports the digital platform's operation, an AI/ML platform that enables machine learning model creation, and integration mechanisms (REST API and MQTT) that connect external systems.

Figure 1 illustrates the stages of creating ball valves, from marketing to finished products. As the technological process progresses, information from one module is transferred to the next. Processes are optimized based on feedback. The augmented reality module is necessary for creating a virtual environment for staff training, presentations, and demonstrations. Note that BÖHMER GmbH, the parent company in Germany, is a member of the voluntary alliance Plattform Industrie 4.0. Using a digital platform to manage Böhmer's German, American, and Kazakhstani companies enables them to participate in the German digital platform, Plattform Industrie 4.0, and reap its benefits (Table 6).

Table 7:
Potential Effects of Creating and Integrating a Digital Platform for the Karaganda Representative Office of Boehmer Armatura LLP into the German Platform Industrie 4.0 Ecosystem

No.	Advantages
1	Collecting large-scale, detailed data in real time for analysis and forecasting
2	Gaining a better understanding of the company's potential and identifying opportunities for developing new products, as well as the company's current position and potential, which contribute to more effective management decisions
3	Remote equipment and maintenance management with software and equipment management platforms
4	Vertical and horizontal integration technologies combine data arrays obtained from equipment into a cloud database, ensuring that user information is updated
5	Cloud data connects the entire value chain, providing software for calculating all financial settlements
6	Segmentation of customers based on differentiated needs and a precise understanding of their service requirements
7	Reduction of unplanned downtime
8	Quick troubleshooting
9	Improved equipment setup speed and time
10	Increased speed of production tasks
11	Standardization of work processes achieve greater efficiency and effectiveness in production
12	Possible use of AI technology in decision-making processes
13	Through better demand forecasting, optimal inventory levels can be maintained in warehouses
14	The ability to quickly connect new modules. System flexibility, i.e., the ability to easily adapt to external and internal environmental requirements
15	Increased revenue and reduced costs

Source: Developed by the authors based on the analysis

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Thus, integrating the Kazakh company Boehmer Armatura LLP into the German company's unified digital platform optimizes asset management and opens access to the Platform Industrie 4.0 ecosystem. This enables the implementation of key digital platform advantages, such as remote equipment control, process standardization, and reduced production costs.

4.4. Development of an Organizational and Technical Mechanism for the Development of Industrial Enterprises in the Context of Digital Transformation in Kazakhstan

An organizational and technical mechanism for the development of industrial enterprises in the context of digital transformation has been developed based on an analysis of literary sources, an assessment of the relative efficiency of industry (DEA), and a study of the characteristics of the Boehmer industrial enterprise (Figure 2).

The basis of the digital ecosystem will be a digital platform that uses artificial intelligence to provide information collection, storage, analytics, visualization, and processing.

The purpose of the organizational and technical mechanism is to ensure the effective functioning and development of the enterprise through the integration of digital technologies and the optimization of business processes.

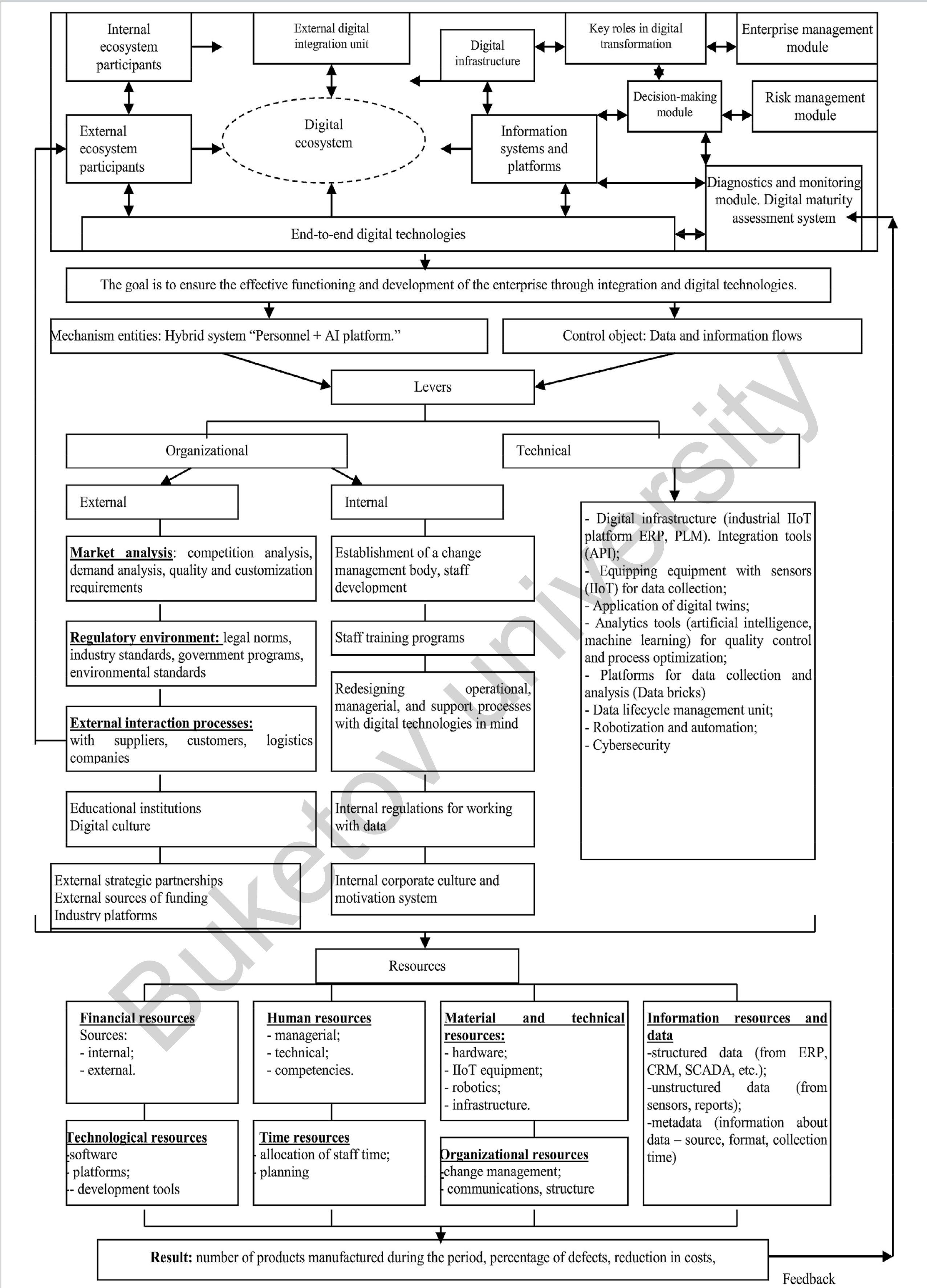

Figure 2:
Organizational and Technical Mechanism of Industrial Enterprise Management in the Context of Digital Transformation
Source: Developed by the authors

Consider the levers of influence of the mechanism's subjects («Personnel + AI platform») on the object of management («Data and information flows»). Technical levers will include digital infrastructure (e.g., an industrial Internet of Things (IoT) platform, Enterprise Resource Planning (ERP), and Product Lifecycle Management (PLM), integration tools (Application Programming Interface (API)), sensors for data collection, digital twins, and analytics tools (e.g., artificial intelligence and machine learning) for quality control and process optimization. Other technical levers include platforms for data collection and analysis (Data Bricks), robotization, automation, and cybersecurity.

The organizational levers of the mechanism will be divided into external and internal levers. External levers will primarily include sales market analysis, competition analysis, demand analysis, quality requirements, and customization. Based on competitors' actions, their implementation of innovations, and changes in customer needs and requirements, decisions will be made regarding the need to create or improve company products using digital technologies. The necessary parameters and properties of the products and the required equipment will be determined. The company's goals will be formulated. BI systems, CRM systems, marketing research, big data analysis, and SWOT and PESTLE analyses can be used for this purpose.

The external levers of the organizational mechanism include the regulatory environment, such as legal norms, industry standards (e.g., cybersecurity), state programs that support digitalization in enterprises, and environmental standards. ESG assessment and regulatory compliance analysis can be applied here.

Internal organizational levers of the mechanism include creating a change management body, forming appropriate personnel, and training and retraining personnel. Other levers include reengineering operational, managerial, and support processes with digital technologies; introducing flexible management systems; establishing internal regulations for working with data and cybersecurity compliance; and developing an internal corporate culture and motivation system.

Resources are needed to implement the organizational and technical mechanism for developing an industrial enterprise in the context of digital transformation. The main types of resources are financial, human, material, technical, technological, temporal, organizational, and informational.

This mechanism will be a feedback mechanism for the development of an industrial enterprise in the context of digital transformation. After receiving the results, the data will be transferred to the «Diagnostics and Monitoring Module».

There, data in the digital ecosystem will be systematized and visualized. Deviations will be identified and their causes analyzed. Decisions will then be transferred to the «Production Management Module».

5. Discussions

The study confirmed the importance of creating effective organizational and technical mechanisms to support the digital transformation of industrial enterprises in Kazakhstan. A review of theoretical approaches and domestic experience revealed that the digital transformation of enterprises involves complex changes in technical and organizational components.

The developed organizational and technical mechanism structure considers the specifics of Kazakhstani industry, including the experience of joint ventures, such as Boehmer Armatura LLP, and modern digital technologies, such as digital platforms and AI-based analytics tools.

A distinctive feature of the proposed mechanism is its inclusion of feedback elements and a digital ecosystem based on AI, allowing the digital transformation process to become continuous and adaptive. This aligns with modern trends identified in the works of Kapustina and Kondratenko, who emphasize the need to develop high-tech industries that can self-develop.

It is important to note that the proposed organizational and technical mechanism is based on the practical experience of the Boehmer Armatura LLP joint venture, which increases its practical value.

However, the developed mechanism requires further practical adaptation, considering industry specifics, the level of enterprises' digital maturity, and personnel readiness.

6. Conclusion

Theoretical analysis has shown that digital transformation directly impacts the production and economic efficiency of enterprises. However, successful implementation requires an effective organizational and technical mechanism.

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The results of the efficiency assessment using data envelopment analysis (DEA) revealed a low return on information and communication technology (ICT) costs, indicating insufficient effectiveness of the mechanisms used for enterprises' digital transformation. These results confirm the need for a comprehensive organizational and technical approach that aims to use ICT infrastructure more efficiently to increase production volumes and profitability. Based on an analysis of theoretical sources and the practical experience of Boehmer Armatura LLP, as well as the results of a quantitative analysis, we have proposed an organizational and technical mechanism for developing industrial enterprises that focuses on effectively integrating digital technologies. This mechanism includes technical and organizational levers and provides feedback and continuous process improvement to increase the efficiency of digital resource use.

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