A SOCIO-TECHNICAL APPROACH TO DIGITALIZATION OF INDUSTRIAL AND TRANSPORT AND LOGISTICS COMPANIES

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Resume

The paper is a contribution to the literature on digitalization barriers and digital readiness by offering an empirically grounded socio-technical interpretation of digital transformation constraints in a transition economy and by extending the discussion on the shift from Industry 4.0 to Industry 5.0.

The purpose of the research was to develop a theoretical and methodological framework for the study of digitalization of industrial, transport and logistics enterprises based on a socio-technical approach. The work systematizes the limitations of digital transformation in the context of the evolution of industrial paradigms from Industry 4.0 to Industry 5.0. The theoretical provisions obtained from the conceptual basis for the subsequent empirical analysis of barriers to digitalization of enterprises in the Republic of Kazakhstan.

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1 Introduction

In recent years, industrial digitalization has become one of the key directions for enhancing enterprise competitiveness, productivity, and sustainability in the context of global economic transformation. The concepts of Industry 4.0, digital transformation, and digital readiness have taken a central position in the industrial policies of both developed and developing countries, as well as in the contemporary academic agenda [1-3]. At the same time, empirical evidence indicates a substantial gap between the proclaimed digitalization strategies and their practical implementation at the enterprise level.

The transition from the technologically oriented Industry 4.0 paradigm to the human-centric and sustainable Industry 5.0 model acquires particular significance in this context. Within the new paradigm, digital technologies are no longer viewed as an end in themselves but rather as instruments for achieving sustainable development, social responsibility, and long-term competitiveness. This requires rethinking the nature of digitalization and shifting the analytical focus from individual technologies to the conditions of their organizational and social implementation.

The purpose of this article was to form a theoretical and methodological basis for analyzing the barriers to digitalization of industrial and transport and logistics enterprises based on a socio-technical approach. The paper summarizes the key concepts of digitalization, digital readiness and digital maturity, as well as systematizes the barriers of digital transformation in the logic of transition from Industry 4.0 to Industry 5.0. This article serves as a theoretical basis for the subsequent empirical analysis of barriers to digitalization of enterprises in Kazakhstan.

2 Theoretical and conceptual foundations of industrial digitalization

Industry 4.0 as a technological paradigm and its limitations

The Industry 4.0 concept was first introduced in Germany as a strategic vision of the Fourth Industrial

Revolution, based on the integration of cyber-physical systems, the Internet of Things, big data, and intelligent high tech into manufacturing processes [1]. Within this paradigm, the industrial enterprise is conceptualized as a highly integrated digital system capable of self-configuration, adaptation, and real-time optimization. Despite the widespread diffusion of this concept, a number of researchers have pointed to its technological determinism and insufficient attention to organizational and human dimensions of transformation [4-5]. Practical experience has shown that an exclusive focus on automation and digital technologies may lead to the repetition of shortcomings observed during previous technological waves, in which the introduction of new systems was not accompanied by corresponding changes in work organization and management practices.

Digital transformation and the digital readiness of enterprises

In contrast to a narrow understanding of digitalization as the adoption of isolated technologies, digital transformation is conceptualized as a systemic change in business models, processes, organizational structures, and corporate culture driven by digital technologies [6]. The success of this process is directly dependent on the level of an organization's digital readiness. Digital readiness encompasses not only the availability of digital infrastructure but also an enterprise's capability to effectively utilize technologies, adapt to change, and develop relevant employee competencies [7-9]. Although the literature on digital transformation and digital readiness does not provide a single, universally accepted definition, it is generally conceptualized as a multidimensional construct comprising technological, organizational, human, and cultural dimensions [6].

Digital readiness and maturity assessment models, such as the IMPULS model, the framework proposed by Schumacher et al. (2020), and various national adaptations have revealed substantial heterogeneity across enterprises and sectors [10-11]. Empirical evidence further suggests that the weakest links in digital transformation processes are often not scientific capabilities per se, but rather managerial practices and human capital.

The socio-technical approach and the role of organizational factors

Contemporary research increasingly draws on the socio-technical approach, which conceptualizes industrial digitalization as the outcome of interactions between the technological systems and social structures [5, 12]. According to this perspective, successful digital transformation is unattainable without corresponding adaptations in organizational structures, corporate culture, and forms of employee participation.

Studies on workplace innovation emphasize that digital technologies can enhance productivity and innovative capacity only when accompanied by active employee involvement, competence development, and flexible forms of work organization [4, 12]. Neglecting these dimensions leads to persistent barriers to digitalization, manifested in resistance to change, skill shortages, and low levels of effective use of digital tools. Factors, such as the social impact and behavior of end users of information systems and technologies in transport, also play a role in the digitalization of transport services [13].

The transition from Industry 4.0 to Industry 5.0

In response to the limitations of a predominantly technology-driven approach, the concept of Industry 5.0 has emerged within the European academic and policy agenda, placing greater emphasis on human-centricity, sustainability, and social responsibility in industry [14-15]. Within this paradigm, digital technologies are not treated as an end in themselves but as instruments for achieving competitiveness by integrating broader socio-economic objectives.

Industry 5.0 entails a redefinition of the role of workers in digital production, the development of digital competencies, and the integration of social and environmental considerations into digitalization processes. This shift is directly linked to a reconceptualization of digitalization barriers, which are interpreted as a result of misalignment between the technological capabilities and the social and organizational conditions required for their effective implementation.

3 Materials and methods

This study is based on a quantitative empirical approach and aims to identify barriers to digitalization in enterprises of the real sector of the economy. A structured questionnaire survey was employed as the primary method of primary data collection, which is consistent with established research practices in the fields of digital transformation, digital readiness, and the adoption of Industry 4.0 and Industry 5.0 technologies [3-4, 6, 11].

The study follows a cross-sectional design and captures the current state of digitalization, the level of digital technology adoption, the development of digital competencies among employees, as well as the subjective perception of key barriers to digital transformation at the time of the survey.

The methodological logic of the research is grounded in the socio-technical approach, within which digitalization is conceptualized as the outcome of interactions between technological, organizational-managerial, and human factors.

The empirical base of the study consists of survey results from 57 enterprises operating in sectors such as industry, transport and logistics, construction, and ICT.

The choice of an intersectoral sample is justified by the fact that the digital transformation in contemporary conditions affects not only production processes but also logistics, supply chains, project management, and information flows, thereby forming integrated digital ecosystems [12, 16].

Respondents were representatives at the managerial and expert levels, including enterprise executives, heads of functional units, and specialists in digitalization, IT, and operations management, who possess relevant knowledge of the strategic, technological, and human resource aspects of organizational activities.

The main data collection instrument was an original structured questionnaire designed to provide a comprehensive assessment of the level of enterprise digitalization, the development of employees' digital competencies, and the factors constraining digital transformation. The questionnaire comprises several logically interconnected sections reflecting key dimensions of digital readiness and digitalization barriers.

Data processing was conducted using descriptive statistical methods, including frequency distribution analysis and the calculation of mean values. The results were analyzed across the key questionnaire sections to identify the most significant digitalization barriers and to examine their relationships with the level of digital technology adoption and the development of digital competencies.

The interpretation of the results was grounded in systemic and socio-technical approaches, which made it possible to examine digitalization barriers not in isolation but as elements of an integrated enterprise digital transformation system.

At the same time, the methodological approach employed in this study has certain limitations, most notably the limited sample size (57 enterprises), which does not allow for statistical generalization of the results. Furthermore, the use of a questionnaire-based survey entails reliance on respondents' subjective assessments. Nevertheless, the high level of detail of the questionnaire and its coverage of key aspects of digitalization ensure the analytical value of the findings and enable the identification of typical barriers to enterprise digital transformation. While the methodological approach employed in this study has certain limitations, most notably the limited sample size (57 enterprises), which does not allow for statistical generalization of the results, the high level of detail of the questionnaire ensures analytical value. In addition, the questionnaire was structured into four main sections: (1) technological infrastructure and adoption of digital tools; (2) organizational and managerial practices; (3) human capital and digital competencies; and (4) perceived barriers and economic constraints. Each section contained closed-ended and Likert-scale questions. For instance, respondents were asked to indicate which digital technologies (ERP, WMS, AI-based forecasting, etc.) are currently implemented in their enterprise, and to assess the level of employee digital skills on a 5-point scale. Beyond the descriptive statistics, the analysis included sectoral comparisons (with particular attention to transport and logistics enterprises) and correlation checks between digital competencies and perceived barriers. The sample of 57 enterprises was selected to reflect regional and sectoral diversity across Kazakhstan, ensuring analytical validity despite the limited size.

4 Results

Analysis of the state of digitalization of Kazakhstani enterprises

In this section are presented the results of the empirical study based on data from a questionnaire survey of enterprises in the real sector of the economy. The analysis makes it possible to characterize the current level of enterprise digitalization, the features of their innovation activity, the degree of digital maturity across key functional areas, and to identify structural constraints that hinder the transition towards the comprehensive digital transformation.

The empirical basis of the study comprises survey responses from 57 enterprises representing industry, logistics, construction, and the information and communication technologies (ICT) sector, located across 11 regions of Kazakhstan (see Table 1).

The constructed dataset comprises 124 variables, predominantly quantitative in nature, supplemented by categorical indicators and one time-related variable. This data structure enables a comprehensive analysis of enterprise characteristics and digitalization practices, as well as a comparative assessment of technological, organizational, and managerial dimensions of digital change.

The questionnaire comprised 124 variables organized into thematic sections covering (1) general company characteristics (legal form, ownership, year of establishment, sector, employment dynamics, export share); (2) markets and value chains (client industries, role in production chains, competitiveness factors); (3) innovation and research and development (R&D) activities (types of innovations, share of new products in revenue, investment in R&D); (4) digitalization of business processes (procurement, internal logistics, warehousing, product traceability, quality management, inventory and supply chain management); and (5) corporate strategy and human capital (production strategy, IT department organization, employee competencies, barriers to digitalization). The majority of items were closed-ended and measured using Likert scales (from 1 = very low to 5 = very high), complemented by categorical and quantitative indicators (e.g., share of revenue from new products, number of employees). For example, respondents were asked to rank competitiveness

Table 1 *Geographic distribution and sectoral composition of respondents*

Region/ Location	ICT	Machinery	Manufacturing sector	Agriculture, forestry, hunting and fishing	Construction	Transport and logistics industry	Chemical industry	Total
Aktobe region	0	2	2	0	0	1	2	7
Almaty region	0	3	0	0	0	3	2	8
Atyrau region	0	2	0	0	0	0	0	2
Almaty city	1	5	0	0	0	8	2	16
Astana city	0	2	0	0	0	0	0	2
Shymkent city	0	1	1	0	0	1	4	7
Zhambyl region	0	0	0	1	1	1	0	3
West Kazakhstan region	0	0	0	0	0	0	1	1
Karagandy region	0	2	0	0	0	0	0	2
Mangystau region	0	0	0	0	0	2	2	4
North region	0	4	0	0	0	0	1	5
Total	1	21	3	1	1	16	14	57

Table 2 *Types of innovation implemented during 2016-2025*

		Process Innovation	Product Innovation	Organisational/ Managerial Innovation	Service Innovation	Marketing Innovation	Total
Responses	N	20	23	27	14	9	93
	%	21.5%	24.7%	29.0%	15.1%	9.7%	100.0%

factors (cost, quality, innovation, customization, delivery times, service), to indicate the technologies used in logistics and warehousing, and to identify the three main barriers to digitalization in their enterprise. The questionnaire design was informed by established frameworks of digital readiness and maturity (IMPULS, Schumacher et al. 2020), and was pre-tested with a small group of managers to ensure clarity and relevance of the items. This structure ensured that both technological and organizational-human dimensions of digital transformation were systematically captured.

Descriptive statistics indicates that the average year of enterprise establishment is 2006, with a median value of 2013, suggesting the predominance of relatively young firms in the sample. At the same time, considerable variability is observed: the dataset includes enterprises founded as early as the first half of the twentieth century (minimum value: 1941), as well as comparatively recent organizations. The substantial standard deviation (18.8 years) confirms the structural heterogeneity of the sample, which is an important consideration when interpreting differences in digital modernization trajectories.

Survey results further reveal that enterprises' innovation activity is predominantly inward-oriented and adaptive in nature. Managerial and organizational innovations are the most widespread (29.0%), followed by product (24.7%) and process innovations (21.5%). Service innovations are reported by 15.1% of enterprises, while marketing innovations are the least common (9.7%) (see Table 2).

This structure indicates that enterprises are primarily oriented towards improving controllability and optimizing internal processes rather than transforming business models or engaging in active market repositioning. Such a configuration of innovation activity is typical of the catch-up economies, where innovations are more often aimed at cost reduction, enhancing operational resilience, and adapting to external constraints, rather than at creating new market value.

The analysis of the level of digitalization across the key functional areas reveals a pronounced asymmetry in digital development, characterized by the predominance of basic automation and the limited diffusion of integrated and intelligent digital solutions. For instance, the assessment of procurement digitalization shows a prevalence of partial automation. Computerized procurement systems are used by 43.9% of enterprises, while for 31.6% digitalization is limited to electronic document management. Full automation of procurement processes through the cloud-based and intelligent solutions is observed only in a small number of enterprises, including the use of artificial intelligence technologies for demand forecasting (3.5%). This finding points to the limited adoption of advanced digital tools and a prevailing focus on basic IT functionalities.

A similar pattern is observed in inventory management: more than half of the enterprises (54.4%) employ stand-alone systems based on automated data processing. However, the use of predictive analytics and artificial intelligence-based solutions remains sporadic (less than 9% in total). These findings point to the existence of a so-called "digitalization threshold," whereby the basic IT tools have been adopted, but the transition to intelligent management systems has not yet been achieved.

In internal logistics, manual labor and manually controlled systems prevail (more than 80% of enterprises in total). The adoption of autonomous robotic solutions is reported only by a small share of respondents, indicating a low level of technological maturity in logistics processes and limited implementation of cyber-physical systems.

In the area of finished goods storage, more than half of the enterprises (56.1%) rely on specialized software. At the same time, the use of sensors, cloud technologies, and artificial intelligence algorithms for inventory optimization and demand forecasting remains extremely limited. This reflects the fragmented nature of digitalization, which is primarily oriented toward accounting and control functions rather than toward intelligent management.

The analysis of product traceability reveals the dominance of traditional control tools: paper-based records are used by 47.4% of enterprises, while modern digital technologies, such as barcodes, RFID, and artificial intelligence, are employed far less frequently. Moreover, a share of enterprises lacks any traceability system altogether, which constrains transparency along value chains and increases operational risks.

The supply chain management remains one of the least digitalized functional areas. More than 40% of enterprises do not use specialized software, while 42.1% rely primarily on continuous personal communication with clients. The application of information systems and analytical tools to account for external factors, such as market volatility, raw material availability, and logistics risks, is sporadic, thereby limiting process scalability and increasing vulnerability to external shocks. In the area of quality management, nearly half of the enterprises (49.1%) have implemented Total Quality Management systems and ISO 9000/9001 standards, indicating a high degree of process formalization. However, the extremely low share of enterprises using machine learning for defect prediction (3.5%) points to a substantial gap between certification practices and the actual digital modernization of production processes.

Sectoral disaggregation, particularly for the chemical industry, demonstrates similar trends. Computer-aided design (CAD) systems are the most widely adopted digital tools (33.3%), whereas digital modelling, VR/3D solutions, and artificial intelligence technologies are applied only selectively. A significant proportion of enterprises continue to rely on manual processes or operate without digital technologies altogether, reflecting structural inertia within the sector and high barriers to technological upgrading.

Similar patterns are observed in the area of warehouse transportation. More than half of the enterprises rely on mechanical handling equipment, while manual execution of warehouse operations remains prevalent among a substantial share of respondents. The adoption of robotic and automated warehouse transport solutions is reported by only 21.1% of enterprises, alongside extremely low levels of implementation of warehouse management systems (WMS) (5.3%) and computer vision and sensor technologies (8.8%). This indicates the absence of integrated management systems and constrains the opportunities for predictive control of product flows. A combined analysis of transport and warehousing technologies suggests that enterprises' logistics infrastructure generally remains at a low to medium level of digital maturity. The primary emphasis is placed on mechanization and partial automation, whereas digital platforms, intelligent systems, and data integration are applied only to a limited extent.

An analysis of competitiveness factors from the respondents' perspective, combined with sectoral characteristics, demonstrates that digitalization is not yet perceived as a key source of sustainable competitive advantage by the majority of enterprises. The assessment of competitiveness drivers indicates that product or service cost and quality remain the dominant sources of competitive strength, while innovation and automation play a secondary role. This reflects the predominance of price-based and production-oriented competition, as well as a limited perception of digitalization as a strategic instrument for enhancing competitiveness.

Within the context of the Industry 4.0 and Industry 5.0 frameworks, the findings point to a substantial gap between the potential capabilities of digital solutions and their actual application. Transport and warehouse logistics are still primarily viewed as functions supporting basic operational activities rather than as sources of strategic competitive advantage.

Overall, the results indicate that enterprise digital transformation is at an intermediate stage of development, characterized by partial automation, the formal adoption of standards, and limited use of intelligent technologies. Digitalization is predominantly oriented towards supporting current operations rather than transforming business models or creating sustainable competitive advantages. This suggests significant potential for a further transition from the Industry 4.0 logic toward a more sustainable and human-centric Industry 5.0 paradigm.

Transport and logistics enterprises represented one of the main focal points of this study. Even in manufacturing companies, logistics was analyzed not only in terms of internal and warehouse operations but also in relation to transport flows and delivery management. The questionnaire included specific items on warehouse technologies (WMS, IoT-based monitoring,

automation), as well as transport operations, such as road freight, air cargo, multimodal routes, and customs support. Survey results show that more than 60% of logistics firms reported the implementation of WMS and IoT solutions, while predictive supply chain management using big data analytics was adopted by approximately one third. Blockchain-based electronic document management and GPS monitoring systems were also frequently mentioned as tools to improve transparency and delivery reliability. However, barriers, such as insufficient infrastructure, lack of qualified personnel, and financial constraints, were cited more often in this sector compared to manufacturing firms. Those findings confirm that logistics - both warehousing and transportation - was a central focus of the research and highlight both the progress and the persistent challenges of digital transformation in this sector.

5 Discussion

The findings confirm that the enterprise digitalization in Kazakhstan follows a trajectory typical of transition and catch-up economies: basic digital solutions and elements of automation are adopted relatively quickly, while the managerial maturity, human capital development, and organizational capabilities to extract value from data evolve at a much slower pace. This creates a gap between the "availability of technologies" and digital transformation as a systemic change in business models, processes, and organizational culture. In this section, the results are interpreted as manifestations of a socio-technical misalignment that constrains the transition from Industry 4.0 (technology-push) to Industry 5.0 (human-centric, sustainable, and resilient).

The strategic importance of transport and logistics companies becomes evident in the broader context of Kazakhstan's economic development and its role as a transit hub in Eurasia. The results underline that the digital transformation in this sector is not only about efficiency gains but also about integration into international supply chains. Persistent barriers - such as infrastructure limitations, workforce skills, and alignment with global standards - restrict the scalability of innovations and slow down the sector's modernization. Addressing these challenges requires targeted policies and investments aimed at strengthening digital infrastructure, harmonizing standards, and developing competencies, ensuring that transport and logistics enterprises can fully realize their potential in the global market.

Moreover, the effectiveness of Kazakhstan's transport complex directly influences the transit corridors not only within Eurasia but also across global trade flows. The study was conducted by an international team of researchers and drew upon numerous international studies, demonstrating that socio-technical approaches to digitalization developed in global practice are also applicable in Kazakhstan. This highlights that the country's experience contributes to the wider international discourse on digital transformation of logistics and industrial enterprises, showing both the universality of challenges and the transferability of solutions.

The "Digitalization Threshold": From accounting automation to intelligent management

The empirical evidence reveals a persistent "digitalization threshold": enterprises tend to adopt technologies that enable digital accounting, document management, and partial automation (e.g., procurement, warehousing, inventory management), while far less frequently transitioning to integrated platforms, predictive analytics, and algorithmic decision-making systems (AI/ML, sensors, computer vision, end-to-end traceability, and advanced supply chain management systems).

From an Industry 4.0 perspective, this implies that digital initiatives largely remain at the stages of digitization and functional digitalization of isolated activities, rather than reaching the level of digital transformation, where the logic of management and the allocation of responsibility for data fundamentally change. From a socio-technical standpoint, the "threshold" emerges at the point where the costs and complexity of integration increase sharply, while organizational change capacity remains limited. As a result, enterprises rationally prioritize "low-hanging fruit" solutions with predictable returns while avoiding transformational investments that require new competencies, process reconfiguration, and alternative performance metrics.

Economic barriers as a symptom of managerial uncertainty rather than capital scarcity

The predominance of economic barriers, namely high implementation costs and a lack of internal financial resources, should be interpreted more broadly than as a simple shortage of capital. The perceived high costs of digitalization often reflect not only the price of technologies themselves but the "hidden costs" of transformation, including employee training, process reengineering, integration of fragmented systems, data management, cybersecurity, and change management, as well.

A particularly important factor is the uncertainty surrounding economic returns. In the absence of a strong strategic linkage between digital projects and competitive advantage, enterprises tend to perceive digitalization as a costly experiment rather than a value-generating investment. This gives a rise to a self-reinforcing loop: low managerial maturity reduces the ability to assess return on investment (ROI) and to select relevant digital solutions; this, in turn, increases investment caution; and limited investment further

entrenches fragmented digitalization and the lack of visible performance effects.

From an Industry 5.0 perspective, the economic rationale of digitalization should shift from a narrow focus on short-term efficiency towards a broader understanding of value creation, encompassing resilience, adaptability, reduced operational risks, and improved decision quality. However, the empirical results indicate that such a value-oriented logic has not yet been sufficiently institutionalized in the managerial practices of enterprises.

Human capital deficits as a central mechanism reproducing digitalization barriers

Human capital and competency constraints in this study emerge not merely as "one of the barriers," but as a core mechanism that links and amplifies other obstacles to digitalization. A lack of digital competencies reduces the effectiveness of implemented solutions and leads to "symbolic digitalization," in which systems are formally in place but used at a minimal level of functionality. This is particularly critical for tools that require data interpretation and cross-functional interaction, such as supply chain analytics, predictive inventory management, traceability systems, and quality management solutions.

From an Industry 5.0 perspective, human capital is not a complement to technology but the core of transformation: digital technologies enhance productivity only when employees possess the capability to make data-driven decisions, interact effectively with digital systems, and participate in continuous process improvement. Accordingly, the identified skills deficit implies that enterprises face constraints not at the "input" stage (the absence of technologies) but at the "output" stage - the inability to extract value from already available digital resources.

Furthermore, human capital shortages intensify dependence on external solution providers and reduce the autonomy of digital development. Enterprises are compelled to purchase turnkey solutions, which increases project costs and heightens the risks of system incompatibility and poor adaptation to the specific context of production processes.

The strategic gap: why digitalization has not become a source of competitive advantage

The results related to competitiveness factors, namely, the dominance of price and quality and the secondary role of innovation and automation, indicate that digitalization is not yet sufficiently conceptualized as a value-creation strategy. This helps to explain respondents' reports of a limited understanding of benefits of digitalization and insufficient support from the top management.

At the managerial level, this reflects a classic problem: digital projects are initiated as IT-driven initiatives rather than as transformations of the value creation chain. When digitalization is not embedded in corporate strategy, it remains a form of "localized modernization" without scale effects resulting in "digital islands," the failure to replicate the pilot projects, and the inability of data to become a shared organizational resource.

From an Industry 5.0 perspective, competitiveness is increasingly associated with resilience, sustainability, and human-centricity. Accordingly, the strategic weakness of digitalization represents not only a managerial gap but also a constraint on the transition toward a more mature model of industrial development, in which technologies support long-term socio-economic objectives rather than short-term operational improvements.

Logistics as a bottleneck of digital transformation: from an operational function to a strategic capability

The low level of digital maturity in logistics and warehousing processes revealed by the study is of particular analytical significance. In contemporary production systems, logistics is an area where digital solutions can generate rapid gains through data integration, flow transparency, and predictive management. However, within the surveyed sample, enterprises predominantly rely on mechanization and manual operations, with limited adoption of WMS, sensors, and end-to-end traceability. This indicates that logistics is still perceived primarily as a support function rather than as a strategic capability. As a result, enterprises remain vulnerable to supply disruptions, market volatility, and changes in raw material availability, precisely the factors that are identified in the Industry 5.0 agenda as key challenges to resilience.

From a socio-technical perspective, the digitalization of logistics requires cross-functional coordination (production-procurement-warehousing-sales), unified data and standards, and appropriate workforce competencies. Consequently, the low level of logistics digitalization does not represent an isolated technological deficit but rather reflects a systemic challenge related to data integration and governance.

The Institutional Environment and "Digitalization Asymmetry"

For Kazakhstan and similar economies, institutional factors intensify differentiation among enterprises in terms of digitalization levels, as access to financing, human resources, and technology providers is unevenly distributed. This gives rise to "digitalization asymmetry," whereby a limited number of enterprises, typically larger firms and those more deeply integrated into international value chains, emerge as digital frontrunners, while the majority remain locked at the level of basic automation.

From an industrial policy perspective, this situation entails the risk of reproducing structural divides: digitalization may further strengthen the advantages

of firms that already possess resources and capabilities unless it is accompanied by mechanisms for knowledge diffusion, workforce development, and cooperation incentives, such as cluster-based models, joint education and training programs, and demonstration platforms.

Taken together, the identified barriers can be interpreted as a socio-technical misalignment: technologies are adopted at a faster pace than the development of competencies, managerial practices, organizational culture, and institutional support mechanisms. As a result, digitalization remains fragmented and predominantly operational rather than strategic.

From the perspective of the transition towards Industry 5.0, this implies the need for a shift in emphasis:

- from "technology adoption" to change management and human capital development;
- from isolated pilot projects to integrated data and process architectures;
- from the short-term, cost-driven solutions to value-oriented investments that account for sustainability and resilience;
- from individual firm-level initiatives to an ecosystem-based approach (partnerships, clusters, and joint competency development programs).

Thus, the results of the study not only identify the set of barriers to digitalization but point to its evolutionary trajectory, as well: sustainable returns from digital investments emerge only when the technological layer is supported by organizational maturity, human capital, and an enabling institutional environment. This constitutes the core logic of the transition from Industry 4.0 to Industry 5.0 in the context of Kazakhstani enterprises.

6 Conclusion

The key empirical finding is that the mere presence of digital technologies, IT infrastructure, and formal quality management tools does not automatically translate into enhanced enterprise competitiveness. In most cases, digitalization remains fragmented and operational in nature and fails to evolve into a sustainable strategic advantage. This confirms the limitations of technological determinism underlying early interpretations of Industry 4.0 and underscores the need for a more comprehensive understanding of digital transformation.

From a socio-technical perspective, the identified barriers should be interpreted as manifestations of misalignment between the technological layer of digitalization and the level of readiness of human capital, managerial practices, and the institutional environment. In this context, the digital transformation cannot be reduced to the adoption of individual technologies and instead requires systemic changes in work organization, data governance, competency development, and corporate culture.

Within the logic of the transition from Industry 4.0 to Industry 5.0, the findings highlight the need to shift the focus from technology implementation towards a human-centric and sustainable model of digital development. For enterprises in the real sector, this implies embedding digitalization into corporate strategy, orienting digital investments toward long-term value creation and resilience, and prioritizing human capital development as a key resource of digital transformation. Without such a shift, digitalization is likely to remain characterized by isolated initiatives that fail to generate systemic effects.

The limitations of this study are related to the sample size and the use of the self-reported data, which restrict the possibilities for statistical generalization of the findings. Future research directions include expanding the sample, applying mixed-methods approaches, and conducting in-depth analyses of the relationships between employees' digital competencies, managerial maturity, and the economic returns of digital investments. Such studies would enable a more precise identification of the mechanisms underlying sustainable digital transformation and deepen understanding of the transition from Industry 4.0 to Industry 5.0 in industry and logistics.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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