

Barriers to digital transformation in industrial, transport and logistics enterprises: empirical evidence from Kazakhstan

Marat Idrissov, Aliya Izbairova, Thomas Stahlecker, Gulmira Mukhanova, Botagoz Kuanyshbayeva

Received: 06 Feb. 2026; Revised: 06 Mar. 2026; Accepted: 27 July 2026<https://doi.org/10.22306/al.v13i3.817>**Barriers to digital transformation in industrial, transport and logistics enterprises: empirical evidence from Kazakhstan****Marat Idrissov**Satbayev University, Department of Transport Engineering and Logistics, Satpaev St 22, 050000 Almaty, Kazakhstan,
Idrissov.M@stud.satbayev.university**Aliya Izbairova**Satbayev University, Department of Transport Engineering and Logistics, Satpaev St 22, 050000 Almaty, Kazakhstan,
a.izbairova@satbayev.university**Thomas Stahlecker**Fraunhofer Institute for Systems and Innovation Research, Breslauer Str. 48, 76139 Karlsruhe-Waldstadt,
Germany, EU, Thomas.Stahlecker@isi.fraunhofer.de**Gulmira Mukhanova**Satbayev University, Department of Transport Engineering and Logistics, Satpaev St 22, 050000 Almaty, Kazakhstan,
g.mukhanova@satbayev.university (corresponding author)**Botagoz Kuanyshbayeva**Ruhr University Bochum, Institute of Development Research and Development Policy (IEE), Universitätsstraße 150,
44801 Bochum Süd, Germany, EU, kbota8788@gmail.com**Keywords:** digital transformation, digital readiness, industry, logistics, Kazakhstan.

Abstract: Paper addresses the problem of systemic barriers to digital transformation, in logistics flows and supply chain management, which hinder the integration of digital technologies into material, information, and financial flows. The aim of the study is to empirically identify and analyze these barriers in industrial, transport, and logistics enterprises in Kazakhstan. The novelty of the research lies in specifying how barriers manifest in a transition economy and in demonstrating their impact on logistics flows and supply chain management. The empirical foundation of the research is a questionnaire survey conducted among 57 enterprises in the real sector of the economy, including industry, transport and logistics, construction, and information and communication technologies. The collected data were analyzed using descriptive statistical methods and interpreted within the broader context of industrial paradigm evolution, from Industry 4.0 toward the human-centric and sustainable Industry 5.0 model. The empirical material of the study reflects the cross-sectoral nature of digital transformation, encompassing production, logistics, management, and information processes within end-to-end digital ecosystems, as revealed through the survey of 57 enterprises in diverse industries. The results indicate that enterprise-level digitalization is still confined mainly to basic automation and fragmented adoption of digital tools, whereas integrated and intelligent solutions remain scarce and underdeveloped. Key barriers to digitalization emerge at the intersection of economic constraints, human capital limitations, organizational-managerial weaknesses, and technological challenges. The most prominent constraints include the high cost of digital solutions, persistent shortages of digital competencies among personnel, and insufficient strategic understanding of the potential benefits of digitalization.

1 Introduction

Digital transformation in enterprises of the real sector is a crucial condition for enhancing competitiveness, sustainability, and adaptability amid ongoing structural changes in the global economy. The problem addressed in this study is that enterprises face significant obstacles in integrating digital technologies into material, information, and financial flows, which limits the development of logistics processes and supply chain management. The aim of the research is to empirically identify and analyze these barriers in industrial, transport, and logistics enterprises. The novelty of the study lies in specifying how barriers manifest in a transition economy and in demonstrating their impact on logistics flows and the formation of end-to-end digital ecosystems. Within industry, transport, and logistics, digital technologies are regarded as essential tools for optimizing processes, increasing transparency in supply chains, and reducing operational risks. However, empirical studies, including findings presented in this research, demonstrate that the actual level of digitalization of enterprises in Kazakhstan remains limited and does not correspond to the potential capabilities of the technologies being implemented.

Despite the proliferation of digitalization strategies and the formal adoption of quality management standards and information systems, digital solutions are still applied in fragmented ways used in fragments and mainly at the level of

Barriers to digital transformation in industrial, transport and logistics enterprises: empirical evidence from Kazakhstan

Marat Idrissov, Aliya Izbairova, Thomas Stahlecker, Gulmira Mukhanova, Botagoz Kuanyshbayeva

basic automation. This situation indicates the presence of persistent barriers that hinder the transition from digitalization of isolated functions to comprehensive digital transformation at the enterprise level. In a transitional these barriers acquire particular importance, as they intensify differences in digital maturity among enterprises and create a “digital asymmetry” across industry and logistics.

The purpose of this article is to empirically identify and systematically analyze barriers to the digitalization of enterprises in Kazakhstan, based on the results of a questionnaire survey of firms in the real sector of the economy. This work focuses on the empirical specification of barriers to digital transformation and their interpretation within the logic of a socio-technical approach and the transition from Industry 4.0 to Industry 5.0.

In the academic literature, barriers to digitalization have traditionally been examined primarily through the lens of technological constraints. More recent studies, however, emphasize that these obstacles are inherently complex and emerge at the intersection of technological, organizational-managerial, human capital, cultural, and institutional factors. In this context, increasing attention is devoted to the socio-technical approach, which conceptualizes digitalization as the outcome of interactions between technological systems and social structures.

Empirical studies reviewed in the literature indicate that the mere availability of digital technologies, infrastructure, and even formal strategic documents does not guarantee productive digitalization of production systems. In many countries, enterprises face situations in which digital solutions are implemented in a fragmented manner, insufficiently embedded in business processes, and fail to deliver the anticipated gains in efficiency and innovativeness [1,2]. This highlights the presence of systemic barriers that impede the transition from technological potential to genuine digital transformation.

This paper aims to provide an analytical systematization of the barriers to digitalization of industrial enterprises based on an interdisciplinary literature review and an empirical study of companies in Kazakhstan. The paper seeks to move beyond a narrow, technology-centric perspective of digitalization toward a comprehensive socio-technical analysis that accounts for the interdependencies between technologies, organizational structures, human capital, and the institutional environment.

2 Literature review

In academic literature, barriers to industrial digitalization have traditionally been analyzed mainly through the lens of technological constraints, such as insufficient automation, data deficiencies, system interoperability problems, and cybersecurity challenges [3,4]. More recent studies, however, emphasize that the most critical obstacles encompass not exclusively technological but also organizational, institutional, and socio-human factors [5-7].

Contemporary research pays particular attention to the gap between the technology-driven Industry 4.0 paradigm and the growing need to transition toward a more human-centric and sustainable model of industrial development, conceptualized within the Industry 5.0 framework [8,9]. In this context, barriers to digitalization are increasingly interpreted as manifestations of misalignment between technological solutions and the social and organizational conditions necessary for their effective implementation.

Despite the widespread diffusion of digital technologies and Industry 4.0 strategies, most industrial enterprises still encounter multi-level constraints that hinder comprehensive digital transformation. Recent research converges on the view that digitalization barriers are inherently complex and arising at the intersection of technological, organizational, human capital, cultural, and institutional factors [6,10-14]. Accordingly, this section presents a systematic classification of the key barriers to industrial digitalization.

Technological barriers

Technological barriers are traditionally considered the primary obstacles to digitalization, encompassing limitations in digital infrastructure, fragmentation of IT systems, low levels of automation, and interoperability problems between equipment and software. In many industrial enterprises, digital technologies are implemented in isolation, without integration into end-to-end production and managerial processes, which significantly diminishes their effectiveness [1,3].

Empirical studies indicate that even when data collection systems are in place, enterprises often fail to utilize the generated data for managerial decision-making and process optimization [1]. Similar conclusions are reported in studies on big data adoption in supply chains, where enterprises often encounter difficulties in data processing, interpretation, and transformation into actionable managerial knowledge [2].

Additional technological barriers include challenges related to cybersecurity, standardization, and the scalability of digital solutions. Small and medium-sized industrial enterprises (SMEs) are particularly vulnerable in this regard due to their limited financial and technical resources, a finding consistently supported by studies on SME digital readiness [4].

Organizational and managerial barriers

Organizational barriers to digitalization are closely associated with the absence of a clear digital strategy, insufficient support from top management, and weak coordination across organizational units. Numerous digital maturity models

Barriers to digital transformation in industrial, transport and logistics enterprises: empirical evidence from Kazakhstan

Marat Idrissov, Aliya Izbairova, Thomas Stahlecker, Gulmira Mukhanova, Botagoz Kuanyshbayeva

underscore that digital transformation necessitates systemic changes in governance and management practices rather than the mere adoption of new technologies [10].

In practice, digitalization initiatives are often implemented as isolated pilot projects that are not embedded within an overarching corporate strategy. This leads to the emergence of so-called “digital islands,” where innovations fail to scale and do not generate a substantial impact on productivity or competitiveness [6]. Moreover, rigid hierarchical management structures constrain the flexibility and adaptability required in the digital economy.

The literature also underscores a shortage of managerial competencies related to digital transformation, particularly at the middle-management level, which plays a pivotal role in translating strategic digital ambitions into operational implementation [11].

Human capital and competency barriers

One of the most critical barriers to industrial digitalization is the shortage of digital competencies among employees. Contemporary production systems require not only highly specialized technical skills but also basic digital competencies across a broad range of occupational groups [7,15]. Empirical studies demonstrate that insufficient levels of digital skills result in the inefficient use of implemented technologies and undermine the expected benefits of digitalization [7,16,17]. The study [18] identifies the skills and competencies employees need to possess for successful digital transformation of the company in the era of Industry 4.0. At the same time, many enterprises tend to focus on short-term needs for “hard” technical skills, while neglecting the development of adaptive, analytical, and interdisciplinary competencies.

An additional challenge is employee resistance to digital change, driven by fears of job displacement, increasing task complexity, and rising qualification requirements. These issues are particularly pronounced in traditional industrial sectors and reinforce the social barriers to digitalization [5].

Cultural and social barriers

Organizational culture plays a pivotal role in the success of digital transformation. Cultures oriented toward stability, hierarchy, and risk minimization often inhibit experimentation and the adoption of digital innovations [19]. Under such conditions, digitalization is frequently perceived as an externally imposed initiative rather than a source of organizational development.

Socio-technical research underscores that the lack of employee participation in digitalization processes reduces trust in and acceptance of new technologies [6]. In contrast, workplace innovation approaches demonstrate that employee involvement and the cultivation of a learning-oriented culture can help overcome social barriers and enhance the effectiveness of digital transformation initiatives.

Institutional and external barriers

The institutional environment also exerts a significant influence on industrial digitalization processes. Insufficient coordination between industrial, innovation, and education policies, as well as limited governmental support for digital initiatives, can slow down enterprise-level digital transformation [8].

Developing and transition economies face additional institutional barriers, including uneven development of digital infrastructure, shortages of qualified human resources, and constrained access to finance [20,21]. These factors intensify the divide between digital frontrunners and laggards and contribute to persistent digital asymmetries within industrial sectors.

3 Methodology

The empirical study employs a quantitative cross-sectional approach aimed at analyzing the current state of enterprise digitalization, the level of digital technology adoption, the development of personnel digital competencies, and the factors constraining digital transformation. This approach was chosen because it provides a reliable snapshot of the current state of digitalization and barriers across enterprises. It is particularly suitable for transition economies such as Kazakhstan, where digitalization develops unevenly across sectors. The quantitative design enables the collection of standardized data from a broad set of enterprises, allowing for statistical comparison between industries and the identification of systemic constraints. A structured questionnaire survey served as the primary method of data collection, consistent with established research practices in the field of enterprise digital readiness and digital maturity [4,10,11].

The empirical basis of the study consists of survey results from 57 enterprises operating in industry, transport, logistics, construction, and the information and communication technology sector. The selection of enterprises was guided by two criteria: (1) representation of key sectors relevant to digital transformation, and (2) availability of managerial and expert staff capable of providing informed assessments of digitalization practices. The cross-sectoral nature of the sample reflects the fact that digital transformation under modern conditions affects not only production processes but also logistics, supply chain management, information flows, and project activities, thereby forming end-to-end digital ecosystems [2,6,22].

The respondents were representatives of managerial and expert levels — enterprise heads, functional department managers, and specialists in digitalization, IT, and operational management — possessing relevant knowledge about the

Barriers to digital transformation in industrial, transport and logistics enterprises: empirical evidence from Kazakhstan

Marat Idrissov, Aliya Izbairova, Thomas Stahlecker, Gulmira Mukhanova, Botagoz Kuanyshbayeva

strategic, technological, and personnel aspects of organizational activity. This composition of respondents ensures the adequacy of assessments of the level of digitalization and the perception of barriers to digital transformation.

The data collection instrument was the author's structured questionnaire, comprising several logically interrelated blocks:

- general characteristics of the enterprise;
- innovation activity;
- the level of digitalization of functional areas;
- digital technologies employed;
- development of digital competencies of the staff.

The generated dataset comprises 124 variables, primarily quantitative in nature, supplemented by categorical indicators, thereby enabling a comprehensive analysis of enterprise digitalization characteristics. The data were processed using descriptive statistical methods, including analysis of frequency distributions and mean values. The interpretation of results was conducted within the framework of a socio-technical approach, allowing the identified barriers to be considered as elements of a unified system of enterprise digital transformation. The literature review demonstrates that barriers to the digitalization of industrial enterprises are complex and multi-level in nature, emerging at the intersection of technological, organizational-managerial, human capital, cultural, and institutional factors. Contemporary research emphasizes that the mere availability of digital technologies and infrastructure does not in itself ensure successful digital transformation if technological adoption is not accompanied by the development of human capital, the adaptation of managerial practices, and adequate institutional support. Within the socio-technical approach, these barriers are interpreted as manifestations of misalignment between technological capabilities and the social and organizational conditions necessary for their effective implementation.

The results of the empirical survey of Kazakhstani enterprises confirm the key conclusions of the literature review and further specify them within the national and sectoral context. The findings indicate that enterprise digitalization is predominantly confined to basic forms of automation and digital record-keeping, while the transition toward integrated and intelligent digital solutions is constrained by a combination of economic, human capital, and managerial limitations. Thus, the empirical results not only reproduce the typology of barriers identified in international studies but also demonstrate their specific manifestations in the context of a transition economy.

4 Results and discussion

This section presents a systematic analysis of digitalization barriers in Kazakhstani enterprises based on the results of the questionnaire survey. The analysis is conducted within the socio-technical framework and aims to identify the dominant constraints on digital transformation, their interrelationships, and their role in shaping the fragmented nature of digitalization. By linking insights from the literature with empirical evidence, the analysis goes beyond describing the level of digitalization to explain the underlying factors that hinder its deepening and transformation into a source of sustainable competitive advantage.

The survey results made it possible to identify and structure the key barriers impeding the digitalization of Kazakhstani industrial and related enterprises. The findings confirm that digitalization barriers are multifactorial in nature and consistent with the socio-technical logic, in which technological constraints are intertwined with human capital, managerial, and institutional conditions (see Table 1).

Table 1 Digitalization barriers as perceived by respondents

Barriers to digitalization*	Responses		Percent of Cases
	N	Percent	
High cost of digital technology implementation	28	19.6%	51.9%
Lack of understanding of the benefits of digitalization	20	14.0%	37.0%
Shortage of appropriately qualified personnel	20	14.0%	37.0%
Insufficient financial capacity to invest in digitalization	20	14.0%	37.0%
Insufficient digital infrastructure for digitalization	13	9.1%	24.1%
Barriers related to insufficient cybersecurity and data privacy	11	7.7%	20.4%
Barriers associated with digital standards, regulations and certifications	10	7.0%	18.5%
Insufficient interoperability between new digital solutions and existing management systems	9	6.3%	16.7%
Resistance of employees to organizational changes induced by digital transformation	5	3.5%	9.3%
Top management does not support digitalization initiatives within the enterprise	4	2.8%	7.4%
Insufficient availability of digital solution providers for the enterprise	3	2.1%	5.6%
Total	143	100.0%	264.8%

*Dichotomy group tabulated at value 1.

Barriers to digital transformation in industrial, transport and logistics enterprises: empirical evidence from Kazakhstan

Marat Idrissov, Aliya Izbairova, Thomas Stahlecker, Gulmira Mukhanova, Botagoz Kuanyshbayeva

The survey results indicate that the most significant barrier to digitalization is the high cost of implementing digital technologies, which was reported by more than half of the surveyed enterprises. This finding suggests that financial constraints remain a key limiting factor in digital transformation, particularly in the context of limited access to long-term financing and the high capital intensity of digital solutions.

The financial barrier is further reinforced by the lack of internal financial resources for investment in digitalization, reflecting not only resource scarcity but also constrained possibilities for capital reallocation within enterprises. Taken together, these results underscore that digitalization is perceived by firms as an investment-intensive and high-risk process, requiring substantial upfront expenditures amid uncertainty regarding economic returns.

A significant constraint on digitalization is also associated with the shortage of qualified personnel possessing the necessary digital competencies. A considerable share of respondents identified the lack of appropriately skilled specialists as a major barrier, corroborating prior research on the critical role of human capital in digital transformation processes. This finding reflects a structural gap between the technological requirements of the digital economy and the current level of workforce preparation, particularly in traditional industrial sectors. The absence of systematic programs for developing digital competencies further increases enterprises' dependence on external solution providers and limits their capacity for autonomous digital upgrading.

The analysis also reveals that digitalization barriers manifest not only at the resource level but also at the level of managerial decision-making. In particular, some respondents pointed to a lack of understanding of the benefits of digitalization, indicating insufficient integration of digital transformation into enterprise strategic planning.

In addition, cases were identified in which top management does not actively support digitalization initiatives, pointing to limited institutional engagement of leadership in digital change processes. Although this barrier is not widespread, its presence is of systemic importance, as managerial support largely determines the prioritization of digital projects and the allocation of resources.

Among technological constraints, respondents emphasized the lack of adequate digital infrastructure and the limited compatibility of new digital solutions with existing management systems. This reflects a situation common to many enterprises, where digitalization takes place within the context of outdated production and IT infrastructures, thereby complicating the integration of advanced solutions.

An additional technological barrier relates to insufficient levels of cybersecurity and data protection, as well as challenges associated with digital standards, regulations, and certification. These factors increase firms' caution toward digital technology adoption and generate institutional risks associated with digitalization.

The least frequently reported, yet still indicative, barriers include a shortage of digital solution providers and employee resistance to changes brought about by digital transformation. The relatively low incidence of reported resistance may be explained by the fact that in many enterprises' digitalization has not yet reached a stage of deep transformation of labor processes, where social tensions tend to become more pronounced. Overall, the findings point to an incomplete formation of a digitalization ecosystem encompassing competencies, financing, solution providers, and institutional support.

Table 2 shows a systematization of barriers to digitalization in enterprises in Kazakhstan based on empirical data and a literature review.

Table 2 Systematization of digitalization barriers in Kazakhstani enterprises: empirical evidence and literature review

Barrier Group	Specific Barriers (Survey Results)	Empirical Manifestations in the Study	Relevant Literature
Economic barriers	High costs of digital technology implementation; Lack of internal financial resources	Dominant barrier for more than half of enterprises; digitalization perceived as an investment-intensive and high-risk process with uncertain returns	Kagermann et al. (2013); Nick et al. (2019); Schumacher et al. (2020); Salamzadeh et al. (2024)
Human capital and competency barriers	Shortage of specialists with digital competencies; Insufficient digital skills among employees	Limited use of AI, analytics, and integrated systems; dependence on external solution providers; prevalence of “symbolic digitalization”	Steinlechner et al. (2021); Howaldt et al. (2016); Dessers et al. (2019); Müller (2020)
Organizational and managerial barriers	Lack of understanding of digitalization benefits; Limited top management support; Absence of a digital strategy	Digital initiatives implemented as isolated pilot projects; emergence of “digital islands” without scaling or strategic impact	Schumacher et al. (2020); Dessers et al. (2019); Salamzadeh et al. (2024)
Technological and infrastructure barriers	Insufficient digital infrastructure; Incompatibility of new solutions with legacy systems; Limited cybersecurity capabilities	Fragmented automation; low adoption of WMS, IoT, and AI; outdated IT landscapes hindering system integration	Qin et al. (2016); Nick et al. (2019); Chonsawat & Sopadang (2020); Queiroz & Telles (2018)

Barriers to digital transformation in industrial, transport and logistics enterprises: empirical evidence from Kazakhstan

Marat Idrissov, Aliya Izbairova, Thomas Stahlecker, Gulmira Mukhanova, Botagoz Kuanyshbayeva

Barrier Group	Specific Barriers (Survey Results)	Empirical Manifestations in the Study	Relevant Literature
Cultural and social barriers	Employee resistance to change; Low employee involvement in digitalization	Less frequently reported, but interpreted as latent; digitalization has not yet reached the stage of deep labor transformation	Howaldt et al. (2016); Kopp et al. (2016); Dessers et al. (2019)
Institutional and external barriers	Insufficient governmental support; Limited access to financing and digital solution providers	Reinforcement of digital asymmetries between enterprises; slower scaling of digital practices	Breque et al. (2021); Alzhanova & Kireyeva (2020); Kireyeva et al. (2022)

Taken together, the identified barriers point to the incomplete formation of a comprehensive digitalization ecosystem encompassing technology providers, a skilled workforce, financial instruments, and institutional support.

Overall, the results of the analysis indicate that the digitalization of Kazakhstani enterprises is constrained primarily by economic and human capital limitations, which are further compounded by technological and managerial barriers. The findings support the argument that digital transformation cannot be reduced to technological adoption alone and instead requires a systemic approach that integrates human capital development, managerial capabilities, and a supportive institutional environment.

4.1 Practical implications for enterprise management and industrial policy

Managerial implications for enterprises

The empirically observed fragmentation of digitalization highlights the need to manage digital initiatives as an integrated portfolio rather than as a collection of isolated pilot projects. In practical terms, this entails defining a target data and process architecture, prioritizing projects based on their impact on the value creation chain, and establishing a cross-functional governance body (e.g., a digital steering committee) involving representatives from production, logistics, finance, and human resources. Without such an approach, digital solutions are likely to continue generating “digital islands” rather than delivering systemic transformation.

Economic justification of digitalization through value-oriented metrics rather than ROI alone

The predominance of economic barriers points to a deficit of managerial tools for assessing the returns on digital investments. It is therefore recommended to complement traditional ROI calculations with value-oriented metrics, such as reductions in downtime and losses, improvements in demand and inventory forecasting accuracy, enhanced traceability, lower operational risks in supply chains, and improvements in the quality and speed of decision-making. This logic aligns digitalization more closely with the Industry 5.0 framework, in which value creation encompasses resilience and sustainability in addition to short-term financial performance.

Human capital strategy as the core of digital transformation

The shortage of digital competencies should be treated as a key second-order barrier: even when technologies are available, enterprises are unable to extract value without the necessary skills and a data-oriented culture. In practical terms, this implies: (a) conducting audits of digital competencies across employee groups; (b) implementing modular upskilling and reskilling programs for operational roles and middle management; (c) embedding on-the-job learning practices based on firm-specific use cases; and (d) developing internal “digital champions” who can reduce dependence on external consultants and facilitate knowledge diffusion within the organization.

Logistics as a priority area for digital impact

The low level of digital maturity in logistics and warehousing underscores the importance of selecting logistics as an effective “entry point” for data integration. In the short term, the greatest impact is often achieved through the implementation of WMS and basic traceability systems, the standardization of master data, and the introduction of scanners and sensors to enhance flow transparency, followed by the application of analytics for inventory management and planning. Such measures strengthen supply chain resilience, which represents a core objective of the Industry 5.0 paradigm.

4.2 Implications for industrial policy and development institutions

Reducing cost barriers through targeted financial instruments

Given that the cost of digitalization encompasses not only technology acquisition but also organizational transformation, blended policy instruments are likely to be most effective. These include co-financing schemes for digital implementation combined with support for training and consultancy services related to process reengineering. Of

Barriers to digital transformation in industrial, transport and logistics enterprises: empirical evidence from Kazakhstan

Marat Idrissov, Aliya Izbairova, Thomas Stahlecker, Gulmira Mukhanova, Botagoz Kuanyshbayeva

particular importance are concessional long-term financial instruments for small and medium-sized enterprises (SMEs) and firms with limited access to capital markets.

Competency-oriented policy as a systemic response to skills shortages

The study's findings underscore the need for institutionalized training and reskilling programs as a systemic response to human capital deficits. These may include sectoral competence centers, dual education schemes, short-term modular training for blue-collar occupations and middle management, and the standardization of digital skill profiles for industry and logistics. Crucially, educational programs should be closely linked to applied enterprise-level use cases; otherwise, their practical impact is likely to remain limited.

The digitalization ecosystem: clusters, demonstration platforms, and knowledge exchange

The fragmentation of digitalization and enterprises' dependence on external solution providers point to the need to institutionalize platforms for piloting and scaling digital solutions. These include testbeds, learning factories, and sectoral innovation hubs and labs. Such instruments reduce implementation risks for enterprises, accelerate the diffusion of best practices, and help overcome the "digitalization threshold" identified in the empirical analysis.

Data standards and interoperability as preconditions for scaling

Challenges related to system incompatibility and outdated IT landscapes highlight the need for policy support aimed at promoting data exchange standards and providing methodological guidance for system integration. At the policy level, this may include the development of reference architectures for key functional areas (such as logistics, quality management, and traceability) and certification mechanisms for digital solutions. Such measures can reduce uncertainty, enhance trust, and lower barriers to large-scale adoption.

Overall, the results confirm that barriers to enterprise digitalization in Kazakhstan should be interpreted as manifestations of a socio-technical misalignment: technologies are adopted more rapidly than the development of competencies, managerial maturity, and institutional support mechanisms. In this context, the transition from Industry 4.0 to Industry 5.0 implies a shift away from technological determinism toward a human-centric and sustainable model of digital development, in which the primary source of competitiveness lies in organizations' ability to integrate technologies into processes, develop human capital, and extract scalable value from data.

5 Conclusions

The aim of this study was to identify and analytically interpret the barriers to enterprise digitalization in Kazakhstan's real sector, based on empirical evidence and within the broader evolution of industrial paradigms from Industry 4.0 to Industry 5.0. The empirical analysis demonstrates that the digital transformation of the surveyed enterprises remains at an intermediate stage, characterized by basic automation, formal adoption of digital standards, and limited deployment of intelligent and integrated solutions.

The findings reveal that the dominant barriers to digitalization emerge at the intersection of economic, human capital, organizational-managerial, and technological factors. Economic constraints are reflected not only in the high costs of digital solutions but also in uncertainty regarding their returns under conditions of weak strategic integration. Shortages of digital competencies constitute a systemic constraint, reducing the effectiveness of implemented technologies and reproducing the fragmented nature of digital initiatives. Organizational and managerial barriers manifest in a limited understanding of the benefits of digitalization and insufficient leadership engagement, while technological and infrastructural constraints further amplify the risks associated with integrating and scaling digital solutions.

From a practical perspective, the results provide guidance for enterprises in designing comprehensive digital strategies, prioritizing investments, and embedding human capital development into transformation programs. They also highlight the need for industrial policy instruments that combine financial support with competency-oriented initiatives, thereby reducing systemic barriers to digitalization.

From a theoretical perspective, the study contributes to the literature on digital readiness and transformation barriers by offering an empirically grounded socio-technical interpretation of digitalization constraints in a transition economy. This perspective underscores that digital transformation cannot be reduced to technological adoption alone; rather, it requires a systemic approach integrating technology, human capital, managerial maturity, and institutional support.

Ultimately, the study advances the understanding of how socio-technical misalignments shape digitalization trajectories in emerging economies and provides a foundation for both academic inquiry and policy design aimed at fostering resilient, human-centric, and sustainable digital development in the era of Industry 5.0.

Barriers to digital transformation in industrial, transport and logistics enterprises: empirical evidence from Kazakhstan

Marat Idrissov, Aliya Izbaïrova, Thomas Stahlecker, Gulmira Mukhanova, Botagoz Kuanyshbayeva

Acknowledgement

This research was funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan under the Grant No. BR27198643 – “Development of digital competences of human capital in industry and logistics through cluster collaboration of science, education and industry”.

References

- [1] NICK, G., SZALLER, A., BERGMANN, J., VÁRGEDŐ, T.: Industry 4.0 readiness in Hungary: model, and the first results in connection to data application, *IFAC-PapersOnLine*, Vol. 52, No. 13, pp. 289-294, 2019. <https://doi.org/10.1016/j.ifacol.2019.11.185>
- [2] QUEIROZ, M.M., TELLES, R.: Big data analytics in supply chain and logistics: An empirical approach, *The International Journal of Logistics Management*, Vol. 29, No. 2, pp. 767-783, 2018. <https://doi.org/10.1108/IJLM-05-2017-0116>
- [3] QIN, J., LIU, Y., GROSVENOR, R.: A categorical framework of manufacturing for Industry 4.0 and beyond, *Procedia CIRP*, Vol. 52, pp. 173-178, 2016. <https://doi.org/10.1016/j.procir.2016.08.005>
- [4] CHONSAWAT, N., SOPADANG, A.: Defining SMEs' Industry 4.0 readiness indicators, *Applied Sciences*, Vol. 10, No. 24, 8998, pp. 1-30, 2020. <https://doi.org/10.3390/app10248998>
- [5] KOPP, R., HOWALDT, J., SCHULTZE, J.: Why Industry 4.0 needs workplace innovation: A critical look at the German debate on advanced manufacturing, *European Journal of Workplace Innovation*, Vol. 2, No. 1, pp. 7-22, 2016. <https://doi.org/10.46364/ejwi.v2i1.373>
- [6] DESSERS, E., DHONDT, S., RAMIOUL, M., DE SCHUTTER, J., PINTELON, L., VAN BOCKHAVEN, W., COREYNEN, W., DE LOOZE, M., VAN HOOTEGEM, G.: Towards a multidisciplinary research framework for studying the digital transformation of industry, *European Journal of Workplace Innovation*, Vol. 5, No. 1, pp. 1-17, 2019. <https://doi.org/10.46364/ejwi.v5i1.523>
- [7] STEINLECHNER, M., SCHUMACHER, A., FUCHS, B., REICHSTHALER, L., SCHLUND, S.: A maturity model to assess digital employee competencies in industrial enterprises, *Procedia CIRP*, Vol. 104, pp. 1185-1190, 2021. <https://doi.org/10.1016/j.procir.2021.11.199>
- [8] BREQUE, M., DE NUL, L., PETRIDIS, A.: *Industry 5.0: Towards a sustainable, human-centric and resilient European industry*, European Commission, Publications Office of the European Union, 2021. <https://doi.org/10.2777/308407>
- [9] MULLER, J.: *Enabling Technologies for Industry 5.0 – Results of a workshop with Europe's technology leaders*, European Commission, Publications Office of the European Union, 2020. <https://data.europa.eu/doi/10.2777/082634>
- [10] SCHUMACHER, A., SIHN, W.: *A Monitoring System for Implementation of Industrial Digitalization and Automation using 143 Key Performance Indicators*, 53rd CIRP Conference on Manufacturing Systems, Procedia CIRP 93, pp. 1310-1315, 2020. <https://doi.org/10.13140/RG.2.2.25061.35040>
- [11] SALAMZADEH, Y., DAMIJ, N., ISA, S.M., KHAN, R.U.: Digital readiness, *International Encyclopedia of Business Management*, Vol. 2, pp. 426-430, 2026. <https://doi.org/10.1016/B978-0-443-13701-3.00436-9>
- [12] KUKETAYEVA, A., MUKHANOVA, G., CSISZÁRIK-KOCSIR, A., MUSTAFINA, A.: Unveiling key factors for successful IT projects in Kazakhstan: an empirical investigation, *Transformations in Business & Economics*, Vol. 23, No. 3A, pp. 722-738, 2024.
- [13] HORVÁTH, D., SZABÓ, R.Z.: Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?, *Technological Forecasting and Social Change*, Vol. 164, pp. 119-132, 2019. <https://doi.org/10.1016/j.techfore.2019.05.021>
- [14] Digital Readiness Index, 2021, [Online], Available: https://www.cisco.com/c/m/en_us/about/corporate-social-responsibility/research-resources/digital-readiness-index.html#/country/KAZ [01 Feb 2026], 2021.
- [15] MORANDINI, M.C., THUM-THYSEN, A., VANDEPLAS, A.: *Facing the digital transformation: Are digital skills enough?*, European Economy Economic Briefs, European Commission, Directorate-General for Economic and Financial Affairs, Luxembourg: Publications Office of the European Union, Vol. 2020, No. 54, pp. 1-18, 2020.
- [16] SATAR, S., ALARIFI, G., ALHAWSAWI, M.S.: Digitalization and Non-profits: Competency Requirements in Non-Profit Sector of Saudi Arabia, *Sustainable Technology and Entrepreneurship*, Vol. 4, No. 1, 100083, pp. 1-11, 2025. <https://doi.org/10.1016/j.stae.2024.100083>
- [17] UZULE, K., VERINA, N.: Digital Barriers in Digital Transition and Digital Transformation: Literature Review, *Economics and Culture*, Vol. 20, No. 1, pp. 125-143, 2023. <http://doi.org/10.2478/jec-2023-0011>
- [18] TREVIÑO-ELIZONDO, B.L., GARCÍA-REYES, H.: An Employee Competency Development Maturity Model for Industry 4.0 Adoption, *Sustainability*, Vol. 15, No. 14, 11371, pp. 1-29, 2023. <https://doi.org/10.3390/su151411371>
- [19] KOPP, R., DHONDT, S., HIRSCH-KREINSEN, H., KOHLGRÜBER, M., PREENEN, P.: Sociotechnical perspectives on digitalisation and Industry 4.0, *International Journal of Technology Transfer and Commercialisation*, Vol. 16, No. 3, pp. 290-309, 2019. <https://doi.org/10.1504/IJTTC.2019.099896>

Barriers to digital transformation in industrial, transport and logistics enterprises: empirical evidence from KazakhstanMarat Idrissov, Aliya Izbairova, Thomas Stahlecker, Gulmira Mukhanova, Botagoz Kuanyshbayeva

- [20] ALZHANOVA, F.G., KIREYEVA, A.A., SATPAYEVA, Z.T., TSOY, A.A., NURBATSIN, A.: Analysis of the level of technological development and digital readiness of scientific research institutes, *Journal of Asian Finance, Economics and Business*, Vol. 7, No. 12, pp. 1133-1147, 2020. <https://doi.org/10.13106/jafeb.2020.vol7.no12.1133>
- [21] KIREYEVA, A.A., SATPAYEVA, Z.T., URDABAYEV, M.T.: Analysis of the Digital Readiness and the Level of the ICT Development in Kazakhstan's Regions, *Ekonomika Regiona [Economy of Regions]*, Vol. 18, No. 2, pp. 464-478, 2022. <https://doi.org/10.17059/ekon.reg.2022-2-12>
- [22] AL-ABABNEH, H.A., ALRHAIMI, S.A.S., SIAM, I.M., ALSALIM, F.I.A., KHADER, J.A.: Digital transformation of supply chain management: trends and prospects, *Acta Logistica*, Vol. 12, No. 4, pp. 769-780, 2025. <https://doi.org/10.22306/al.v12i4.713>

Review process

Single-blind peer review process.