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Regression Analysis of Digitalization in Kazakhstan: Mathematical Modeling of Information Space Dynamics

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Abstract

Digital transformation is reshaping social and economic relations through the adoption of digital technologies, playing a crucial role in Kazakhstan's modernization and economic diversification. This study aims to comprehensively analyze the multifaceted process of digital transformation in Kazakhstan, with a particular emphasis on identifying potential risks and opportunities for societal development. An empirical approach using inferential statistical methods was employed, with a sample of 200 participants, including information technology (IT) professionals engaged in educational IT programs. Data were collected through questionnaires, in-depth interviews, and documentation analysis. The study identified key operational risks such as information system failures, business continuity disruptions, and data migration errors. Security risks, such as cybersecurity threats, confidential data leaks, and unauthorized access, were also highlighted. Additionally, human resource risks were noted, such as insufficient staff qualifications, resistance to change, and difficulties in adapting to new technologies. Promising areas of innovative development were identified, including the acceleration of new product development, improved business process efficiency, and the creation of new business models. The economic benefits of digital transformation include reduced operating costs, increased labor productivity, and expanded market opportunities. Social effects include enhanced service accessibility, improved digital competencies among the population, and an overall better quality of life. Based on the study's findings, it is recommended that comprehensive security measures be implemented, including the installation of modern security systems, multi-factor authentication, and regular security audits. Prioritizing human capital development through training programs, motivation systems, and fostering a digital transformation culture is also essential. Kazakhstan's digital transformation is a complex yet promising process, with its success relying on a systematic approach that integrates technological, organizational, and human factors to maximize benefits while minimizing risks.

Keywords: Digital society, Kazakhstan, prospects, risks, transformation, mathematical modeling, regression analysis.

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Introduction

Global trends highlight the growing importance of digital transformation, with digital technologies playing an increasingly vital role in national economies. The pursuit of digitalization has become a key strategic development priority for many countries in the modern global landscape (Parviainen et al., 2017). The rapid advancement of technologies driving economic digitalization facilitates seamless interaction among governments, the private sector, and civil society, contributing to a dynamic and expansive transformation. A wide range of countries, including both emerging and developed economies such as Saudi Arabia, India, Russia, China, South Korea, Malaysia, Singapore, Australia, New Zealand, and Kazakhstan, are actively implementing national digitalization strategies (Švarc et al., 2020). China integrates traditional and digital sectors through its Internet Plus program, while Singapore advances its Smart Economy initiative. Canada is developing an Information and Communications Technology (ICT) hub in Toronto, and South Korea is promoting its Creative Economy agenda, emphasizing entrepreneurship, human capital development, and ICT innovation diffusion. Denmark, prioritizes public sector digitalization (Hanelt et al., 2021). Since the digital revolution converted all forms of information into digital formats, a universal method of communication now exists worldwide. However, the degree of enterprise digital transformation varies across nations. In Kazakhstan, the public sector serves as the primary driver of digital transformation, with the highest Digital Implementation Index (DII), according to the Center for Integration Studies of the Eurasian Development Bank. The rapid evolution of digital transformation has considerably lowered market entry barriers, creating both opportunities and challenges. This shift has intensified competition, particularly in the media and communications sectors (Niggli & Rutzer, 2023). Ultimately, the rate of digital transformation is an essential factor. The correlation between technological advancements and digital changes highlights a qualitative increase in development in the new digital era, bringing forth both new challenges and opportunities (Chattergoon & Kerr, 2022; Dyantyi et al., 2025; Manzi & Moreeng, 2024; Shabalala, 2024; Shava, 2022).

The ongoing transition from an analog to a digital economy necessitates the widespread adoption of digital technologies, fundamentally restructuring daily operations and shifting workforce roles from traditional tasks to information-centric specializations. The integration of artificial intelligence into decision-making processes, facilitated by adaptive algorithms that learn from customer interaction data, serves as a key driver of digitalization (Makeleni et al., 2023; Tolstykh

& Afonin, 2021). This transformation is built on three foundational pillars: technological capabilities, data infrastructure, and human capital. In today's economic landscape, the ability to collect, manage, and strategically utilize vast amounts of data has become a critical competitive advantage across sectors. Within the framework of the Fourth Industrial Revolution, an organization's digital capital, defined as its capacity to generate value exclusively from data assets, has gained increasing importance. Data function as the core of the digital economy, making the digitalization of production processes through computational systems and the implementation of digital modeling and design technologies a practical approach to addressing digital economy development challenges. This transformation brings important advantages, including increased labor productivity, strengthened corporate competitiveness, and optimized production costs.

Kazakhstan presents a unique case in the digital transformation of society, as it is a relatively young state that gained independence following the collapse of the USSR. This raises an important question: while the world is advancing in digital transformation, how prepared is Kazakhstan for these changes? Domestic researchers often rely on global practices due to the limited study of this topic within the country. The potential conflicts and outcomes of Kazakhstan's digital transformation remain an open question, requiring further empirical research. The findings from such studies could contribute valuable insights into the field of domestic conflict and serve as a foundation for future studies.

Digital transformation has recently been implemented in government agencies across the Republic of Kazakhstan, with various domestic studies on this topic conducted in scientific centers throughout the country. According to the United Nations, Kazakhstan has made considerable progress in digital transformation. The highest rate of digital case usage is observed among residents of Almaty at 97%, while the lowest rate is recorded in the Kyzylorda region at 78%. However, participation in digital transformation remains uneven across different regions, with the most active engagement seen in Astana, Almaty, Shymkent, and Aktobe (Tagay & Beisenov, 2022). In recent years, digitalization has been leveraged to address key economic challenges within the country. By increasing digital literacy, there is a strategic effort to integrate a larger portion of the population into economic development initiatives and facilitate the establishment of new business ventures at various levels (Alibekova et al., 2020).

The digitalization of education and the integration of innovative technologies into the educational process remain pressing issues. Researchers continue to examine the benefits and challenges of

digital transformation in education, exploring various technological tools and their impact on educational quality. A key focus is on the adaptation of the educational system to evolving digital realities (Abdiyev et al., 2023; Moldagali et al., 2022). Gqoli (2024) highlights the use of digital technologies in teaching mathematics in rural areas, analyzing students' perspectives on the adoption of digital tools in mathematics education, and identifying both the challenges and opportunities associated with technology use in rural settings. Special emphasis is placed on tailoring digital solutions to local conditions and specific educational needs.

Threats to national security posed by unverified information in the digital space are important. Such situations contribute to the rise of individuals who, despite lacking formal education on a topic, consider themselves informed. The illegal dissemination of unverified information can lead to social, political, and ethnic conflicts within a state. The Republic of Kazakhstan is implementing information security measures for the first time based on global best practices. While information serves as a tool for knowledge dissemination, it also has a chaotic and potentially destructive nature (Alibekova et al., 2020). For example, on January 1 and 4, 2022, unverified terrorist-related information spread through Kazakhstani messaging platforms, intensifying public conflict sentiments. Due to uneven digital literacy, terrorists were able to sustain their activities in the country for an extended period. A large portion of hooligan groups involved in the unrest were residents of suburban settlements, highlighting the lower level of digital literacy in remote areas compared to urban populations. Research conducted by the Institute for Strategic Research under the President of Kazakhstan has documented these disparities (Kazakhstan Ministry of Digital Development, 2022). Predicting future conflicts in the information space is only possible through mathematical modeling. Strengthening information security and improving digital literacy among citizens can help prevent these threats (Maltabarov & Sarybayev, 2024). A more digitally literate population would allow the government to implement state policies more effectively. Increasing digital literacy is a key strategy for preventing information conflicts, and mathematical modeling based on global experience can enable Kazakhstan to anticipate and address potential digital threats (Dulambayeva & Zhumasheva, 2021).

Research on the impact of digitalization on the political involvement of Kazakhstani youth is gaining increasing attention. Social media and digital platforms have transformed the way young people engage in politics, with particular focus on the evolution of political activity in the online space and the effects of the events of January 2022 on digital political participation (Tolen et al.,

2023). Previous studies have examined various aspects of digital transformation, including project objectives, challenges, and solutions (Gertzen et al., 2022; Almeida et al., 2020; Feliciano-Cestero et al., 2022). However, these studies primarily focused on the goals and benefits of digital transformation initiatives. This study takes a different approach by exploring both the risks and opportunities associated with digitalization, offering a unique perspective. It contributes to the academic field by introducing a novel theoretical exploratory framework developed from a real case study, distinguishing it from prior research.

The primary objective of this study is to examine the opportunities and risks associated with digital transformation in Kazakh society. To conduct exploratory research, relevant data must be collected and organized according to predefined research questions. These questions are carefully designed to guide the analysis and interpretation of the gathered information. The research questions include:

1) What digital transformations have been identified in the research on this issue?

2) What risks are associated with digital transformation in Kazakh Society?

3) What are the prospects of digital transformation in Kazakh society?

4) Can digital transformation help resolve conflicts and improve the well-being of the population in Kazakhstan?

Overview of digital transformation in Kazakhstan

Kazakhstan has the largest economy in Central Asia, benefiting from substantial natural resource endowments, including major hydrocarbon reserves—ranking 12th globally in oil and 14th in natural gas—as well as strategic mineral deposits, holding 30% of the world's manganese and 25% of its chrome ore reserves, along with considerable tungsten and molybdenum resources. Additionally, its vast territorial expanse, making it the ninth-largest country by area, provides potential for agricultural and industrial development. However, in the modern global economy, resource abundance alone is not sufficient to ensure international competitiveness (Gambino, 2020).

To address this challenge, the government initiated the *Digital Kazakhstan* state program through a presidential decree in 2017. This strategic initiative aims to achieve several key objectives, the digital transformation of core economic sectors, enhancement of information and communication technology infrastructure, implementation of electronic governance systems, and promotion of technology-driven entrepreneurship. As a result, Kazakhstan was ranked among the world's 30

most digitally developed nations in 2022, according to the Kazakhstan Digital Development Authority (2022), and continues to advance its digital reforms. Kazakhstan's digital landscape has seen remarkable progress, with an Internet penetration rate of 92.9% in 2022 and a narrowed rural-urban digital divide of just 4%. The country's global positioning in key technological indices further reflects this development, ranking 51st in the ICT Development Index and 58th in the Network Readiness Index (International Telecommunication Union, 2022).

The IT sector in Kazakhstan is experiencing considerable growth, with programming, consulting, and associated services generating 772 billion tenge (approximately USD 1.67 billion) in revenue in 2022, reflecting a 19.5% year-over-year increase. This growth trajectory continued into 2023, with first-quarter earnings rising by 23.4% compared to the same period in 2022. The industry is highly concentrated in major urban centers, with Almaty and Astana emerging as leading IT hubs, accounting for 49% and 41.5% of IT services, respectively. The sector has also seen substantial expansion, as evidenced by a 2.7-fold increase in software development and IT consulting firms over the past four years (GlobalCIO, 2023).

Software development accounts for over 50% of ICT services in Kazakhstan, with EPAM, a multinational corporation, being the leading tax contributor among registered software enterprises. Domestic market players primarily focus on specialized sectors such as financial technology, industrial digital transformation, quasi-public services, and e-government initiatives. Recent geopolitical developments in the region have led to an influx of IT enterprises and professionals from Belarus, Russia, and Ukraine, further shaping the local technology landscape. The ongoing digital transformation across economic sectors continues to drive high demand for both domestic and international IT specialists in the labor market.

The establishment of AstanaHub Technopark in 2018 marked an important milestone in Kazakhstan's IT sector. This initiative, designed to foster technological enterprises through tax incentives and a supportive ecosystem, has achieved notable economic success. According to the Kazakhstan Ministry of Digital Development, Technopark contributed to IT service exports reaching 123.3 billion tenge by mid-2022, while the total revenue generated by participating entities since its inception has amounted to 383 billion tenge (Suominen, 2024).

The Technopark currently hosts over 1,100 registered enterprises and has provided specialized IT education to more than 15,000 individuals through various programs since 2018. This educational component is particularly important given the shortage of qualified professionals in the digital

transformation sector. The initiative addresses both infrastructural and human capital development needs within Kazakhstan's emerging digital economy. One of Astana Hub's main objectives is to promote the growth of technology-focused entrepreneurship. Its acceleration and incubation programs have already produced over 2,000 graduates (Tagay & Beisenov, 2022). Universities such as Al-Farabi Kazakh National University, Nazarbayev University, and IT universities offer free courses to enhance digital knowledge among the population. According to the Ministry of Education and Science of Kazakhstan, 40,000 people have completed such courses in recent years, with new projects emerging annually to support the national goal of improving digital education. JSC National Information Technologies launched digital literacy training for the population through the "Open Government" course in 2018. According to nitec.kz, from June 1 to August 29, 2018, 500,000 citizens participated in the training. As part of monitoring and assessing training quality, IT company employees were sent to regions including Atyrau, East Kazakhstan, Almaty, Kostanay, and Pavlodar. Detailed reports were compiled based on the findings. As part of the "Open Government" course, JSC National Information Technologies, in collaboration with JSC NIKH Zerde, produced video lessons that are publicly available on platforms such as kaztube.kz and YouTube. Under the "Digital Kazakhstan" state program, the goal was to gradually increase the population's digital literacy level to 83% by 2022, a target that was successfully achieved (Dulambayeva & Zhumasheva, 2021).

Since 2023, the Connect-ed Foundation has been providing free digital literacy education to children across Kazakhstan while also fostering digital citizenship through an educational platform. At Abai Kazakh National Pedagogical University, under the leadership of E.Kh. Zhabayeva, a project was developed to improve digital literacy among students. On April 4, 2013, the Ministry of Science and Education of the Republic of Kazakhstan introduced changes to school curricula, requiring students in grades 1-4 to begin studying digital literacy. This initiative gained further momentum in 2020 due to the pandemic, prompting the Ministry to expand digital literacy education to all schools nationwide. Additionally, specialized advanced training courses for computer science teachers were launched to support the effective implementation of digital literacy programs (Sultanbayeva & Lozhnikova, 2021).

Digital transformation

Digital transformation (DT) encompasses the evolution of business models driven by the integration of digital technologies across all domains of human society (Stolterman & Fors, 2004).

This transformation is often reflected in the shift from traditional products and services to digital formats, offering enhanced value propositions compared to their physical counterparts (Gassmann et al., 2014). The dynamic nature of digital transformation addresses fundamental changes in sectoral economics, leveraging digital technologies to improve market interactions, competitiveness, productivity, and innovation (Hess et al., 2016). As digital transformation continues to expand, a growing body of research examines its impact on both developed and developing nations (Tijan et al., 2021). Studies show that key elements of digital transformation can drive multiple positive outcomes, including enhanced production efficiency, increased labor productivity, quality job creation, equitable wage distribution, virtual service delivery, and sustained innovation (Matt et al., 2015). Digital transformation fundamentally alters how businesses operate and deliver value to customers through the integration of digital technologies into all sectors (Quinn et al., 2016). It influences customer experiences, operational procedures, and business models. Furthermore, as digital transformation becomes deeply embedded in business operations, certain industries are likely to experience greater growth opportunities in the future.

Value in digital transformation is created through the sharing of industrial data and insights. Collaboration is streamlined by providing easy access to compiled, curated, and shared information, eliminating the need for in-person meetings and excessive emails. Instant access to reliable data for all team members enhances workflow transitions, optimizes productivity, and reduces errors. Artificial intelligence (AI) plays a crucial role by identifying patterns in industrial data that may not be immediately apparent to humans, uncovering mistakes and opportunities that might otherwise go unnoticed. Additionally, Augmented Reality (AR) and Virtual Reality (VR) visualization technologies enhance data comprehension and support rapid analytical decision-making. By utilizing immersive visual representation techniques, researchers and analysts can process complex datasets more effectively, allowing for intuitive and accelerated insights. These advanced visualization tools facilitate a deeper and more immediate understanding of intricate information structures, reducing cognitive load and improving the accuracy of analytical judgments.

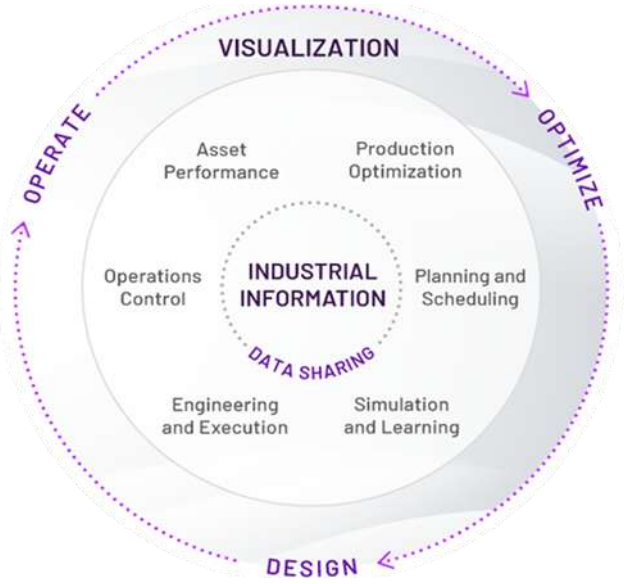

Figure 1. Overview of Digital Transformation

Figure 1 illustrates a framework for industrial information management, emphasizing the interconnected processes of design, optimization, operation, and visualization within the context of digital transformation. At the center of the diagram is "Industrial Information," supported by robust data-sharing mechanisms. This emphasizes the critical role of centralized, accessible data as the foundation for decision-making, operational optimization, and innovation. In the context of Kazakhstan's digital transformation, this framework underscores the importance of investing in ICT infrastructure to enable seamless data integration and utilization. Such advancements are essential for achieving the objectives of the national project “Digital Kazakhstan,” ensuring that digital technologies effectively enhance industrial operations and drive sustainable development.

The design phase includes engineering, execution, and simulation, emphasizing the role of digital tools in creating virtual models, testing systems, and efficiently implementing designs. This stage enables organizations to refine processes before physical execution, reducing costs and improving accuracy. The optimization phase encompasses production optimization and planning, demonstrating how digital technologies enhance resource allocation, productivity, and scalability. This aligns with findings on economic efficiency, showing how digital transformation drives cost-effectiveness and operational improvements. The operating phase focuses on asset performance and operational control, ensuring real-time system and asset management. This reduces risks such as cybersecurity threats, which are highlighted as key challenges in digital transformation. Real-time monitoring allows for predictive maintenance, minimizing downtime and improving overall

efficiency. The visualization phase enables stakeholders at all levels to access and interpret data-driven insights, ensuring informed decision-making. By improving accessibility, visualization tools help address challenges such as digital inequality, allowing broader participation in data-driven processes and enhancing transparency in digital transformation initiatives.

Risks involved in digital transformation

Operational risk is one of the most important risks businesses face, as it directly impacts the future value and development of a company. Hu (2021) argues that operational risk is closely related to firm value. Recent studies by Ari Data (2019) and Cheng (2022) provide deeper insights into the complex relationship between operational risk, financial performance, and corporate value, particularly in the banking sector. These studies present a counterintuitive perspective, indicating that when strategically managed, operational risk can lead to positive outcomes for organizational performance. Additionally, digitalization plays a crucial role in shaping operational risk exposure, affecting how businesses manage and mitigate these risks (Uddin et al., 2024).

Several studies have reported that while digital transformation can enhance corporate value, reducing business risks can also contribute to increasing enterprise value. This suggests a relationship between enterprise business risk and digital transformation, where managing risks effectively may strengthen the impact of digital transformation on enterprise value. In other words, business risk acts as a mediating factor in the relationship between digital transformation and enterprise value, affecting how digital initiatives translate into long-term business success.

Prospects of digital transformation

The role of AI in digital transformation has become increasingly important. AI was first adopted in Western countries to support societal digitalization, with Wall Street banks integrating AI into their operations as early as the 2000s to adapt to evolving business conditions and market demands. Initially, this step proved highly effective in digitizing employees and customers within the banking system. As a result, the U.S. market was able to reshape various business models, corporate culture, and work procedures. Beyond the financial sector, AI offers algorithmic mechanisms for resolving complex conflicts and facilitating large-scale state projects in the digital space. Given the challenges of processing vast amounts of information manually, AI has played a critical role over the past decade in managing data-intensive tasks and optimizing decision-making processes (Gibson, 2024).

The conceptualization of digital transformation, as articulated by Gilch & Sieweke (2021), presents it as a sophisticated organizational paradigm where digital technologies function as strategic tools for environmental sensing and market opportunity recognition. This process involves a multidimensional approach to technological integration, fundamentally restructuring organizational capabilities through the strategic deployment of advanced digital infrastructures. Wu et al. (2021) claim that digital transformation provides additional momentum for business development by integrating digital technologies into existing production systems. However, the effectiveness of this transformation is inevitably affected by data flow dynamics and external uncertainties. According to Huang et al. (2021), digital transformation can enhance enterprise value and overall business performance, while Cheng (2022) finds a positive correlation between productivity and digital transformation. Liu et al. (2023) highlight the beneficial impact of digital transformation on the volume of patent applications, grants, and research and development intensity. Based on signal transmission theory, government innovation subsidy incentives play a guiding role in helping businesses gain stakeholder confidence, directing financial resources toward enterprise innovation, and strengthening their capital base for research and development (Appio et al., 2021; Lee, 2011). These incentives contribute to overcoming challenges, reducing the likelihood of innovation failure, and enhancing an organization's ability to manage risks (Ivanov et al., 2019; Lichtenthaler, 2016).

Foreign studies on economic development have also examined the digital transformation of Kazakhstan. In the context of economic partnerships with European countries, global experience highlights the crucial role of digital education in fostering economic cooperation. The widespread adoption of digital payment technologies and Kazakhstan's leadership in this sector within Central Asia have drawn the attention of Western countries. This interest presents opportunities for developing new business and educational programs based on mutual collaboration in the economic and business sectors. According to Times, Kazakhstan is on the right path toward digital transformation (Suominen, 2024).

Digitalization can play a crucial role in maintaining economic stability and preventing future social conflicts within the country. By leveraging digital technologies, it becomes possible to affect the trajectory of rapidly evolving events, counteract information propaganda, and manage situations more effectively. Digitalization also facilitates communication between the government and citizens by establishing feedback mechanisms, which can enhance mutual understanding

(Assyltayeva et al., 2024; Mukanov, 2023). Additionally, digitalization serves as a tool for reducing social tensions by enabling citizens to engage directly with the government on pressing issues. This aligns with Tokayev's vision for New Kazakhstan as a "listening state," introducing necessary reforms to replace outdated governance practices (Francesco et al., 2020).

Literature-based data show that digital transformation enhances the value and efficiency of innovation in private firms. Contemporary scholarly research highlights digital technology adoption as a multidimensional strategic mechanism that fundamentally reshapes organizational capabilities and value generation processes. Integrating key studies by Loebbecke et al. (2015), Meng et al. (2024), Zhou (2023), and Marín et al. (2023), this analysis explores the considerable impact of digital technological integration across enterprise ecosystems.

Digital transformation accelerates enterprise innovation, with its most important policy impacts seen in cost reduction, profit growth, efficiency enhancement, and the promotion of innovation (Peng & Tao, 2022). However, innovation outcomes can be easily replicated, and spillover effects may reduce businesses' motivation for research and development, particularly when they struggle to mitigate the risks associated with innovation. To address this challenge, the implementation of the Visible Hand strategy has emerged as a key mechanism for risk compensation and sharing, fostering innovation in private enterprises. According to Carboni (2011), beneficiary enterprises engage in more private research and development (R&D) than they would have without public support, demonstrating the positive impact of government assistance on private R&D investment. Innovation subsidies help private companies share innovation risks, ultimately increasing their potential for technological advancement and sustainable growth.

Digital technology is increasingly recognized as a crucial risk-reduction strategy, particularly through the lens of information processing theory. Digital transformation enhances information accessibility, enabling private firms to more effectively identify and integrate external knowledge—an essential capability given the growing complexity of information they must manage (Qinqin et al., 2023). According to domestic research, over the past five years, the number of small and medium-sized businesses in Kazakhstan has grown by 34.67% compared to 2020, largely due to the rising digital literacy of the population. This trend has contributed to the expansion and development of the Kazakh market. Research conducted by scientists at Nazarbayev University shows that digital literacy has increased by 43% compared to 2022, leading to a noticeable decline in the activity of factors that contribute to conflicts in the information space.

These findings suggest that improving digital literacy has had positive effects on conflict prediction through mathematical modeling in the digital sphere. Currently, information security remains one of the most pressing national concerns, and increasing digital literacy has played a key role in addressing this challenge. Since mass digitalization in Kazakhstan began earlier than in other Central Asian states, the country's digital literacy levels are relatively higher than those of its neighbors, including Kyrgyzstan, Uzbekistan, Turkmenistan, and Tajikistan. As a result, Kazakhstan is now considered the leading country in Central Asia in terms of digitalization. This process is expected to drive further economic growth and attract labor migrants to Kazakhstan. According to R Case research, digitalization could position Kazakhstan as a new economic hub in Central Asia within the next decade (Moldagali et al., 2022).

The collection and processing of market data using digital technologies enable businesses to make informed decisions and enhance investment efficiency. At the same time, leveraging big data promotes information transparency, facilitates the exchange of data resources, and strengthens investor confidence in corporate innovation initiatives. Moreover, businesses upgrade their technological capabilities and draw insights from peer research to better assess and mitigate the risks associated with innovation failure.

Methodology

Research Design

This study examines digital transformation in Kazakh society, focusing on its associated risks and opportunities. A quantitative empirical approach is employed, utilizing inferential statistical methods to analyze data. Through this approach, the study aims to provide insights into the digital transformation landscape, particularly in the context of IT adoption and educational programs in Kazakhstan. A fuzzy mathematical model of risk management in digital transformation is used as one of the research methods, allowing for the simulation of potential outcomes. Mathematical methods offer a more precise and objective assessment of social processes within any country. This research approach has recently gained traction at the London Royal Institute of Applied Mathematics, where it is frequently used to model social relations and conflicts in the United Kingdom.

Study Sample

The study's target population consists of individuals directly involved in Kazakhstan's digital transformation landscape, including IT service providers and participants in educational IT programs. A purposive sampling technique was used to select 200 participants, including IT professionals, educators, and students engaged in digital training initiatives. Sex of participants to a study as this is very necessary. However, from our study data in Table 1 showed that majority (56.7%) of the participants of this study are females while males were only a slight difference of 43.3%. The largest proportion was made up of participants aged 18 years, accounting for 22.9% of the survey participants, followed by participants aged 20 years (18.6%), participants aged 21 years accounted for 17.3%, participants aged 19 years accounted for 13.0%, participants aged 22 years accounted for 10.4% and participants aged 23 years and above accounted for 13.4%. We assessed the percentage of participants by specialty. The overwhelming majority (55.4%) of participants were studying in the humanities, and 44.6% in technical specialties. At the same time, if we analyze by years of study, the majority (48.1%) of participants were studying in the 4th year, 29.0% in the 2nd year, 13.0% in the 3rd year, and 10.0% in the 1st year. Different cities/regions directly related to this study were selected and the research data showed that 54.1% of the respondents were from Almaty, 27.3% from Astana, 16.9% from Almaty region and 1.7% from Shymkent.

The selection criteria ensured that participants had substantial experience or exposure to digital technologies, providing relevant insights into the research focus. The sample was drawn using a random stratified approach and conducted independently in Almaty. Participants included students and teachers from eight universities, as well as Almaty resident's familiar with digital transformation. As the largest city in Kazakhstan, home to 15% of the country's population, Almaty offers a representative demographic, as students from all regions study there. Each student in Almaty reflects the political psychology of their home region regarding digital transformation. According to city statistics from the Akimat, 60% of students in Almaty come from other regions, while 40% are residents. This distribution suggests that at least 50% of survey participants represent various regions of Kazakhstan, enhancing the reliability and objectivity of the research findings.

One-third of Kazakhstan's population is concentrated in the southern region, where the cities of Almaty and Shymkent, both of republican significance, are located. The southern region leads in

digital literacy in terms of the number of digitally literate individuals. However, the highest percentage of digital literacy belongs to residents of the northern region, though they tend to be less politically active. In contrast, the western region maintains an average level of digital literacy but stands out for its high political engagement. The interview for this study was conducted in Almaty, a city where only 17% of residents are locals, making it a diverse hub with representation from all regions of Kazakhstan. This demographic diversity enhances the objectivity of the social interview, making it more reliable compared to surveys conducted in other cities (Sultanbayeva & Lozhnikova, 2021).

Data Collection

Rather than employing conventional data collection instruments, our study utilized analytical tools specifically designed for documentary research. Following Coffey's (2014) documentary analysis methodology, we developed a comprehensive analytical framework consisting of four interconnected components tailored to our research focus on digital religious identity.

The primary analytical instrument was a systematically developed coding schema derived from both a priori theoretical constructs and emergent patterns identified during preliminary analysis. This coding schema consisted of 47 distinct codes organized into seven thematic categories: (1) digital religious practices, (2) identity markers, (3) authority structures, (4) community formation, (5) technological affordances, (6) cultural contextualization, and (7) religious transformation processes. Each code was operationally defined according to Wood and Kroger's (2000) discourse analysis principles, with explicit inclusion and exclusion criteria to ensure consistent application across the documentary corpus.

A thematic matrix instrument was developed to systematically map relationships between identified concepts, following Miles, Huberman and Saldaña's (2019) qualitative data display techniques. This matrix enabled the visualization of complex interconnections between digital engagement patterns and religious identity formation processes, facilitating the identification of both manifest and latent patterns across the documentary corpus. The matrix was structured with digital engagement practices along one axis and identity formation processes along the other, creating analytical intersections that illuminated key relationships.

To enhance analytical rigor, we employed analytical memoing as an instrument for documenting interpretive insights, methodological decisions, and theoretical developments throughout the

analytical process. Following Birks, Chapman, and Francis's (2008) guidelines for reflexive memoing, these analytical notes served as both process documentation and conceptual scaffolding for our emerging theoretical framework. The memoing process adhered to Charmaz's (2014) constructivist approach, emphasizing theoretical sensitivity while maintaining analytical transparency.

For identifying temporal and evolutionary patterns in digital religious engagement, we developed a chronological mapping instrument that tracked transformations in religious identity construction across our documentary corpus. This instrument, informed by Gee's (2014) discourse analysis techniques, enabled the identification of shifting patterns in how religious identity is negotiated within increasingly digitalized environments. The chronological mapping was particularly valuable for understanding how religious authorities in Kazakhstan have adapted their approaches to digital engagement over time.

All analytical instruments were refined through an iterative process of application and evaluation, with adjustments made to enhance their conceptual validity and analytical utility. This iterative refinement process aligns with Altheide and Schneider’s (2013) ethnographic content analysis approach, which emphasizes flexible instrument development responsive to emerging analytical insights. The final analytical framework thus represented a methodologically robust approach to examining the complex interrelationships between digital technologies and religious identity formation in Kazakhstan's distinctive cultural context.

Data Collection

Primary data were collected through structured questionnaires designed to capture participants' perspectives on the risks and prospects of digital transformation in Kazakh society. The questionnaire included both closed-ended and Likert-scale questions, addressing areas such as digital skills, infrastructure, regulatory challenges, and the socio-economic impact of digital adoption. The social survey consisted of 42 main questions on the research topic. The social survey also has 5 subscales depending on the participants’ answers. The Likert scale itself was formed from collective responses to a set of items (usually eight or more), and a format in which responses were rated on a range. The results of the research work were attached together with the article, where the results of the social survey were fully analyzed. Also included in the attached research document is 42 main tables. Table 32 is a cross tabulation of approach to conflict resolution and

effects of application of mathematical modeling approach. Approach to conflict resolution involves an index built from table 11 that contains distribution of respondents on Approaches to conflict resolution. Effects of application of mathematical modeling approach on the other hand was measured with reported effects in table 14. Rejection region: If $p \leq .05$ reject the null hypothesis (Ho), but if $p > .05$, we accept the null hypothesis. The test is a one-tailed test. With the computed $\chi 2 = 9.908a$; $df = 1$; the test shows that there was a statistically significant relationship ($P. \leq .002$) between approach to conflict resolution and effects of application of mathematical modeling approach. Therefore, the substantive which hypothesis states that Application of mathematical modeling approach to conflict resolution in Almaty will have significant effects in combating gender based or local conflicts is valid and therefore upheld. (As mentioned above, all the results of the social survey were attached along with the article as a separate research document.)

Before distribution, a pilot test was conducted with 20 participants to ensure the clarity and validity of the questions, and feedback was used to refine the final version of the questionnaire. This measurement tool has been utilized in several European research institutes, including the Royal Mathematical Institute in London, the Institute for Policy Studies in Stockholm, and Sorbonne University, over the past decade. The methodology is particularly useful for quickly obtaining accurate insights, with subscales adaptable to the content, scope, and focus of the study. In this research, the conflict potential of individuals' temperament in the social space during the era of digitalization was examined. The interview process covered individuals aged 16 to 55, with many participants being students from national universities across different regions. The interview consisted of 20 main questions and sub-questions, structured to optimize the accuracy of responses and facilitate mathematical modeling of the findings.

Data collection begins with verifying the accuracy of both qualitative and quantitative data. When samples are correctly selected, they serve as a reliable basis for making informed decisions. In this study, samples were objectively chosen, and additional expert evaluations were conducted to enhance accuracy. An algebraic method was applied to minimize the risk of uncertainty, a methodology developed by European scientists two centuries ago to analyze and solve complex social and interdisciplinary issues. Effective data collection not only improves the success of problem research but also plays a crucial role in mathematical modeling and forecasting various challenges across different fields and levels (Aung et al., 2020).

Data Analysis

The collected data were analyzed using inferential statistical methods. Descriptive statistics were first applied to summarize the demographic characteristics of the participants and provide an overview of the survey responses. To examine relationships between variables and make inferences about the broader population, inferential statistical techniques such as t-tests and ANOVA were utilized. These methods allowed for the assessment of significant differences in perceptions of digital transformation risks and prospects among various groups within the sample. The hypothesis of normal population distribution was tested using the Pearson goodness-of-fit test during the study. The length of the partial interval and the sample size were evaluated multiple times throughout the research. The interval midpoints were calculated, which allowed for the determination of the sample mean. The critical value of the degrees of freedom provided objective assessments of the study's validity (Kuzembay, 2023).

The social interview comprised approximately 20 questions aimed at assessing people's digital literacy and determining their conflict activity. The interview primarily involved young people, with no restrictions based on the characteristics of youth from different regions of Kazakhstan. Most of the respondents were students.

During the socio-statistical analysis, we verified the responses of interview participants and cross-checked their accuracy using probability theory. The research results were applied to mathematical modeling only after this verification process. According to Parker (2019), this method ensures objectivity with a probability of 90%.

Additionally, a correlation analysis was conducted to examine the relationship between the level of digital education received by participants and their perception of the risks and benefits of digital transformation. Statistical analysis was performed using SPSS software to ensure the accuracy and reliability of the findings.

Limitations of the Study

The study has several limitations. Firstly, the use of purposive sampling may restrict the generalizability of the findings to the broader Kazakh society. Secondly, the reliance on self-reported data could introduce biases, as participants might provide socially desirable responses. Despite these limitations, the study provides valuable insights into the risks and prospects of digital transformation in Kazakhstan, contributing to the broader discourse on digital adoption in

emerging economies. While purposive sampling was appropriate for selecting participants with relevant characteristics, it still limits generalizability. Since the study focuses on a specific group, such as IT professionals in educational programs, the findings may not fully reflect the experiences of the entire Kazakh population. Recognizing this limitation ensures transparency and encourages future research to incorporate more diverse sampling methods to improve generalizability.

Findings

The analysis provided important insights into the digital transformation of Kazakh society. The study found that participants generally had a positive perception of digital transformation, identifying key benefits such as enhanced access to information, improved digital skills, and increased economic opportunities. However, concerns were also raised, particularly regarding digital inequality, inadequate infrastructure, and regulatory challenges. Correlation analysis revealed a strong positive relationship between digital education levels and optimistic views on digital transformation, suggesting that participants with greater exposure to IT programs were more likely to recognize its benefits. These findings suggest that targeted digital education initiatives could help mitigate some of the perceived risks and accelerate digital adoption in Kazakhstan. The results were divided into two categories: The first focused on descriptive statistics, assessing whether participants acknowledged digital transformation in Kazakhstan and their perceptions of its risks and prospects. The second category involved inferential statistics, which were used to validate and support the study's findings.

Descriptive Analysis

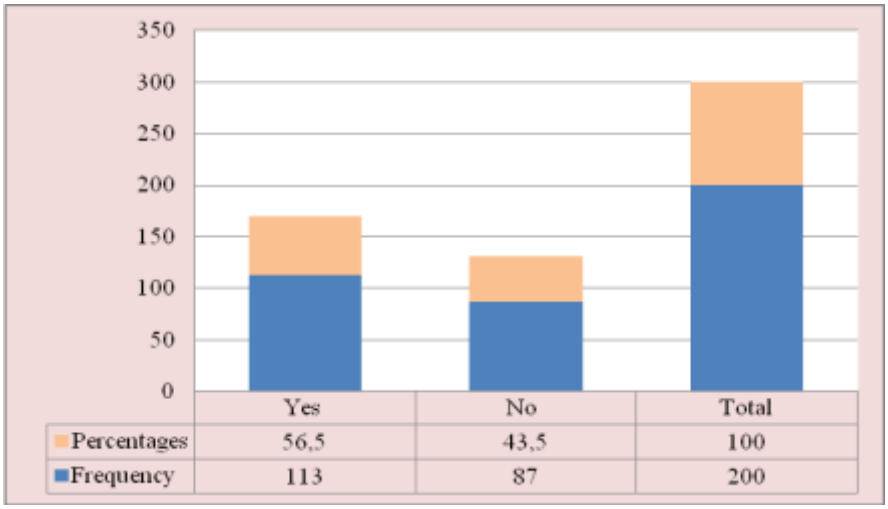

Figure 2. Do You Think There is Digital Transformation in Kazakh Society

Figure 2 illustrates the distribution of participants' views on the presence of digital transformation in Kazakh society. More than half of the participants (55.5%) agreed that digital transformation is taking place, while 45.5% disagreed. This finding shows that many respondents recognize digital transformation in Kazakh society, though a significant portion remains skeptical about its extent or impact.

Table 1

What Statement Best Describes Digital Transformation to You?

Description	Mentioned	Not mentioned	Total
User adoption rates	79 (39.5%)	121(60.5%)	200.0
Making data usable	110 (55.0%)	90 (34.9%)	200.0
Empowering non-IT users	101(50.5%)	99(49.5%)	200.0
Simplifying IT complex processes	113(56.5%)	87(43.5%)	200.0

Data in Table 1 showed that many participants (39.5%) identified user adoption rates as the key factor defining digital transformation. Additionally, 55.0% considered making data usable as a determining factor, while 50.5% emphasized the importance of empowering non-IT users. The highest percentage (56.5%) highlighted simplifying complex IT processes as a crucial aspect of digital transformation.

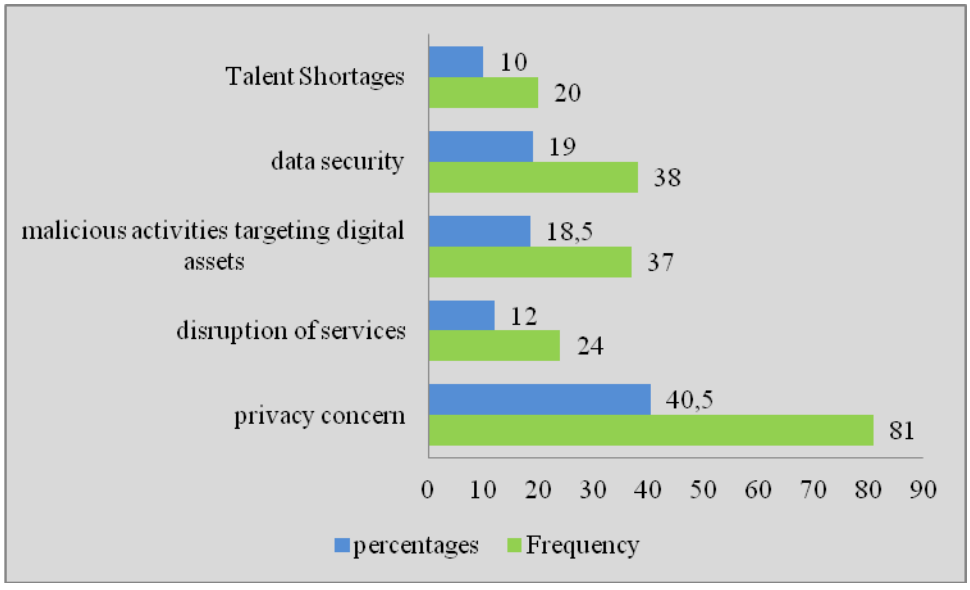

Figure 3. What are the Risks Associated with Digital Transformation

Data in Figure 3 showed that 40.5% of participants identified privacy concerns as the primary risk associated with digital transformation. This was followed by data security concerns at 19.0%, malicious activities targeting digital assets at 18.5%, disruption of services at 12.0%, and talent shortages at 10.0%.

Table 2

What Signifies Prospects in Digital Transformation

Prospects	Frequency	Percent
Lowering the risks associated with running a business	55	27.5
Fostering Business creativity	48	24.0
making data more accessible	40	20.0
Minimize instances of poor decision-making	36	18.0
Minimize instances of wasteful investments	21	10.5
Total	200	100.0

Results from Table 2 revealed that 27.5% of participants identified lowering the risks associated with running a business as the primary benefit of digital transformation. Additionally, 24.0% indicated fostering business creativity, 20.0% highlighted making data more accessible, 18.0% mentioned minimizing instances of poor decision-making, and 10.5% pointed to reducing wasteful investments. These findings suggest that most participants view risk reduction in business operations as the key prospect of digital transformation in Kazakhstan, emphasizing the role of digital technologies in enhancing business stability and efficiency.

Inferential Analysis

Table 3

*Digital Transformation * Digital Transformation Risks Crosstabulation*

Digital transformation	Digital transformation risks					Total
	Privacy concern	Disruption of services	Malicious activities targeting digital assets	Data security	Talent Shortages	
Yes	48(42.5%)	18(15.9%)	31(27.4%)	7(6.2%)	9(8.0%)	113(100.0%)
No	33(37.9%)	6(6.9%)	6(6.9%)	31(35.6%)	11(12.6%)	87(100.0%)
Total	81(40.5%)	24(12.0%)	37(18.5%)	38(19.0%)	20(10.0%)	200(100.0%)

$\chi 2=38.295^{a}$, df=4, N=191, p< .000

Table 3 presents a cross-tabulation of digital transformation and digital transformation risks. Digital transformation was assessed using an index derived from Figure 1, categorizing responses

as "yes" or "no," while digital transformation risks were measured using data from Figure 2, which categorized different risk factors associated with digital transformation.

The rejection region for the hypothesis test is defined as follows: if $p \leq .05$, the null hypothesis (Ho) is rejected, indicating a statistically significant relationship; if $p > .05$, the null hypothesis is accepted. The test follows a one-tailed approach.

With a computed χ^2 value of 38.295, degrees of freedom (df) = 4, and a significance level of $p < .000$, the results indicate a statistically significant relationship between digital transformation and digital transformation risks. This suggests that the risks associated with digital transformation are influenced by the extent of digital transformation itself.

Table 4

*Digital Transformation * Prospects of Digital Transformation Crosstabulation*

Digital transformation	Prospects of Digital transformation					**Total**
	fostering business creativity	lowering the risks associated with running a business	making data more accessible	minimize instances of poor decision-making	minimize instances of wasteful investments	
Yes	32(28.3%)	30(26.5%)	22(19.5%)	16(14.2%)	13(11.5%)	113(100.0%)
No	23(26.4%)	18(20.7%)	18(20.7%)	20(23.0%)	8(9.2%)	87(100.0%)
Total	55(27.5%)	48(24.0%)	40(20.0%)	36(18.0%)	21(10.5%)	200(100.0%)

$\chi 2=3.181^a$, df=4, N=191, p< .528

Table 4 presents a cross-tabulation of digital transformation and the prospects of digital transformation. Digital transformation was assessed using an index derived from Figure 1, categorizing responses as "yes" or "no," while the prospects of digital transformation were measured using data from Table 2, which categorized different benefits associated with digital transformation.

The rejection region for the hypothesis test is defined as follows: if $p \leq .05$, the null hypothesis (Ho) is rejected, indicating a statistically significant relationship; if $p > .05$, the null hypothesis is accepted. The test follows a one-tailed approach.

With a computed χ^2 value of 3.181, degrees of freedom (df) = 4, and a significance level of $p = .528$, the results indicate that there is no statistically significant relationship between digital transformation and the prospects of digital transformation. This suggests that the perceived benefits of digital transformation are not directly influenced by the extent of digital transformation itself.

Multiple regression analysis

Regression analyses were conducted to verify the objectivity of the research. Additionally, statistical analyses were applied at the final stage to enhance the probability of achieving accurate and objective results. For a study of this nature, it is recommended to multiple regression analysis be performed to further assess digital transformation in Kazakh society. This approach allows for a more comprehensive examination of the relationship between variables identified in existing literature, reducing errors in prediction. Furthermore, multiple regression analysis can determine which variable has the strongest predictive influence on digital transformation in Kazakh society, as demonstrated in the following analysis.

Table 5

Dependent Variable: Digital Transformation Risks

Model		Unstandardized coefficients		Standardized coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	2.607	.645		4.043	.000
	user adoption rates,	-.084	.206	-.029	-.406	.685
	making data usable	.400	.206	.139	1.938	.054
	Empowering non-IT users	-.247	.203	-.087	-1.217	.025
	Simplifying IT complex processes	-.156	.206	-.054	-.755	.451

R= 3,39 R^2= 11.52 F= 2 p= 0,5

The multiple regression analysis presented above included independent variables such as simplifying IT complex processes, user adoption rates, empowering non-IT users, and making data usable as predictor variables to assess their influence on digital transformation risks. All five variables statistically significantly contributed to the prediction, with $p < .05$. Among them, two variables—making data usable ($p < .054$) and empowering non-IT users ($p < .025$)—were found to be statistically significant predictors of digital transformation risks. These findings suggest that in the future, making data more accessible and empowering non-IT users could play a crucial role in mitigating digital transformation risks. The results were obtained using ordinal regression analysis, which goes beyond simple descriptive statistics by providing a comparative analysis. This approach enables a more comprehensive examination of the relationships between variables rather than merely assessing their individual effects.

Discussion

The results of the study confirmed that digitalization in society can directly influence political processes within the state. Most respondents indicated that they possess digital literacy and are well-informed about political issues. In contrast, those with lower levels of digital literacy were generally less aware of the political landscape. It was observed that individuals with low digital literacy are more susceptible to misinformation and, consequently, more likely to be drawn into conflicts. Also, people with higher digital literacy tend to verify information before reacting and are less likely to participate in provocative events. The study concluded that in a society with high digital literacy, information security concerns are significantly reduced. Through mathematical modeling of conflicts, it became evident that digitalization plays a crucial role in conflict prevention in the modern era.

The research uncovers significant connections between digital transformation and operational risk exposure. Information from various sources suggests that digital transformation often plays a crucial role in increasing cybersecurity risks. Gupta et al. (2022) highlight that hacking has become both easier and more affordable for cybercriminals, placing all industries at risk. Hackers have multiple entry points to exploit vulnerabilities, turning cybercrime into a significant, albeit illegal, industry. Additionally, there is a fundamental asymmetry between attackers and defenders—while hackers need only a single successful breach, cybersecurity teams must maintain constant, foolproof defense mechanisms. As the digital landscape expands, the complexity of protection increases, making resilience a top priority. The modern digital transformation paradigm presents a dual reality, offering unprecedented technological opportunities while simultaneously exposing systemic vulnerabilities. While global digitalization drives progress, it also amplifies critical risks that require in-depth analytical evaluation and proactive security measures.

Research findings show that digitalization enhances business creativity by improving data accessibility. The principal-agent theory suggests that there is often a knowledge gap between decision-makers and those executing tasks. Given the natural inclination of individuals to act in their own best interests and avoid risk, decision-makers may be hesitant to encourage risk-taking or allocate sufficient resources to research and development (Liu et al., 2023). However, digital technology helps streamline business operations, enhances transparency in financial and operational data, and improves client oversight (Wang, 2023). By addressing short-term tendencies among task performers, digitalization not only strengthens organizational management but also

fosters creativity and investment in research. Modern digital technological paradigms fundamentally reshape information exchange and resource allocation, breaking down traditional barriers of spatial and temporal limitations. Drawing on insights from Ferreira et al. (2019) and Matarazzo et al. (2021), this analysis examines the transformative potential of digital connectivity in organizational ecosystems.

The process of digital transformation accelerates innovation by reducing the risks associated with business operations. Initiating innovation projects often involves considerable uncertainty, requiring decision-makers to acquire the necessary knowledge to navigate potential challenges (Liu et al., 2023). Contemporary organizational strategic frameworks highlight a complex interplay between operational risk tolerance, technological capabilities, and investment in innovation. Drawing from the work of Chania et al. (2019), this research examines the intricate relationship between risk perception and technological innovation potential.

Digital transformation helps mitigate risk aversion, reduces poor decision-making, and minimizes wasteful investments (Ghezzi & Cavallo, 2020). Digital tools lower the costs of information gathering, curb the tendency of management to make premature investment decisions, and encourage a more calculated approach to risk-taking (Ghezzi & Cavallo, 2020). Digital technologies fundamentally reshape organizational risk-taking behavior and decision-making processes by reducing information acquisition costs, preventing premature opportunity pursuit, and optimizing resource allocation. The increased operational flexibility and improved access to capital facilitated by digital infrastructure create favorable conditions for greater organizational risk-taking (Tian et al., 2022).

Through digital systems, management can swiftly identify operational issues and manage risks more effectively. Moreover, digital transformation breaks down industry barriers, fosters competition across borders, and encourages specialization and collaboration (Bresciani et al., 2021). This cross-sector connectivity facilitates the exchange of both innovation and operational risks among businesses, ensuring continuous advancements in private sector innovation.

In several Central Asian countries, digital transformation is making important progress in labor migration. Kyrgyzstan, Uzbekistan, and Tajikistan are among the nations whose citizens migrate annually in search of better job opportunities, primarily moving to Russia, Turkey, Europe, and the United States. In recent years, these countries have advanced in digital migration by establishing resource centers for migrants and integrating digital channels into labor migration

processes. Digital platforms have already been implemented in Tajikistan and Uzbekistan, with plans for expansion into Kyrgyzstan. As this study examines digital transformation in Kazakhstan, it is evident that the country is a regional leader in adopting and implementing digital solutions across various sectors of daily life (Maltabarov & Sarybayev, 2024). Uzbekistan, in contrast, only began its transition toward digital transformation in 2022. According to Uzbekistan's state project, the country aims to achieve 80% digitalization by 2030. In pursuing this goal, Uzbek policymakers have primarily drawn inspiration from Kazakhstan's model of digital education for the population (Khakimov, 2024).

In Tajikistan, the digital transformation of the national economy is in progress, relying on global best practices and Kazakhstan's experience in digital transformation. Kazakhstan's "digital citizenship" project has served as an impetus for many Central Asian countries, including Tajikistan. Strategic studies conducted by scientific institutes in Dushanbe highlight Kazakhstan's influential role in advancing digitalization across Central Asia. However, digital transformation in Tajikistan is progressing at a moderate pace, ranking lower than Kazakhstan, Uzbekistan, and Kyrgyzstan, but ahead of Turkmenistan (Turdibekov, 2018). In Turkmenistan, digital transformation is primarily limited to state platforms, serving as a tool for disseminating national policies and providing information. According to the UN, only 20% of Turkmenistan's population has received digital education, placing the country at a low level of digital transformation implementation in the region (Volmamedova et al., 2024).

Digital transformation plays a key role in fostering business creativity by easing access to funding. Businesses that embrace digital transformation find it easier to gain recognition from government bodies, banks, and other financial institutions, increasing their potential to secure investments and alleviate funding challenges, which in turn encourages innovation (Hung & Nham, 2023). Additionally, digital transformation enhances financial transparency, improving businesses' prospects for future expansion (Wang, 2023). The adoption of digital technologies has expanded opportunities for businesses to access investment, aligning economic and institutional goals more effectively. Digitalization simplifies the process for investors and financial entities to oversee and contribute to business growth, making it a more efficient tool than conventional methods for reducing financial obstacles and enhancing economic participation. Digital financial services—including payment systems, credit, insurance, and investment services—play a crucial role in bridging information gaps and supporting smaller businesses in securing funding (Zhang et al.,

2023). The widespread adoption of digital technologies removes geographical constraints on information and capital flows, providing external investors with better decision-making capabilities through enhanced data accessibility. This digital infrastructure attracts a more diverse investor base, creating favorable conditions for fostering innovation and technological progress in the private sector. Furthermore, integrating digital systems within corporate frameworks optimizes investment efficiency by reducing suboptimal capital allocation (Zhou, 2023). As businesses become more innovative and leverage digital channels for investment, their global competitiveness increases (Kravchuk et al., 2022).

Fuzzy Mathematical Model for Managing Risks in Digital Transformation

Digital transformation is a critical driver of enterprise innovation, significantly impacting cost efficiency, profit generation, and productivity enhancement (Peng & Tao, 2022). The fuzzy mathematical model, similar in structure to Cronbach's alpha, is widely recognized for its objectivity in research applications. Recently, this model has gained widespread use in various European research institutes. For mathematical modeling in this study, the same methods used in Cronbach's alpha were applied to derive an index indicator of truth, ensuring accuracy and reliability in assessing digital transformation's impact.

While innovation often drives economic growth, the potential for replication and spillover effects can reduce businesses' motivation for R&D if they are unable to mitigate associated risks. The implementation of the "Visible Hand" mechanism has emerged as an effective approach to managing and distributing these risks, ensuring sustained innovation in the private sector. This regulatory framework functions as a risk-compensation instrument, enabling firms to continue their R&D efforts despite market uncertainties. Research by Carboni (2011) highlights that public support positively affects private R&D investments, enhancing innovation potential by helping businesses share the risks associated with these initiatives.

Digital technology has been recognized as a pivotal tool for reducing risks in innovation, particularly through improved information processing (Qinqin et al., 2023). By enhancing access to critical information, digital transformation allows organizations to identify external knowledge, analyze market data, and improve investment efficiency. The use of big data fosters transparency facilitates resource-sharing, and strengthens trust among external investors, all of which are essential for supporting corporate innovation projects. Concurrently, private companies enhance

their technological capabilities and draw insights from peer research, enabling more effective management of innovation risks.

Despite its advantages, digital transformation introduces unique information security challenges, particularly in cloud computing, where vulnerabilities stem from hardware, software, and organizational management practices. To mitigate these risks, a mathematical set-based model has been proposed to identify and quantify information security threats associated with cloud technology. This model enables organizations to evaluate financial losses, countermeasure costs, resource values, and the severity of risks. A fuzzy assessment framework underpins this approach by assigning values to cloud technology components based on their direct impact on information security concerns (Sharmila & Sakthi, 2019; Klöber et al., 2018).

To effectively manage information security risks, a generalized formal algorithm for fuzzy assessment has been developed. This algorithm utilizes mathematical tools from fuzzy-set theory to model cloud technology, estimate risks, and propose mitigation strategies. Following the guidelines of NIST SP 800-39, the algorithm is structured into two phases. The first phase involves defining the cloud technology model, identifying its components, and categorizing information security threats. The second phase focuses on risk estimation, evaluating potential losses, threat probabilities, and recommending risk management strategies (Asadi, 2015; Alfonso et al., 2017).

The cloud technology model is mathematically represented as S={D, U, V, R}S = \{D, U, V, R\}, where D denotes information resources, U represents identified risks, V reflects vulnerabilities, and R captures the connections between model components. Measurement scales and assessment functions are integrated into the model, enabling a detailed evaluation of risks using fuzzy, discrete, or continuous objects (Korablev & Kazakov, 2016; Arunraj et al., 2013).

This methodologically rigorous framework enables the development of comprehensive protocols for cloud-based cybersecurity risk management, establishing a resilient architecture for threat mitigation and supporting secure digital transformation initiatives across various organizational contexts. By systematically applying this model, businesses can more effectively balance innovation opportunities with the risks inherent in the digital landscape, ensuring both technological advancement and robust security measures.

Conclusions

The academic literature extensively explores digital transformation, yet it still needs a clearer definition, a deeper understanding of essential requirements, and a strategic long-term perspective. To provide a more structured framework for both research and practical application, this study examines digital transformation within Kazakh society, focusing on its risks and opportunities. This study offers a comprehensive review of existing literature on digital transformation, revealing a substantial amount of ongoing research in the field. By contributing to the current body of knowledge, the study enhances understanding of digital transformation in organizations, identifies key risks and opportunities, and presents the field in a more organized and comprehensible manner. The biggest risk associated with digital transformation is security-related. The widespread adoption of emerging technologies has increased organizational vulnerability to cyber threats, which manifest through multiple attack vectors, including data exfiltration, ransomware attacks, unauthorized system access, and other forms of malicious cyber activity. To maintain operational resilience and protect stakeholder interests, enterprises must implement robust cybersecurity frameworks and controls tailored to their threat landscape. Key measures include firewalls, encryption, and multi-factor authentication. Future research should expand its focus to include comparative analyses with other developing nations and longitudinal studies to assess the long-term impact of digital transformation initiatives in Kazakhstan. By addressing these security challenges and capitalizing on identified opportunities, Kazakhstan can strengthen its position as a leader in digital transformation within the Central Asian region.

In conclusion, digital transformation is a complex process that impacts all aspects of life in Kazakhstani society. The study's findings highlight that the successful implementation of digital initiatives requires a systematic approach to change management and the development of digital competencies. Cybersecurity and personal data protection must be prioritized as digitalization expands. The analysis of Kazakhstan's digital transformation reveals the need for further improvements in regulatory frameworks and technical infrastructure, making it essential to incorporate international best practices while adapting them to local conditions. The development of human capital and the enhancement of digital literacy among the population are critical factors for success. Additionally, digital transformation should be accompanied by continuous monitoring and evaluation to ensure the effectiveness of implemented measures. Ensuring inclusiveness by providing equal access to digital technologies for all segments of the population is fundamental.

The study confirms that digital transformation creates new opportunities for economic growth and social development in Kazakhstan. A promising area for further research is examining its impact on the competitiveness of Kazakhstani enterprises in the international market. The findings of this study serve as a foundation for strategic recommendations aimed at enhancing digital transformation processes in Kazakhstan.

Based on the analysis of digital transformation in Kazakh society, the following scientific recommendations can be formulated:

- A comprehensive state program for digital literacy should be developed, with a special focus on older generations and rural residents. This program should include a system for certifying digital skills and mechanisms to incentivize learning.
- Compulsory courses on digital technologies should be introduced across all educational institutions, from schools to retraining programs, with training materials regularly updated to align with technological advancements.
- A system of tax incentives should be established for companies investing in digital infrastructure and workforce training, particularly in remote regions of the country.
- An interagency coordination center for cybersecurity should be created with the authority to respond to threats promptly and develop preventive measures to protect digital infrastructure.
- A public-private partnership system should be introduced to develop digital platforms for public service delivery, involving leading IT companies.
- Mechanisms for the legal protection of citizens' personal data should be developed for digital services, including clear procedures for oversight and accountability in cases of violations.
- A dedicated fund should be established to support domestic IT startups, with a streamlined process for obtaining funding and expert guidance.
- A monitoring and evaluation system should be implemented to assess the effectiveness of digital transformation based on international standards, with regular publication of results and strategy adjustments.
- A labor market adaptation program should be developed for the digital economy, incorporating retraining mechanisms for workers in declining professions.
- A national open data platform should be created, incorporating monetization mechanisms to encourage the development of innovative digital services.

- The objectives of the study were achieved, and the hypotheses were confirmed through regression and fuzzy analysis. The results were compared, reinforcing the objectivity of the study and enhancing the scientific credibility of the research. This analysis suggests that the issue of digital transformation is not only relevant in Kazakhstan but also in neighboring countries. The mathematical approach demonstrated that hypotheses related to digital transformation can be expanded to address broader social challenges, highlighting the potential for further interdisciplinary research in this field.

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