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ASSESSING THE IMPACT OF DIGITAL TECHNOLOGIES AND ARTIFICIAL INTELLIGENCE (AI) ON THE EFFICIENCY OF SUPPLY CHAIN

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ABSTRACT. The study investigates the role of digital transformation, including artificial intelligence and other technologies, in the logistics enterprises. It aims to assess the impact of digital technologies on supply chain efficiency. The multiple linear regression analysis was used to identify the most critical digital technologies for supply chain efficiency dimensions measured by logistics enterprises' performance indicators. The data collected from surveying 106 respondents of Kazakhstani logistics companies was processed using the SPSS software program. The overall Cronbach's alpha value of 0.90 for both variables demonstrates a high internal consistency between all 13 indicators. The research results show that the most used digital technologies in the field of the supply chain are Barcode and GPS. In addition, Barcode and RFID were found to be critical technologies that affect supply chain's efficiency indicators. The research findings related to the supply efficiency dimensions revealed the following: 1) the average growth rate of production costs was estimated at 0.27, indicating moderate growth; 2) the level of information support was evaluated at about 0.27; 3) the document turnover rate has an average value of about 0.31, which indicates some delay in processes; 4) the availability of innovative technologies was estimated to be about 0.28. Thus, the observed correlation between technology usage frequency and positive performance outcomes highlights the strategic importance of investing in the right digital tools to drive operational excellence in the supply chain.

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Introduction

The consequences of the COVID-19 pandemic, coupled with the problematic political situation resulting from the war in Ukraine, have led to supply shortages and increased prices of many essential, commonly used goods. The aggravated systemic issues in multiple supply chains have compelled both developed and developing countries to seek ways to enhance their efficiency (Kalkan, 2018). Supply chain enterprises have been forced to improve their performance to sustain long-term growth and profitability in an increasingly competitive environment (Sudit, 1995; Setyaningsih & Kelle, 2021). An efficient supply chain helps reducing costs and save time that can be allocated to other resources by streamlining the processes and actors involved (Alshurideh et al., 2022; Ryciuk, 2022). Numerous factors can enhance the efficiency of supply chains, including human resources (Lichocik and Sadowski, 2013), organizational culture (Lichocik & Sadowski, 2013; Piotrowicz & Kedziora, 2018; Pakurár et al., 2019), financial management (Reiner & Hoffman, 2006), as well as digital technologies (Meyr et al., 2002; Kamble et al., 2018; Gorecki et al., 2020; Bag et al., 2021a, b). With the rapid development of technologies such as cloud computing, artificial intelligence (AI), service-oriented design, internet of things (IoT), and digital twins (Govindan et al., 2022; Sarker, 2022), technical innovations are rapidly bringing significant advancements to the supply chain industry.

More advanced technologies such as the Internet of Things (IoT), cyber-security, robotic systems, big data, and social media-based systems have become essential elements of creating an efficient supply chain (Winkelhaus & Grosse, 2020; Turja, 2024). In contemporary times, the rapid development of digitalization and AI has introduced a new perspective to the supply chain industry, helping to achieve maximum output with minimal resource investment (Kamble et al., 2018; Gorecki et al., 2020; Bag et al., 2021a, b). The success of a supply chain is contingent upon the implementation of the most advanced IT solutions (Belkacem Bouzid & Merzoug, 2021; Kawa, 2021), as these solutions can enhance operational efficiency by continuously integrating new technologies (Sauvage, 2003).

In developing countries such as Kazakhstan, the introduction of digital technologies and AI is still in its early stages, particularly within the supply chain sector (Akhmetova et al., 2022), and research on digitalization in this context remains limited. Additionally, the available literature indicates that existing supply chain theory does not provide a comprehensive foundation for evaluating supply chain efficiency (Khan et al., 2010). To enhance supply chain productivity, it is crucial to identify technologies that directly improve the efficiency of logistics activities. Consequently, further research is needed to assess the intensity of technology use within the supply chain system (Mutanov et al., 2020). COVID-19 has additionally accelerated the adoption of technologies in supply chains with an unprecedented pace (McKinsey, 2022). However, the extent to which they impact supply chain performance remains debatable, as only few studies have provided empirical evidence (Nour, 2022). Additionally, the high cost and

frequent failure of technology adoption necessitate the assessment of critical technologies, including AI (Maghsoudi et al., 2023), that genuinely enhance supply chain efficiency (Karia et al., 2018; Straková et al., 2022). Therefore, this study aims to identify the key technologies that directly affect supply chain performance. Accordingly, we have formulated the two below research questions:

RQ 1: Which digital technologies are most often used in logistics companies in Kazakhstan?

RQ 2: What kind of digital technologies affect the efficiency of the supply chain in Kazakhstan?

We position our study to address the above research questions from the perspective of Technology-Organization-Environment (TOE) theory (Tornatzky & Fleischer, 1990) that explains how a firm's context influences the adoption and implementation of innovations. Since the availability of innovative technologies and high speed of document flow achieved with their use are among the key indicators of supply chain performance, we acknowledge that the company's existing technologies are crucial as key influencers of the technological change pace, and aim to explore the technology's implementation efficiency with the lens of TOE framework (Collins et al., 1988). As different technologies exert varying impacts, just as other national or cultural contexts and industries have distinct effects (Baker, 2011), our study is aimed at assessing how Kazakhstani firms have succeeded in implementing different digital technologies and how this has affected supply chain performance indicators related to the adoption of innovation.

1. Literature review

Supply Chain Efficiency

The contribution to the synthetic measure of supply chain efficiency will vary depending on the perception of its particular area (Lichocik & Sadowski, 2013). Evaluating supply chain efficiency involves assessing various metrics, performance indicators, and methodologies to gauge the effectiveness of supply chain processes in achieving organizational goals (Bretzke, 2013). Thus, supply chain efficiency should be perceived as a function of efficiency within such areas as costs, customer service quality, ecology, and x-efficiency, measured by business responsibility according to the added value creation model (Lichocik & Sadowski, 2013). X-efficiency refers to the degree of efficiency maintained by firms in reducing costs and maximizing output without sacrificing quality. In the context of retail, x-efficiency encompasses the effective allocation and utilization of resources to optimize operational performance and productivity, ultimately driving sustainable growth and profitability for retail businesses (Larksuite, 2024). Another approach to evaluating supply chain efficiency is the use of Key Performance Indicators (KPIs). Typical KPIs include inventory turnover, measuring how quickly inventory is sold or used within a specific time frame (Chopra & Meindl, 2007); order fulfillment cycle time, measuring the time taken to fulfill customer orders from placement to delivery (Christopher, 2016); cash-to-cash cycle time, measuring the time it takes for capital invested in inventory to be converted back into cash through sales (Gupta et al., 2014); and supply chain costs, measuring the total costs incurred across the supply chain, including transportation, warehousing, and inventory carrying costs (Simchi-Levi et al., 2008; Kot et al., 2018). These metrics can differ based on factors such as the size of the company, its type, operational domain, and availability of data (Setyaningsih & Kelle, 2021; Velychko, 2015).

Another model is the Total Cost of Ownership (TCO), which considers the costs associated with acquiring, using, and maintaining a product or service throughout its lifecycle. TCO analysis helps identify hidden costs within the supply chain and aids in decision-making

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for process improvements (Ellram, 1995). However, its limitation lies in its focus solely on cost dimensions and neglecting other factors that may affect supply chain efficiency. Due to the limitations of the models and approaches, the study found the KPI method, which covers a wide range of metrics from different levels of the supply chain, as applicable for assessing the supply chain efficiency. Metrics such as the level of information support can improve the quality of delivery information received by customers and evaluate supplier performance, thereby increasing overall supply chain efficiency (Strandhagen et al., 2017; Ding, 2018; Rai et al., 2021). Additionally, other relevant KPI metrics include production cost growth rate, document turnover rate, and the availability of innovative technologies (Beyca et al., 2018). These metrics can be applicable with TOE framework due to its link to innovation adoption (Collins et al., 1988).

The Technology-Organization-Environment (TOE) theory

Existing research has shown that the TOE framework is widely applicable and effective in explaining phenomena across various technological, industrial, and cultural or national contexts (Baker, 2011). Moreover, the flexibility to adjust the factors or measures for each new research setting makes the TOE framework exceptionally adaptable (Rogers, 1995). The TOE model was firstly described by Tornatzky and Fleischer's (1990) as an organization-level theory.

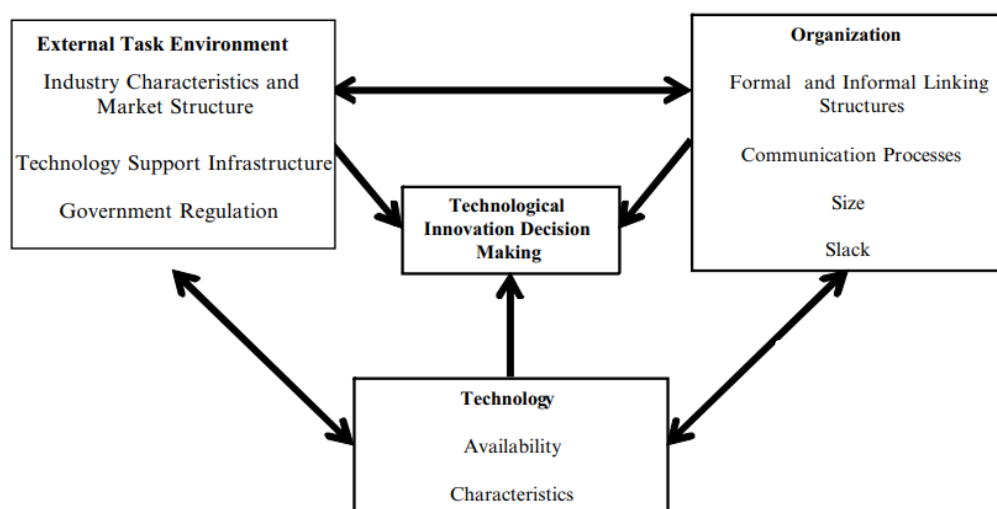


Figure 1. The technology–organization–environment framework
Source: (Tornatzky & Fleischer, 1990)

As presented in Figure 1, in each empirical study examining the TOE framework, researchers have utilized slightly different factors for the technological, organizational, and environmental contexts that affect innovation adoption level which is a dimension of supply chain efficiency (Baker, 2011). This study focuses on technological context which depicts existing digital and new technologies that are relevant to each firm (Nguyen et al., 2022). Examples of technological context include the introduction of barcode scanning in the grocery sector during the 1970s and 1980s, the implementation of RFID technology in numerous companies, and the transition to cloud computing that started in the early 2000s (Baker, 2011).

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The Role of Digital Technologies and AI in the Supply Chain Efficiency

The literature analysis indicates that digital technologies play a multifaceted role in enhancing supply chain efficiency. They contribute by improving data management (Li et al., 2020; Yan et al., 2017), fostering collaboration (Bag et al., 2020), enabling automation (Ding, 2018; Kedziora, 2022; Brandín & Abrishami, 2021), optimizing processes, ensuring compliance (Zheng et al., 2017; Dweekat et al., 2017), and enhancing customer service (Lichocik & Sadowski, 2013; Spieske & Birkel, 2021). Leveraging the capabilities of digital technologies can provide companies with value in the dynamic and interconnected business environment of today (Kedziora & Hyrynsalmi, 2023). The study by Raja and Venkatachalam (2022) identified a range of technologies that can significantly improve efficiency within third-party logistics and supply chain industries, including GPS, barcodes, RFID, IoT, cloud computing, and AI. The following table summarizes the most frequently cited technologies in the literature that impact supply chain efficiency (Table 1).

Table 1. The list of most cited digital technologies in the literature from the Scopus database

Technology	Sources	Amount of Citations at Scopus
Artificial intelligence	Ding, 2018; Radanliev et al., 2020; Strandhagen et al., 2017; Cagliano et al., 2021; Li et al., 2017a; Bag et al., 2020; Thiebes et al., 2021; Dossou & Nachidi, 2017; Bienhaus & Haddud, 2018; Sanders et al., 2019; Oh, 2019; Ahuett-Garza & Kurfess, 2018; Schütze et al., 2018	13
Internet of things	Zhong et al., 2017; Kalsoom et al., 2020; Krugh et al., 2017; Trappey et al., 2017a; Adhitya et al., 2020; Li et al., 2020; Sim and Cho, 2021; Majeed & Rupasinghe, 2017; Mostafa et al., 2019; Bisio et al., 2018; Dweekat et al., 2017; Brandín & Abrishami, 2021; Pyun & Rha, 2021.	13
Cloud computing	Strandhagen et al., 2017; Ding, 2018; Rai et al., 2021; Long et al., 2018; Zheng & Wu, 2017; Romero-Silva & de Leeuw, 2021; Fernandez-Miranda, et al., 2017; Kang et al., 2016; Yan et al., 2017; Oku et al., 2015	10
RFID	Zhong et al., 2017; Corches et al., 2021; Biswal et al., 2018; Ustundag & Tanyas, 2009; Trappey et al., 2017a; Garfinkel, S. L., & Rosenberg, 2005; Finkenzeller, 2010; Sheffi, 2018; Duarte et al., 2018	9
Blockchain	Tapscott, D., & Tapscott, 2016; Iansiti, M., & Lakhani, 2017; Crosby et al., 2016; Pilkington, M. 2017; Zheng et al., 2017; Deloitte, 2017; Ivanov, D., & Dolgui, 2019; Deb, M., & Agrawal, 2020	8
Barcode	Gwynne, 1999; Mangan, 2008; Mentzer, et al., 2001; Wisner, et al., 2014; Waters, 2003; Simchi-Levi et al., 2019; Chopra, S., & Meindl, 2021	7
Digital twins	Rodić, 2017; Zhong et al., 2017; Ivanov & Dolgui, 2021; Aheleroff et al., 2021; Qi & Tao, 2018; Kaivo-Oja et al., 2020; Andaluz, 2017	7
GPS	Vanderroost et al., 2017b; Raji et al., 2021; Spieske & Birkel, 2021; Tsuchiya et al., 2018a,b; Dallasega et al., 2017; Ding 2018; Fernandez-Caramés et al., 2018	7
Robotics	Kusiak, 2018; Müller et al., 2017; Bahrin et al., 2016; Ma et al., 2017	4

Source: Authors' analysis based on the literature review

Table 1 presents digital technologies frequently mentioned in the literature as revolutionizing supply chain management and improving efficiency, visibility, and agility. IoT is the most mentioned, as its objective is to provide advanced connectivity of electronic devices at any time and place (Govindan et al., 2022), as well as AI, which enables the automatic

arrangement of production compositions, including real-time monitoring and control of manufacturing operations and production processes (Zhong et.al, 2017; Oh, 2019). Furthermore, one of the most cited digital technologies is cloud computing, which can be applied specifically in forecasting and planning, as well as sourcing, procurement, and logistics (Govindan et al., 2022). This list ends with Robotics technologies used for intelligence automation in various industrial contexts that can enhance the efficiency of the supply chain (Siderska et al., 2023; Sobczak, 2022).

2. Research methodology

Research design

Based on the literature review, independent variables of digital technologies and dependent variables of logistics performance indicators are identified. The moderator variable is the respondent companies' activity sector (see Figure 2).

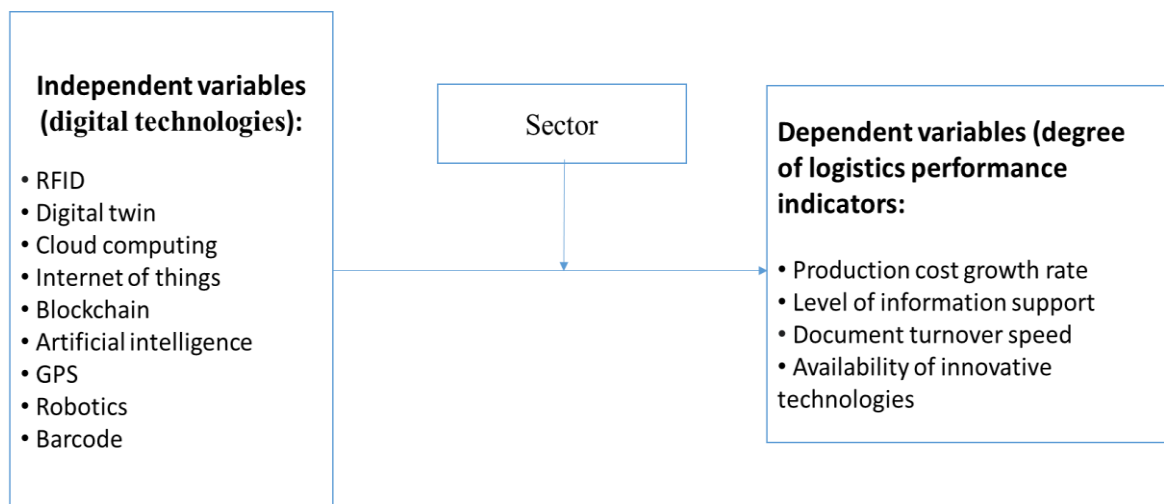


Figure 2. Research design

Source: based on the literature review

Figure 2 depicts 9 the most cited digital technologies in the literature as the independent variables. On the other hand, four supply chain efficiency dimensions based on by complex performance assessment approach (Govindan et al., 2022) were chosen as the dependent variables. The study investigates the influence of digital processes on the degree of performance indicators of the supply chain by using multiple linear regression analysis for answering the research question. The moderator is the industry of the companies and their type of activity. As a result of applying this model, the regression analysis identified the best P-values, indicating a strong correlation between the independent variable X and the dependent variable Y. It should be noted that before conducting the regression analysis, a correlation analysis of the independent variables was performed to detect multicollinearity. Based on its results, four regression models were developed, each incorporating a specific combination of independent variables to minimize the effect of multicollinearity.

Research Sample

The survey was conducted among the respondents from logistics companies in Kazakhstan from September to December 2023 via Google Forms. Thus, the study used spatial data for one year. 112 responses out of 173 were received (response rate 65%), 106 of which

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were selected for further research as valid for making calculations. The respondents were managers, directors, and heads of supply chain and logistics departments of various companies engaged in logistics activity. The respondents examined the use of intensity of digital technologies from 0 to 5 according to the Likert scale. Then they evaluated the selected supply chain efficiency criteria according to request of the questionnaire. The detailed structure of the questionnaire is presented in the Appendix section.

The following figure illustrates the level of difference between the respondent companies by type of activity and the overall number of answers received during the survey completion (see Figure 3). As shown in Figure 3, seven types of companies were identified based on the survey results. The highest frequency of answers is traced for trade enterprises (28% of coverage) and warehousing and storage organizations (response rate 26%).

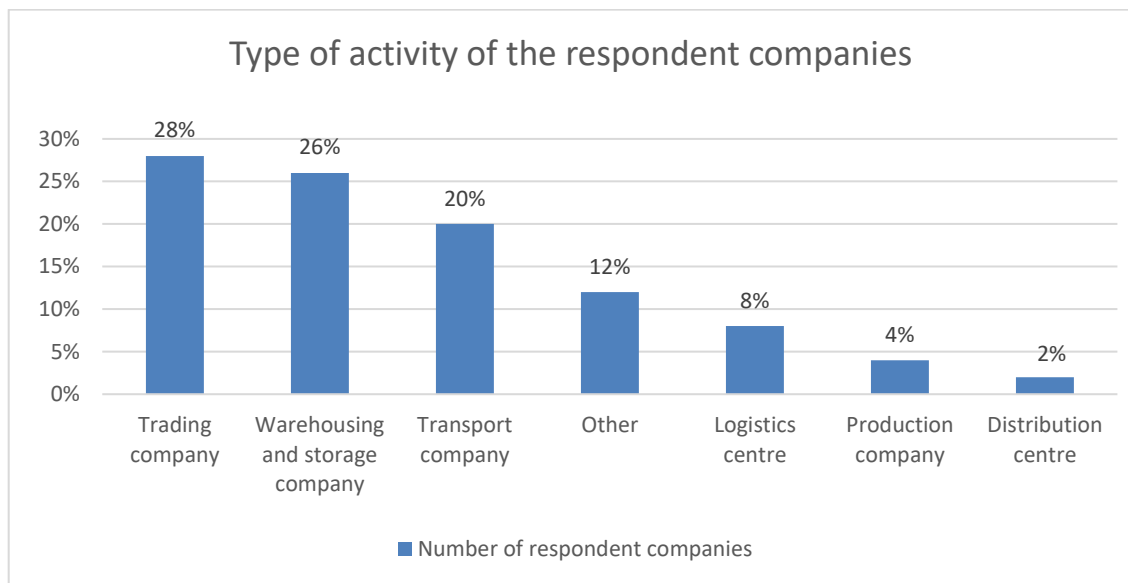


Figure 3. Type of activity of the respondent companies

Source: own elaboration

Reliability testing

Reliability testing formed in SPSS program allowed us to determine the significance of the test questionnaire that was distributed to the respondent companies and professionals in the specific logistics industry.

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Table 2. The results of Cronbach Alpha testing

Parameters and their subparameters to be tested	Results of reliability testing	Quantity of parameters to be tested
1. Digital technologies: - RFID; - Digital twin; - Cloud Computing; - Internet of Things; - Blockchain; - Artificial Intelligence; - GPS; - Robotics; - Barcode.	0,88	9
2. Degree of logistics performance indicators: - Production cost growth rate; - Level of information support; - Document turnover speed; - Availability of innovative technologies.	0,91	4
Total	0,90	13

Source: Authors' results based on SPSS calculations

As depicted in Table 2, for the digital technology domain, a Cronbach's alpha of 0.88 indicates high internal consistency between 9 processes, implying that these processes reliably measure a similar underlying domain. Similarly, for the degree of logistics performance measures, a Cronbach's alpha of 0.91 indicates a high level of internal consistency between 4 processes.

The overall combined Cronbach's alpha value of 0.90 for both areas indicates a high internal consistency between all 13 indicators collectively. Accordingly, based on Cronbach's alpha values, it can be concluded that the scales and questionnaires used to measure digital technology and logistics performance degree illustrate proper internal consistency, which gives confidence in the reliability of these indicators.

3. Results

The survey regarding the frequency of using digital technologies was designed to collect feedback on a Likert scale (from 0 to 5) (see Figure 4).

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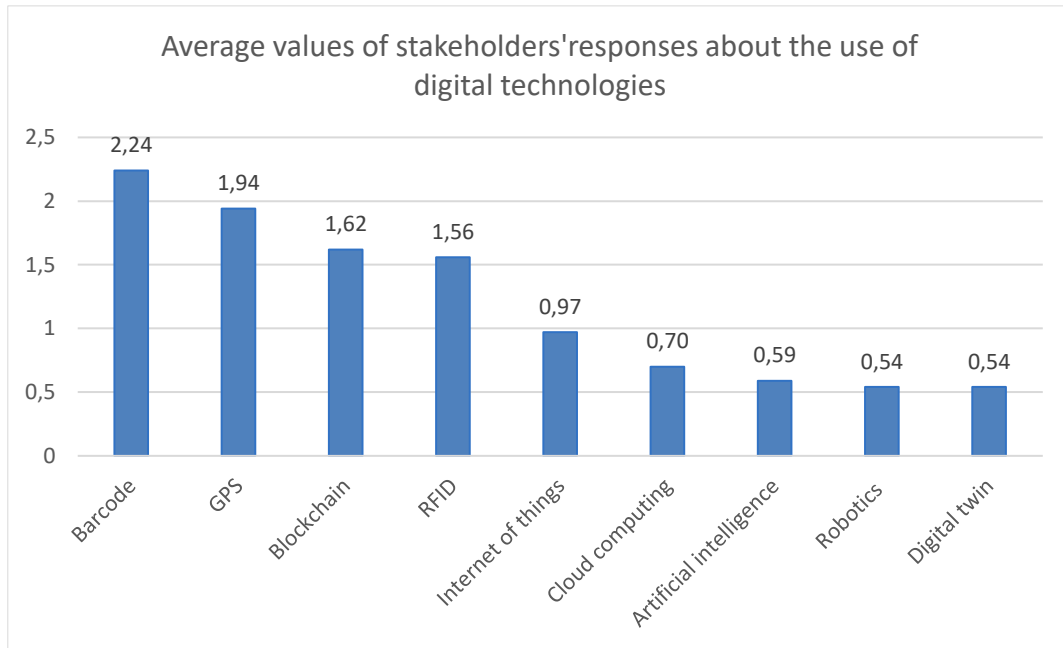


Figure 4. Average values of stakeholders' responses about the use of digital technologies
Source: own elaboration

As shown in Figure 4, the best average values are for Barcode and GPS. Furthermore, respondents assessed the questionnaire regarding the degree of logistics performance indicators on a 10-point Likert scale. The average values of the respondents' answers are shown in Figure 5.

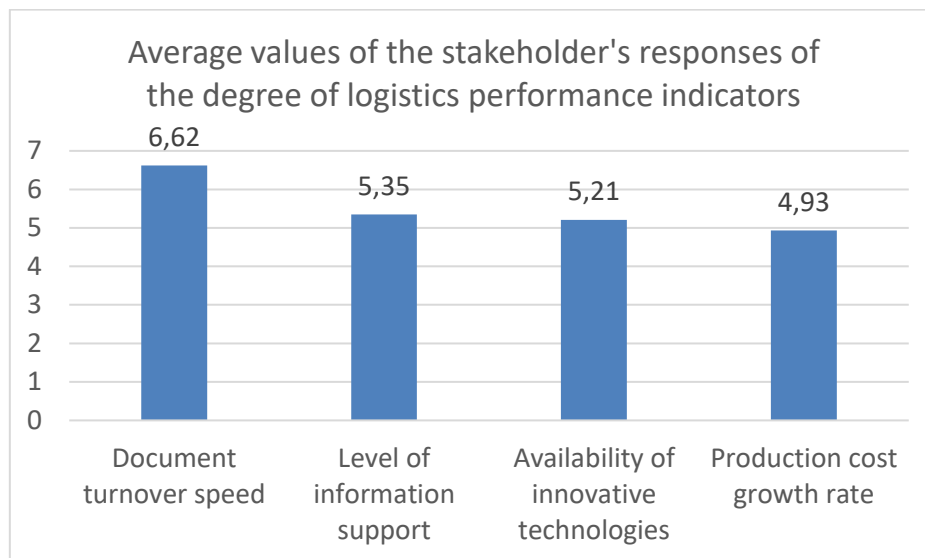


Figure 5. Average values of the stakeholder's responses to the degree of logistics performance indicators
Source: own elaboration

According to the results of a questionnaire designed for employees in logistics services, the speed of document processing has the highest weighted average. The possible explanations are concentrated in Discussion section.

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Furthermore, Table 3 shows the critical, descriptive statistics of logistics performance indicators. Descriptive statistics mainly reflect the mode, median and other identified indicators.

Table 3. Descriptive statistics (degree of logistics performance indicators)

Meanings	Production cost growth rate	Level of information support	Document turnover speed	Availability of innovative technologies
Standard error	0,269	0,272	0,312	0,284
Median	5	6	8	5
Mode	1	7	10	5
Standard deviation	2,769	2,802	3,211	2,924

Source: Authors' results

The key indicators of all variables are measured among the defined data set. The average growth rate of input costs was estimated at 0.27, indicating moderate growth. The level of information support was evaluated at about 0.27, suggesting a medium level of support. The document turnover rate has an average value of about 0.31, such value reflects some delay in processes. The availability of innovative technologies is estimated to be about 0.28, which, on the one hand, means an average level of accessibility for use in production processes. The following Table 4 shows the critical descriptive statistics of digital technologies.

Table 4. Descriptive statistics (digital technologies)

Meanings	RFID	Digital twin	Cloud computing	Internet of things	Block chain	Artificial Intelligence	GPS	Robotics	Barcode
Standard error	0,164	0,108	0,125	0,151	0,189	0,112	0,182	0,106	0,197
Median	1	0	0	0	0	0	2	0	2
Standard deviation	1,691	1,114	1,289	1,552	1,944	1,153	1,876	1,088	2,031

Source: Authors' results

As shown in Table 4, on average, the indicators for these digital technologies are distributed among values from 0 to 2. Standard deviations point out some variation in values relative to the mean. The independent variables X with the most significant influence on the dependent variables Y were identified based on the regression analysis results. The results are reflected in Table 5 below.

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Table 5. The impact of digital technologies on the degree of logistics performance indicators

Parameter	Production cost growth rate	Level of information support	Document turnover speed	Availability of innovative technologies
Regression equation	$y = 3.48 + 0.37x_1 + 0.39x_2 + E$	$y = 3.79 + 0.38x_1 + 0.37x_2 + E$	$y = 5.07 + 0.37x_1 + 0.43x_2 + E$	$y = 3.88 + 0.37x_1 + 0.34x_2 + E$
Standard error	(0.18 x_1), (0.150 x_2)	(0.167 x_1), (0.153 x_2)	(0.176 x_1), (0.168 x_2)	(0.198 x_1), (0.164 x_2)
Student's test (a)	9.493	10.031	11.796	9.700
Student's test (b ₁)	2.017	2.296	2.088	1.851
Student's test (b ₂)	2.616	2.378	2.538	2.064
P-value (a)	0.00	0.00	0.00	0.00
P-value (b ₁)	0.05** (RFID)	0.02*** (GPS)	0.04** (Blockchain)	0.07** (RFID)
P-value (b ₂)	0.01*** (Barcode)	0.02*** (Barcode)	0.01*** (Barcode)	0.04** (Barcode)
Fisher's test (F)	13.92	14.50	12.01	9.91
Fisher's test (Significance F)	0.000	0.000	0.000	0.000

Source: Authors' results. * indicates significance level at 0.10 level, ** indicates significance level at 0.05 level, *** indicates significance level at 0.01 level

From the data in the table above, it is appropriate to identify the following digital technologies that significantly influence the degree of various logistics performance indicators: Barcode, RFID, GPS, Blockchain.

The residuals at the level of each of the four obtained models were tested for normality using the Kolmogorov-Smirnov test, the results of which are presented in Table 6.

Table 6. Testing residuals for normality using the Kolmogorov-Smirnov test

Criteria	Production cost growth rate	Level of information support	Document turnover speed	Availability of innovative technologies
N of observations	106	106	106	106
Asymp. sig. (two-tailed)	0.187	0,213	0,200	0,086

Source: Authors' results based on SPSS calculations

Since all obtained values are >0.05, it is reasonable to conclude that the residuals in each of the four models follow a normal distribution.

4. Discussion

Based on the results of our survey regarding the frequency of digital technology use within companies (on a Likert scale from 0 to 5), it should be noted that Barcode and GPS have comparatively higher usage. This can be associated with relatively low cost of implementing these technologies within companies. Such result partly shows support for Raja and Venkatachalam's (2022) statement on the impact of digital technology on logistics performance. According to the results received from respondent logistics companies in the Republic of Kazakhstan, - not all digital technologies are widely used by organisations. In this regard, it is reasonable to assume the finding by Akhmetova et al. (2022) that digital technology and AI in logistics are at an early stage of development. Nevertheless, Barcode, GPS, as well as Blockchain and RFID showed the best values in the sphere of their use by the respondent companies in Kazakhstan. In this regard, it is worth noting the similarity with Kedziora's (2022) research of business processes automation. Technology such as the Internet of things, for instance, did not show a significant correlation with logistics performance in our analysis. Here again we refer to Winkelhaus and Grosse's (2020) argument that this kind of technology is quite advanced and innovative, and Kazakhstan, as noted earlier, is only at the initial stage of development and implementation of digital solutions, particularly in the supply chain sector.

The results obtained from the assessment of the degree of logistics performance indicators within their companies by stakeholders revealed that such parameter as document turnover speed is evaluated the highest. This output is attributed to the comprehensive digitalization of document processing and a reduction in the time taken to process orders at the signature stages. Document turnover speed is the relevant indicator of the KPI method chosen for this study. In this regard, the results of our survey demonstrate adherence to the thesis of the research of Beyca et al. (2018). The obtained results of the influence of independent variables X (digital technologies) on dependent variables Y (degree of logistics performance indicators) fully correlate with the assertion of Zheng et al. (2017) and Dweekat et al. (2017) that digital technologies are most directly involved in improving the degree of efficiency of supply chain activities, as well as in optimizing processes, ensuring compliance.

According to the obtained final results, the specific F values (13.92, 14.50, 12.01, 9.91) confirm that there is a linear relationship between the dependent variables and the explanatory factors in the models. The high F values indicate a good explanatory power of the model and the presence of significant factors that explain changes in the efficiency of logistics activities. Such an interpretation allows us to assert that the constructed models are suitable for analyzing the impact of these factors on logistics efficiency. In this regard, the next step is to describe the results of the P-values in more detail below.

Production cost growth rate: a statistically significant P-value for barcode usage of 0.01 indicates a potential relationship between barcode implementation and a reduction in the growth rate of production costs in a company. This is interpreted as an increase in the efficiency of production processes, cost reduction, and labour productivity due to barcode implementation. Level of information support: a statistically significant P-value for barcode usage of 0.02 points to a potential relationship between barcode implementation and increased information provision in the company. Such value means improved availability and correctness of data, increased transparency, and efficiency of information processes. Document turnover speed: a statistically significant P-value for blockchain usage of 0.04 illustrates a potential relationship between blockchain adoption and an increase in the speed of document flow in a company. The meaning is attributed to reduced processing and transmission time and improved document integrity and security through blockchain technology. Availability of innovative technologies: the best P-value for barcode usage of 0.04 among those presented indicates a potential

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relationship between barcode adoption and the availability of innovative technologies in the company. The reason to it, on the one hand, is that the barcode is a relatively cheap and available digital technology that can be easily adopted as part of the company's innovation initiatives.

According to our analysis of the survey data, several statements can be drawn concerning the two research questions.

RQ 1: Barcodes, GPS, Blockchain, and RFID are identified as the most prevalent digital technologies employed by logistics companies in Kazakhstan. This trend is likely influenced by factors such as the relatively low implementation costs of these technologies and their established effectiveness in enhancing operational efficiency and supply chain visibility. The widespread adoption of these technologies reflects a forward-thinking approach by logistics companies in Kazakhstan, as they utilize digital tools to optimize their processes and maintain competitiveness in the global market. Although Barcodes, GPS, Blockchain, and RFID dominate the current landscape, there is a clear opportunity to explore and adopt additional digital technologies to address specific challenges and further enhance logistics capabilities. Future research should investigate the feasibility and potential impacts of integrating emerging technologies such as artificial intelligence, the Internet of Things (IoT), and predictive analytics within the logistics sector in Kazakhstan.

RQ 2: Barcode, RFID, GPS and Blockchain technologies are recognized as the primary drivers of positive impacts on logistics performance indicators, according to responses from surveyed companies. These technologies have shown substantial benefits in improving inventory management accuracy, streamlining supply chain processes, and enhancing transparency and traceability. The observed correlation between the frequency of technology usage and favorable performance outcomes underscores the strategic importance of investing in appropriate digital tools to achieve operational excellence and meet evolving customer expectations. It is noteworthy that trading and warehousing companies constitute the majority of respondents in the survey, emphasizing the critical role of these sectors in Kazakhstan's logistics landscape and their proactive stance towards adopting technological innovations to remain competitive in a rapidly changing market environment. To verify the reliability of the obtained data, the residuals of each of the 4 constructed models were tested for normality and the result proved to be statistically significant. Additionally, the robust Cronbach's Alpha test results validate the reliability and consistency of the survey questionnaire and research methodology used in this study, enhancing the credibility and overall trustworthiness of the research outcomes.

These conclusions provide valuable insights into the current state of digital technology adoption and its impact on logistics performance in Kazakhstan, while also highlighting areas for future exploration and strategic investment to drive continued growth and competitiveness in the sector.

From the perspective of TOE theory, at the macro level of our study, we examined the influence of one aspect of Technology (T) on Technological Innovation Decision-Making. In this regard, we propose the following perspective on the TOE theory framework:

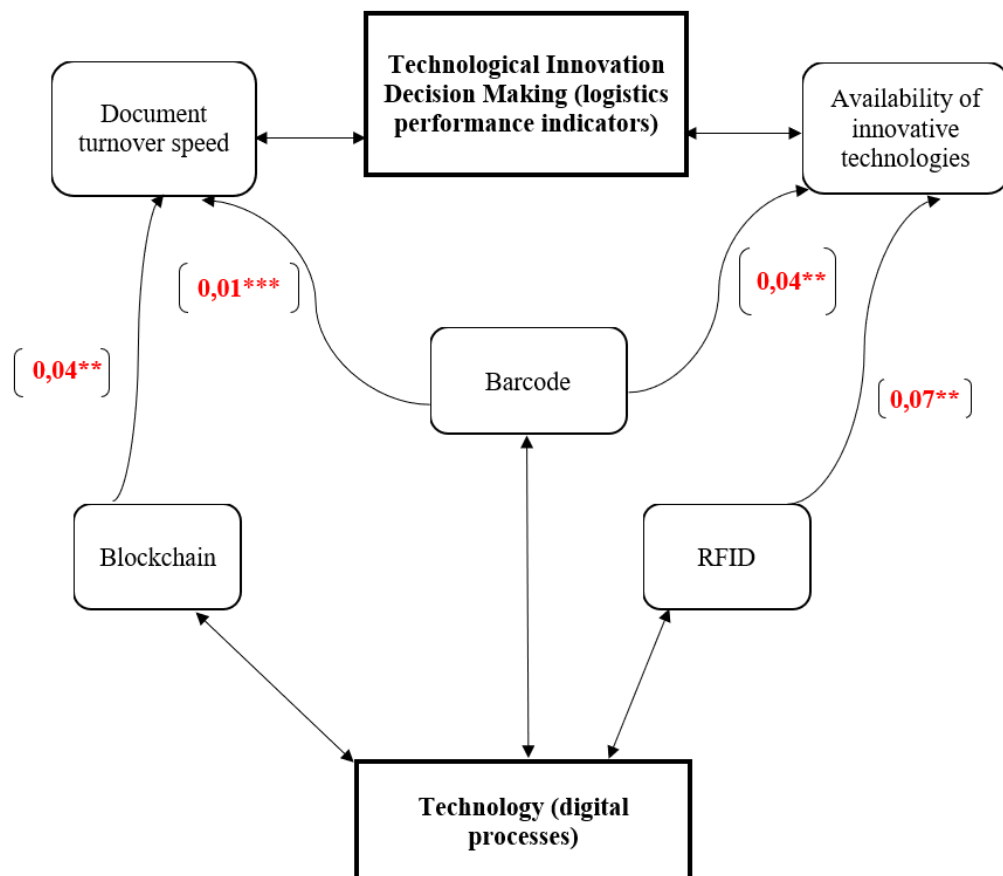


Figure 6. Impact indicators of digital technologies on the efficiency of logistics performance
Source: own elaboration based on TOE theory (Tornatzky & Fleischer, 1990)

Since this study focuses mainly on two logistics performance indicators - document turnover speed and availability of innovative technologies, according to the TOE theory of Tornatzky and Fleischer (1990), the pattern of the greatest impact of the identified digital technologies on these two indicators is illustrated above. Some other technologies are relatively less influential due to the fact that in the Republic of Kazakhstan digital technologies and AI are at an early stage of development, as indicated in the study by Akhmetova et al. (2022). Accordingly, this paper identifies those digital solutions that best correlate with supply chain performance, which in turn makes contribution in scientific gap in the direction, previously noted by Mutanov et al. (2020).

Conclusions

To summarize the findings of this study and the corresponding thesis, each section of the paper contributes to the overall analysis in the following manner.

The Introduction section emphasized the significance of employing digital technologies to enhance the efficiency of logistics activities and highlighted the existing gap in research on this topic. The Introduction section also outlined the TOE theory which was chosen as a framework for our study in terms of finding the result on the stated Research Questions. The Literature Review section compared various approaches for assessing supply chain efficiency, utilizing metrics such as cost efficiency, customer service efficiency, CSR efficiency,

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ecological efficiency, and x-efficiency. It examined methods including Key Performance Indicators (KPIs), the Supply Chain Operations Reference (SCOR) Model, Total Cost of Ownership (TCO), and Supply Chain Mapping. Due to the limitations associated with these models and approaches, the KPI method emerged as the most applicable, given its comprehensive range of metrics across different supply chain levels. Additionally, this section identified the most frequently cited digital technologies in the literature, as reported in the Scopus database, which were deemed relevant for enhancing supply chain efficiency and subsequently utilized in the research methods section. The Research methodology section was developed in alignment with the literature review. It identified nine independent variables related to digital technologies and four dependent variables concerning logistics performance indicators. The activity sector of respondent companies was considered as a moderator variable. The Results section presented the average responses from stakeholders regarding the utilization of digital technologies, with Barcode and GPS showing the highest values. It also assessed average responses related to logistics performance indicators, where document turnover speed exhibited the highest weighted average. Descriptive statistics provided insights into the standard measures of both dependent and independent variables. Regression analysis revealed that Barcode, RFID, GPS and Blockchain technologies significantly influenced logistics performance indicators. The final versions of the models excluded variables with multicollinearity. The residuals of each of the four obtained models met the criteria for normality (>0.05) based on the test results. The Discussion section extended the analysis of the results obtained, offering a detailed interpretation, including the proposal of an individual authors' concept along the lines of macro TOE theory. The practical significance of this research lies in its ability to guide logistics companies in focusing on the most impactful digital technologies, as identified by the study, and potentially expanding their use on a broader scale. Companies are also encouraged to investigate the reasons behind the underutilization of other digital technologies that showed weaker impacts on supply chain efficiency. This may be attributable to high implementation costs or the perceived irrelevance of these technologies within the logistics context of the Republic of Kazakhstan.

The study acknowledges several limitations. Firstly, the sample size is confined to 106 responses from a single country, the Republic of Kazakhstan. This limited sample size may not accurately reflect the broader population of logistics companies, particularly given the diverse range of logistics operations on a global scale. Secondly, despite the range of technologies applied in supply chain activities, only nine were selected as independent variables. Thirdly, the study employed a specific approach focusing on only four dimensions of supply chain efficiency, whereas the literature suggests various other complex criteria. Consequently, it is recommended that future research expand both the sample size and geographic scope, incorporating additional countries. Future studies should also consider evaluating the impact of other digital technologies on supply chains and potentially include additional dimensions of supply chain efficiency as dependent variables.

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Appendix

Dear respondents!

The survey is conducted in order to collect materials for the dissertation work in the field of digital transformation of functioning of the logistical centres of the Republic of Kazakhstan on the basis of the Fulfillment-concept of the specialty "Logistics (by branches)".

The research is anonymous and the results will be used only in a summarised form.

The questionnaire will take maximum 5 minutes of your time. Thank you for taking part in this survey!

What type of activity is your company engaged in?

Production company _____

Trading enterprise _____

Transport enterprise _____

Distribution centre _____

Warehousing and storage enterprise _____

Logistics centre _____

Other _____

1. How often you use digital technologies in your activity. Please indicate the frequency of use of each technology from 0 to 5, where:

5 - Always

4 - Quite often

3 - Often

2 - Rarely

1 - Very rarely

0 – Never

Table 1 - Use of digital technologies in logistics

** Rate the frequency of use of each technology "from 0 to 5"*

No	Application of digital technologies in logistics	Frequency of use of digital technologies from 0 to 5
1	RFID (Radio Frequency Identification)	
2	Digital twin	
3	Cloud Computing	
4	Internet of Things	
5	Blockchain	
6	Artificial Intelligence	
7	GPS	
8	Robotics	
9	Barcode	

2. Please rate the degree of your company's logistics performance indicators (Table 2) from 1 to 10, where:

1 - Low degree of efficiency

10 - High degree of efficiency

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Table 2 – Degree of logistics performance indicators

** Rate the frequency of use of each technology "from 1 to 10"*

№	Logistics performance indicators	Degree of logistics performance indicators
1	Production cost growth rate	
2	Level of information support	
3	Document turnover speed	
4	Availability of innovative technologies	

Thank you for your participation!