Digital transformation of supply chain management: trends and prospects

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Abstract: Digital transformation of supply chain management is becoming a key competitiveness factor for companies around the world. The introduction of modern technologies such as the Internet of Things (IoT), artificial intelligence (AI), blockchain and robotics significantly affect information flows and the efficiency of business processes, reducing costs and improving the quality of customer service and logistics. But still, there is not yet a general approach to assessing the potential impact of these technologies on the supply chain. The main contribution of the proposed approach is that it integrates firm digital transformation in the supply chain such as Amazon, Walmart and DHL through exhaustive and flexible assessment tools. The approach provides not just the measurement of current situation but also prediction for future situation, so it can be utilized as a powerful logistics and supply chain management strategic planning tool. The findings suggest enhanced supply chain performance at Amazon, Walmart and DHL by virtue of digitalization. time in the warehouse by 30-40%, increased inventory accuracy to 99% and reduced delivery costs by 25-40%. These modifications verify that digital transformation business processes in logistics work. Digitizing supply chains results in so many benefits in terms of increased operational efficiency, lower costs and better service to customers. Their replacement by newer technologies has made the system more flexible and responsive to changes in supply and demand. The study results emphasise the importance of incorporating digital offerings to remain competitive in international markets.

1 Introduction

Digitalization in supply chain management is a component of forming strategic development of the business in context of globalization, strengthening competition and consumer preferences updates. The rapid convergence towards digital technologies is a game changer for logistics and product operations, and the interaction between all entities in the supply chain – suppliers, distributors, partners and end consumers. Introducing technologies such as IoT, AI, blockchain, cloud computing and robotics can dramatically transform the way supply chain management is done, optimise processes, improve productivity and cut costs. Digitalization of supply chain is the hot theme in contemporary researches, bringing a lot to process the manufacturing logistics. Digitalization of supply chains necessitates deviating and changing the orchestration and control of planning activities to allow focusing potential for the implementation of quicker speed up to delivery times,

improved demand forecasting precision, better inventory handling, and higher investment and operation transparency. In the period of global changes and instability, when significant changes are taking place in international politics and economics, while environmental challenges introduced challenges for companies that require a quick response, and digitalisation has become the basic instrument of adapting to these changes. Digitization helps companies become more flexible and robust, respond more quickly to shifts in demand, and anticipate requirements by tapping data analytics. In fact, innovations such as machine learning, big data provide the possibility to enhance the precision for demand forecasting, and the application of robot systems in warehousing make the automation of the warehouse operations and logistics delivery becomes more frequent, which leads to the decrease of the time and cost for the order processing. However, the integration of new technologies and systems faces several challenges, for which a scientific response is

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needed. Back up: Rewind back to COVID-19 in the Spring of 2020 and we see what's really behind digital transformation: It's that our supply chains - now multiple and complex - must be more efficient. Today's supply chains comprise several layers and partners communicating through different mediums. This results in a more difficult to manage situation in terms of supply coordination, inventory monitoring and maximizing, and customer service levels. Digitalization provides a way for organizations to predict demand more precisely, manage inventories better, and optimize their logistics processes [1]. The use of blockchain technologies makes all these operations transparent and secure – which is very important in a globalised world since it can be hard to track the origin of goods and their authenticity. Utilization of the IoT, and sensors, presents real-time information about goods anywhere along the supply chain, thus enabling a prompt response to unexpected events or failures in transportation. Further, organisations that are running digital technologies which they implement can benefit from being more competitive through better inventory management processes, shortened lead-times for orders and enhance customer service. Nowhere is this more prevalent than for businesses in fiercely competitive markets such as retail, e-commerce and logistics. Nevertheless, in spite of its obvious benefits, introducing digital technologies into supply chain management is not without its challenges. One of them is the high cost of new technical implementations, and small and medium-sized enterprises find it difficult to overcome this barrier. Lack of adequate resources also hinders many firms to deploy digital solutions at scale and compete with large market incumbents. Another challenge is to consolidate the new technologies with the old systems. The majority of companies already possess a large number of sophisticated information systems that support the operations and management of supply chain processes, and the introduction of new technologies may entail costly efforts to interconnect and interoperable with them. This results into costly employee training and infrastructure updates. The process of digitalization can also lead to data losings and cyber menaces being a menace. For protection of information and safeguard from hackers, companies have to use security systems, which results into the high cost. For supply chains, this is problematic, as there is the exchange of information between a large number of actors who can all cause information leakage. It is also worth mention that the digital transformation of supply chain management is still at the advancing stage and few technologies have become matured. This makes it all the more crucial for businesses to still look for new tactics and technology to revolutionize the way they do things. Specific elements that could benefit from more comprehensive research and practical application include use of artificial intelligence to predict and plan deliveries, using blockchain to make operations more transparent, and automation of goods' transportation and storage using robots and drones. Moreover, complete around

digitalization doesn't just boast a technological requirement, but also to organizational shifts. Organizations need to prepare their employees for new competences and foster a digital way of thinking, as well as attune internal processes to the new reality [2]. This implies an integral plan and also scientific works focused on the good judgement when incorporating digital technologies in the operation and management of companies. One clear message: Digital changed the game and value of the supply chain, not only a technology transformation, but an organization transformation for organizations. The fact of the matter is that digital solutions are still the way to go, as well as the ability to enhance effectiveness in operations, and decrease costs as well as enhance business agility and resilience. Nevertheless, in addition to the obvious advantages, few very significant obstacles have restricted its development and implementation costs, hard to connect existing systems, and security aspects. More research in this space is required to provide solutions that will assist companies in improving their supply chain capabilities and minimizing risks in the competitive digital economy.

1.1 The theoretical basis of digital transformation in supply chain management: essential features in contemporary society

Today, supply chains have become intricate multi-tiered networks that span the entire gamut of product flow – from raw material suppliers to consumers. Efficient supply chain has a straight influence on the productivity of the Company, costs and competitiveness. To solve this issue, there is a need for the redefinition of classical methodologies for chains management due to implementation of digital technologies. This has given rise to a trend that is referred to as the digital transformation of supply chain management. Digitalisation in this sense refers to the consistent use of digital technologies (such as Internet of Things, AI, machine learning, big data, cloud platforms and blockchain) in order to improve transparency, speed, flexibility, adaptability and efficiency of the overall logistics system. Such a transition is not only technological, but it also involves changes of processes, business models, organizational culture, etc.

Digital transformation of the supply chain is a profound change in the entire logistics and resource mmanagement system of a company through the introduction and integration of modern digital technologies [3]. This phenomenon cannot be viewed solely as a technological upgrade. It involves rethinking strategic approaches to management, organizational structures, business models, and interactions between all participants in the logistics network. In theoretical terms, digital transformation of the supply chain is studied within the framework of several key conceptual approaches. First of all, it is considered as a manifestation of systemic evolution. According to the systemic approach, the supply chain is a complex dynamic system that includes many interconnected elements:

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suppliers, manufacturers, logistics operators, distributors, retail chains, customers, and regulators. These participants are linked by flows of information, material resources, and finance. Digitalization enhances the coherence and manageability of the system, creating conditions for functioning in real time. Information flows take priority over physical ones, and management decisions are made based on timely and reliable information. Thus, the system moves from reactive management to a proactive model based on forecasting and scenario modelling.

Digital transformation is also closely related to the Resource-Based View (RBV), which views a company's internal resources as the basis for sustainable competitive advantage. Within this theory, digital technologies are considered unique and difficult to replicate resources that can significantly improve the efficiency of business processes. Consequently, the digital maturity of an organization becomes part of its strategic capital and determines the ability to adapt to rapidly changing external conditions [4]. The organizational and behavioral aspect of digital transformation is no less important. In scientific literature, it is often associated with the theory of organizational change, according to which any radical transformation requires personnel training, changes in corporate culture, the introduction of new forms of leadership, and increased flexibility of internal processes. Digitalization of supply chains changes the logic of employees' work: the emphasis shifts from routine operations to analytics, data-driven decision-making, and cross-functional interaction. This requires new competencies - digital literacy, the ability to work with analytical tools, an understanding of the principles of AI and machine learning. Resistance to change, lack of digital skills, fear of automation - all this can become a serious barrier to digitalization. In this regard, the success of the transformation depends not only on the level of technology, but also on the company's readiness for institutional and cultural changes. In terms of assessing the level of digital transformation, digital maturity models (Digital Maturity Models) are actively used in the theoretical field, such as the models of Deloitte, Gartner, PwC and Capgemini. These models describe the stages of digital transformation from basic automation and disparate implementation of IT solutions to full digital integration, end-to-end analytics and autonomous decision-making. Maturity assessment includes such parameters as the level of digitalization of processes, integration with partners, the use of cloud platforms, the presence of a centralized data warehouse and the use of AI to optimize operations. The theoretical significance of these models is that they allow quantitatively and qualitatively measuring the progress of digital transformation, comparing organizations with each other, and identifying bottlenecks in their digital strategy. Thus, digital transformation of supply chains is a multifaceted and interdisciplinary process that should be analysed not only as the implementation of technologies, but also as a strategic restructuring of the entire logistics architecture. Theoretical approaches - systemic, resource,

organizational - help to more deeply understand the causes, mechanisms and consequences of this process. In the context of global instability, growing uncertainty and intensifying competition, digitalization of the supply chain is becoming not just a competitive advantage, but a factor in the survival and sustainable development of companies.

1.2 Theory of development of digital transformation of supply chain management of modern companies

Digital transformation of supply chain management is a process of strategic and technological restructuring of companies' logistics and production systems in order to increase their flexibility, transparency, sustainability and customer focus. he theoretical understanding of digital transformation in supply chain and logistics management is based on a combination of several interdisciplinary approaches that reflect the evolution of practice and scientific thought. Modern theories of digital transformation of supply chains are based on the concept of an evolutionary transition from traditional logistics to intelligent digital ecosystems:

– Automation (Digitalization 1.0): implementation of IT inventory management systems (ERP, WMS, TMS), simplification of document flow.

– Integration (2.0): data consolidation between departments, creation of a unified information environment, electronic data exchange between companies.

– Digital coordination (3.0): implementation of IoT, real-time analytics, platform approach, increased chain transparency.

– Intelligent ecosystems (4.0+): use of AI, digital twins, blockchain and predictive analytics for autonomous supply chain management [5].

This transition reflects the movement from local digital improvement to end-to-end transformation, in which decisions are made based on data and with the participation of all links in the chain in a single digital space.

The supply chain is definitely a complex adaptive system in which each element (supplier, manufacturer, distributor, retailer, consumer) is interconnected. Systems theory allows us to consider supply chains as a cyber-physical system controlled by information flows. Digitalization enhances coordination and reduces transaction costs. Of no small importance is the resource-capability theory (RBV), according to which companies achieve sustainable advantage by possessing unique resources. In the context of digital transformation, such resources are digital platforms, data, digital competencies and algorithms. Digital transformation allows us to create differentiating capabilities: demand forecasting, reduction of delivery cycles, risk management. The theory of organizational change provides for the fact that any transformation is, first of all, a change in the behavior, culture and structure of the company. Digital

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transformation of supply chains requires a new type of leadership, agile organization, readiness for experiments and cross-functional interaction. The success of the transformation depends on the ability of companies to manage change and learn during the implementation process. The theory of sustainable supply chains in an unstable external environment, digital transformation becomes a tool for increasing the resilience of supply chains: identifying risks, responding in real time, developing alternative scenarios. Here, digitalization helps adapt the system to external shocks (COVID-19, crises, sanctions, etc.). Current conditions significantly influence the content of digital transformation. Among the key features:

− Global disruptions in logistics and demand require companies to quickly adapt and develop flexible digital solutions.

− The ESG agenda and sustainability are pushing for the implementation of tracking technologies, reducing emissions and supply transparency.

− The digital ecosystem and platform approach are becoming the dominant model: companies are uniting in digital networks where they exchange data and jointly manage risks and chains.

− The growing role of data and analytics: management is becoming proactive, based on big data and predictive analytics.

The theory of digital transformation of supply chain management is based on a comprehensive interdisciplinary approach that combines system, organizational, resource and behavioral analysis. It reflects the transition from local digital improvements to the creation of fully integrated digital ecosystems that are able to adapt, learn and predict changes. In conditions of increased uncertainty, sustainability requirements and rapid technological evolution, digital transformation is becoming not just desirable, but necessary for the survival and growth of companies.

2 Literature review

Digital transformation of supply chains is a multifaceted process of implementing modern information technologies to improve the efficiency, transparency, and sustainability of logistics and production systems. In recent decades, this topic has attracted the attention of researchers and practitioners, resulting in a significant volume of scientific literature. One of the focuses of research is understanding the fix and the degree of method the implementation of technologies as Internet of Things, Big Data, Artificial Intelligence, Blockchain, and Cloud Computing have in supply chain management, and logistics [6]. By leveraging IoT and AI, we can achieve a much higher degree of accuracy when forecasting demand and reduce delivery time on the last mile. But the adoption of these technologies involves great investment and an organizational shift that might deter the small-and medium-sized companies from implementing these technologies. Much research has been carried out on the use of specific technologies especially including Internet of Things (IoT), Big Data, AI, Blockchain, RPA, Digital Twins, Cloud based technologies and ML-based solutions. IOT is viewed as one of those vital frameworks that link physical entities - be it machinery, vehicle or warehouse – to digital world. IoT is the enabler of the revolution of logistic industry. However, the IoT has made it possible to gather real-time information, to make decision using updated information49 [7]. In doing so, it also enhances demand forecast, inventory planning and supply state monitoring. Big Data plus predictive analytics are therefore regarded as the indispensable foundation for agile and adaptable SCM. It is however noted that the power to store and manoeuvre massive volumes of structured and unstructured information such as sales forecasts, weather information and social networks can greatly extend the capabilities of logistics systems for analyses [8]. However, as some researchers have recognized, e.g., [9], effective Big Data utilization depends not only on technology, but also on altering organizational culture and staff competencies. One of the most discussed technologies is blockchain, which is considered as a tool for increasing transparency and trust in supply chains. Blockchain ensures immutability of records, automation of contract execution (via smart contracts) and decentralized management, which is especially important for complex international supply chains [10]. However, a critical analysis of these publications shows that the use of blockchain is limited to pilot projects so far, and there are many unresolved issues, including scalability, legal support and energy costs. Digital twins are a relatively new but rapidly developing concept. According to research [11], digital twins allow modelling and predicting the behavior of logistics systems in the digital space, which increases the accuracy of decision-making and reduces operational risks. This technology is especially relevant in conditions of unstable supplies, when it is necessary to quickly respond to failures, find alternative routes and redistribute resources. It should be noted that many publications emphasize the interrelation of technologies. For example, digital twins are impossible without integrating data from IoT devices and processing them using Big Data and AI. Thus, the key challenge of digital transformation and supply chains is the need to create a single digital architecture capable of combining disparate tools into a single system [12]. However, despite the high activity of scientific publications in this area, there are a number of significant methodological and empirical limitations. Firstly, most studies are conceptual in nature and rely on theoretical modelling or case studies that are not accompanied by representative quantitative data. Secondly, the scientific discussion clearly shows an imbalance between the technical and managerial components of digital transformation. Most publications focus on the characteristics of technologies, while much less attention is

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paid to the problems of organizational resistance, changes in corporate culture, transformation of business models and managerial competencies. This is especially noticeable in comparison with classical works on strategic management in logistics [13], which emphasize the need to align technological innovations with the goals and structure of the organization. A critical analysis also reveals ambiguity in assessing the effects of digitalization. Some studies demonstrate impressive results: reduced delivery times, lower operating costs, and improved forecast accuracy. However, other publications, including peer-reviewed practice-oriented journals, highlight that digitalization often comes with hidden costs associated with cyber risks, technical failures, compatibility issues, and the need to constantly update the IT infrastructure. In addition, it is noted that digital technologies do not always lead to increased profits - in some cases, IT investments are not justified due to weak operational integration [14]. Empirical studies show that digital transformation in logistics and supply chain management is uneven. According to the World Economic Forum, about 70% of large companies in the G20 countries have already implemented elements of digital logistics, while in developing economies this figure does not exceed 20-25% [15]. This is confirmed by the results of comparative studies, which show significant differences in the level of digital maturity between regions and industries. Food and pharmaceutical supply chains turned out to be especially vulnerable to digital disruptions, which became apparent during periods of crisis. Clearly, digitalization can increase inequality, both between companies of different sizes and between regions. Moreover, the use of AI and the automation of decision-making give rise to issues of responsibility, transparency of algorithms and data privacy [16]. It is also necessary to note the progress in the standardization of digital processes in logistics. Leading international organizations such as ISO and GS1 are developing unified protocols for electronic data exchange, product tracking and supply chain verification. However, research shows that the level of adoption of these standards remains low among SMEs, which hinders large-scale transformation of the sector. A review of the scientific literature on the topic of digital transformation of supply chain management reveals significant advances in the analysis of the implementation of individual digital technologies, such as blockchain, the Internet of Things (IoT), big data, and artificial intelligence. Most studies focus on the technical aspects of integrating these solutions or improving the efficiency of individual links in the supply chain. However, there remains a noticeable gap in the study of systemic management transformation, when digitalization is viewed not as a tool, but as a strategic paradigm that changes the structure and logic of the entire supply chain. Insufficient attention has been paid to the study of the complex impact of digital initiatives on sustainability, adaptability, risk management, and strategic planning in global chains. In addition, most existing studies are based on theoretical models or case studies of a limited number of companies, which does not allow for general conclusions to be drawn about the trends and consequences of digital transformation at the scale of industries or economies. Thus, there is a need for empirically based, interdisciplinary research that combines managerial, technological, and economic approaches. This will fill the gap in understanding how digital transformation impacts the sustainability and competitiveness of supply chains in the long term. Thus, the scientific literature on digital transformation of supply chains shows a steady increase in interest, but remains fragmented, methodologically heterogeneous and often divorced from the realities of everyday logistics practice. Significant advances in theoretical understanding and technical modeling have been identified, but there is an obvious lack of systematic empirical research covering a wide range of companies, industries and regions. Promising areas for further research include the development of adaptive digitalization models for companies with different degrees of digital maturity, analysis of the cost-effectiveness of digital investments, studying the impact of digitalization on sustainability and risks, as well as the creation of interdisciplinary approaches combining IT, logistics, HR management and sustainable development. Digital transformation of their supply chains is an elaborate and multi-faceted exercise that requires the introduction of emerging technologies and changes in structures and work culture. Although substantial progresses have been made in this regard, some bottlenecks and limitations exist, such as high system-wide implementation costs, the quality of data, threats of cyber security and staff training etc. The success of the digital transformation depends on a holistic strategy covering technological, organizational and societal aspects.

3 Methodology
3.1 *Peer review process*
In the context of the growing digitalization of global logistics processes, companies are massively introducing innovative technologies — from IoT and blockchain to digital twins and AI systems. However, without a clearly defined methodology for assessing their economic and operational efficiency, such implementations may not pay off, lead to distorted management decisions or invisible risks. Given the above, it should be noted that the methodology is based on the integration of principles for assessing the effectiveness of IT investments (ROI, TCO) and supply chain management metrics [17,18]. It is important to take into account not only the direct financial effect, but also non-financial benefits, including sustainability, transparency, flexibility and risk reduction. Undoubtedly, the implementation of the presented methodology is necessary for conducting a quantitative assessment of the impact of digital solutions on the supply chain management system (cost, delivery time, service level, etc.); comparing the costs and benefits of technology implementation; strategic adjustment of digital initiatives; evidence base for investments in IT infrastructure. It is important to note that the methodology is based on the

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integration of principles for assessing the effectiveness of IT investments (ROI, TCO) and metrics of the supply chain management system [19]. It is important to take into account not only the direct financial effect, but also non-financial benefits, including sustainability, transparency, flexibility and risk reduction. The methodology can be applied at the level of: business processes (microefficiency: speed, accuracy, transparency); supply chains as a whole (macroefficiency: adaptability, sustainability, cybersecurity); financial return (economic efficiency - ROI, NPV, IRR, etc.) [20]. Key metrics and indicators for assessing the effectiveness of digital technologies in supply chain management of modern companies are presented in Table 1.

Table 1 Key metrics and indicators for assessing the effectiveness of digital technologies in supply chain management of modern companies

DIRECTION	KEY METRICS AND INDICATORS	CALCULATION METHODOLOGY
ECONOMIC	ROI (Return on Investment)	$\frac{\text{Net Benefit}}{\text{Investment}} * 100\%$
	TCO (Total Cost of Ownership)	$\text{Direct} + \text{Indirect} + \text{Hidden Costs of the Life Cycle of Digital Technology}$
	Payback Period (Payback Period)	$\frac{\text{Initial Investment}}{\text{Cash Flow for the Year}}$
OPERATIONAL	OTIF (On-Time In-Full Delivery)	percentage of timely and full deliveries
	Inventory Turnover Ratio	inventory turnover
	Lead Time Reduction	reduction in time between order and delivery
	Order Fulfillment Cycle Time	order fulfillment cycle
STRATEGIC AND NON-FINANCIAL	Level of digital maturity	assessment according to SCOR, Gartner, BCG, etc.
	Quality of data in the chain	rate of errors, incomplete records, etc.
	Level of transparency	Level of transparency and traceability
	Adaptability of the chain	response time to failures

To substantiate the final results of the methodology, it is necessary to use the integrated indicator of the effectiveness of digital transformation (DTEI – Digital Transformation Efficiency Index) (1):

$$DTEI = \alpha \cdot \frac{\Delta KPI_{oper}}{\Delta KPI_{\substack{base \\ oper}}} + \beta \cdot \frac{\Delta KPI_{econ}}{\Delta KPI_{\substack{base \\ econ}}} + \gamma \cdot \frac{S_{gual}}{S_{ma[}} - \delta \cdot R \qquad (1)$$

Where: ΔKPI_{oper} - change in operational indicators (delivery time, turnover, errors, etc.); ΔKPI_{econ} - change in economic metrics (revenue, margin, TCO, etc.); S_{qual} - score assessment of non-financial benefits (on an expert scale: transparency, flexibility, sustainability); S_{max} - maximum possible score; R - level of digital risks (e.g. cyber threats, integration failures, IT instability); $\alpha, \beta, \gamma, \delta$ - weighting factors determined depending on the company's priorities.

The methodology for assessing the effectiveness of digital technologies presented above was applied to analyze the results of implementing such technologies as IoT, AI, Big Data, Blockchain and Robotics in large global companies such as Amazon, Maersk, DHL and FedEx. All companies using these technologies in supply chain management have demonstrated significant improvements in both operational and financial efficiency. The selected steps enable us to effectively answer the research questions posed, as they cover both strategic and operational aspects of digital transformation. This approach helps to identify the real-world consequences of implementing digital solutions in supply chain management, including the impact on sustainability, adaptability, and productivity. The analysis of practical examples allows us to understand which technologies provide the greatest value, and the comparison of data from different companies allows us to identify common patterns and differences. This provides a deep and balanced understanding of change processes, reflecting both general trends and industry specifics in the context of the digital economy.

4 Results and discussion

Digital transformation of supply chain management is a comprehensive process of implementing and using

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modern digital technologies to optimize, automate and improve the efficiency of all aspects of logistics, inventory management, transportation and interaction between supply chain participants. In recent years, the trend towards digitalization has been spreading across all areas of business, and supply chains are no exception. The introduction of innovative technologies allows companies to increase the speed of order fulfilment, improve forecasting accuracy, reduce costs and increase process transparency. Digital transformation in supply chain management requires the integration of many advanced technologies and tools. These include the internet of things, artificial intelligence, machine learning, big data, analytics, blockchain, cloud and robotics. These new technologies target each aspect of supply: from planning and procurement to delivery and after sales service [21]. The digital transformation of supply chains is anything but one-size-fits-all and depends a great deal on the industry, company size, the level of digitalization, among others. The features and the specifics of digitalisation of the supply chains of the contemporary enterprises are presented in Figure 1.
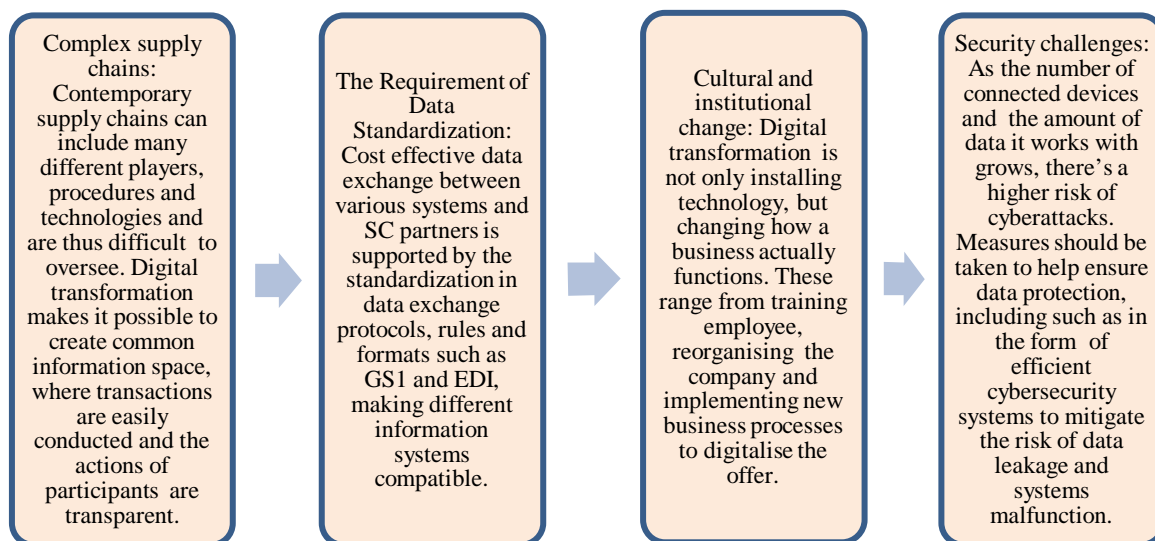

Figure 1 Features and specifics of digital transformation of supply chains of modern companies

Based on the presented features of digital transformation of supply chain management, it is clear that this process is not just a technological upgrade, but a comprehensive strategic transformation of the entire logistics and operational infrastructure of companies. Features of digital transformation, such as multi-level integration of participants, the need to standardize processes and data, a high level of complexity of supply chains, the introduction of cloud solutions and the need to adapt the corporate culture, indicate the systemic nature of the changes. Digitalization of logistics requires not only the modernization of technical means, but also a complete transformation of approaches to management, planning and interaction within the company and with external partners. In addition, digital transformation inevitably entails increased attention to cybersecurity, data protection issues, change management and improving the digital competencies of personnel. These aspects, being specific, emphasize that transformation is not a linear or one-time process - on the contrary, it is evolutionary in nature, requiring constant adaptation and revision of business models [21,22]. The significant complexity of digital supply chains and the involvement of a large number of participants require the implementation of universal and compatible solutions that comply with international standards, as well as the company's ability to adapt to new technologies and quickly change strategy in response to changes in the external environment. Thus, the features of digital transformation emphasize its critical importance for increasing the sustainability, efficiency and competitiveness of modern logistics systems. Ignoring these features can lead to loss of control, reduced service quality and loss of market positions. Companies that have recognized these features and competently adapted their strategies receive significant advantages in the digital economy. The main aspects of digital transformation of supply chain management of modern companies are presented in Table 2.

Table 2 Key moments of digital transformation of supply chain management of contemporary enterprises

DIRECTION	FEATURES OF SUPPLY CHAIN MANAGEMENT TRANSFORMATION
INTEGRATION OF DIGITAL TECHNOLOGIES	The integration of multiple digital solutions in a single system that helps to manage efficiently all supply chain concerns in real time is at the base of digital transformation. This includes leveraging the Internet of Things to monitor the status of goods and vehicles end-to-end. These parameters are not only exchanged among several information systems (ERP, WMS, TMS), but even among several actors in a supply chain

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	using cloud platforms and software as a service (SaaS). This makes the management more efficiently and accurate.
AUTOMATION OF PROCESSES	The use of automation, as such, of course constitutes part of the digitalization of activities. This can be anything from warehousing processes that have automation bots in them, to planning and logistics which are automated with the help of AI and machine learning. For instance, robotic warehouses can clearly manage inventory, packaging, sorting and delivery of products, thus making saving on labor and improving effectiveness. Transport is another field of automation where such mass utilization of automated vehicles or drones (delivery-to-door or last-mile delivery) is the major factor in reducing logistics costs and service times.
FORECASTING AND ANALYTICS	Prediction plays a crucial role in digitalization of supply chains. Leveraging big data analytics and machine learning models can greatly enhance demand forecasting and optimize logistics and supply chain. By aggregating data sources (IoT devices, transaction data, social media, purchase data, etc.), businesses can now predict future product needs by analyzing current product usage patterns, reduce inventory, prevent stock-outs, and expedite order delivery. Leveraging analytics tools to track and analyze data likewise supports enhanced forecasting by looking at past data and trends. This, in turn, minimizes a number of logistical risks, such as the risk of having no supplies or the risk of running out of products that are sold out.
RISK MANAGEMENT	Supply chain risk management can benefit from the digital transformation process. Real-time supply chain monitoring using data analytics, AI and IoT Monitoring every part of your supply chain in real time means you can rapidly see when things go wrong –whether that's a delay, a breakdown, an accident, a supply break – and do something about it. Blockchain Tracking the origin and state of goods also helps to build trust in the supply chain and reduce the possibility of fraud.
CLOUD PLATFORMS AND ECOSYSTEMS	Supply chain digitalization benefits from cloud solutions. They provide organizations across all geographical locations with access to required data and applications, who experience improved process flexibility and greater collaboration among supply chain members. This is increasingly significant in this age of globalization and geographic diversification of business. Cloud systems save on capital costs, too, because they don't need the kind of heavy investment in hardware that has been required in the past.
BLOCKCHAIN AND SECURITY	Data protection is a fundamental part of digitalisation. In this context, blockchain technology offers novel solutions for maintaining transparency, reliability and irrevocability of transactions. By doing so in logistics we provide a solution where we can offer a specific way to guarantee the reliability of that information on supply, to avoid fraud, to optimize in the contract management and eventually boost the trust of the parties involved in the supply chain. It is important for transnational shipments in particular to guarantee the security and safety of data all along the transport route.
MOBILE AND FLEXIBLE SOLUTIONS	Present-day mobile technologies can bring about a great deal of freedom and flexibility for companies. Mobile applications alone, for instance, facilitate tracking of goods and updating of order statuses while allowing notifications about potential malfunctions and enabling on-the-fly planning. Mobile solutions are playing a significant role in the digitalization of the supply chain and provide all involved parties customer, supplier and logistics system operator with an enhanced form of interaction.

Digital transformation of supply chains is a necessity in today's environment. Globalization, increased competition and increasing consumer demands require companies to take a more flexible and efficient approach to supply chain management. Structuring the benefits that companies can gain from digital transformation of supply chain management and logistics systems of modern companies includes:

– Improved customer experience: Today's consumers demand faster, more accurate deliveries, as well as greater transparency and information about the delivery process. Digital transformation helps companies improve their operational performance, which leads to higher customer satisfaction.

– Reduced costs and increased efficiency: Automation of processes, use of data analytics and optimization of logistics operations help reduce the costs of storing, transporting and handling goods, and speed up order fulfillment.

– Competitiveness: Companies that do not implement digital technologies risk falling behind competitors who are using innovations to improve their logistics infrastructure and improve operational efficiency.

– Risks uncertainties: In a fast-changing world, with global economic turmoil and with threats such as the COVID-19 pandemic, companies have to be nimble and agile enough to react to changes in the supply chain. Digitalisation enables supply chain agility and robustness, which is a critical aspect to stay competitive [23].

Digital reshaping of supply chain management As an example for resilience, efficiency and flexibility for logistics and supply management, the digital re-shaping of supply chains is an essential component. Modern digital technologies are enabling organisations to focus not just on improving processes but also increasing the level of service to their customers, reducing costs and managing risk. With globalisation, more competitive markets and greater uncertainties companies have little choice but to engage in the digital transformation of their business if they are to remain competitive and survive in the long run. It is worth mentioning that the digitization of supply chains is a necessity today for any company that wants to gain competitive advantage, as well as reducing costs and

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improving durability. Deployment of disruptive technologies like AI, blockchain, cloud solutions, automation, among others allows for new possibilities in process optimization, enhanced customer experience and development of entirely new business models. It is important to note that successful digitalization requires not only the implementation of technologies, but also changes in corporate culture, personnel training and revision of business processes. Companies that can effectively integrate digital solutions into their supply chains will have significant advantages in today's market conditions. To assess the effectiveness of digital technologies in supply chains, official data from companies such as Amazon, Maersk, DHL and FedEx were used as input data. However, it is important to understand that accurate data from commercial studies or official reports are often not publicly available, and companies often share only generalized results, which does not always allow for high-quality analysis and evaluation. The input data from companies to assess the effectiveness of digital technologies in supply chains to support key trends and prospects is presented in Table 3.

Table 3 Input data from companies to assess the effectiveness of digital technologies in supply chains to support key trends and prospects

INDICATOR	COMPANY				UNIT
	AMAZON	MAERSK	DHL	FEDEX	
TECHNOLOGY TYPE	IoT, AI	Blockchain,	IoT, Big Data	Digital Twins	-
INVESTMENTS IN DIGITALIZATION	200.00	120.00	150.00	180.00	$ million
DIRECT COSTS	120.00	80.00	100.00	110.00	$ million
INDIRECT COSTS	40.00	20.00	30.00	40.00	$ million
HIDDEN COSTS	40.00	20.00	20.00	30.00	$ million
CASH FLOW FOR THE YEAR	45.00	30.00	50.00	60.00	million/year
EXPECTED NET BENEFIT	90.00	60.00	75.00	90.00	$ million
ORDERS FULFILLED PER YEAR	200 000.00	500 00.00	1 200 000.00	1 500 000.00	Orders
NUMBER OF ORDERS FULFILLED ON TIME AND IN FULL	1 960 000.00	480 000.00	1 164 000.00	1 425 000.00	Orders
ORDER LEAD TIME (before implementation)	3	12	5	4.5	days
ORDER LEAD TIME (after implementation)	1.5	8	3.2	3	days
AVERAGE INVENTORY LEVEL ($ million)	500.00	400.00	300.00	350.00	$ million
COST OF GOODS SOLD (COGS)	4100.00	3000.00	2550.00	2730.00	$ million
DIGITAL MATURITY LEVEL (SCOR/BCG, max. 5)	4	4	3	4	points
SHARE OF CORRECT DATA IN THE IS	98.00%	95.00%	97.00%	96.00%	%
DATA ENGINEERING EFFICIENCY INDEX	0.85	0.90	0.88	0.87	from 0 to 1
TRANSPARENCY (on internal company scale)	95.00%	92.00%	94.00%	93.00%	%
AVERAGE RESPONSE TIME TO FAILURE	2	3	2.5	2	hours

Source: consolidated data based on sources [21-24]

The key results of assessing the effectiveness of digital technologies in supply chain management of modern companies are presented in Figure 2.

Conceptualizing the presented results, it should be noted that all companies using digital technologies demonstrated a high ROI (50% for all companies), which confirms the cost-effectiveness of supply chain digitalization. At the same time, the payback period varies from 3 to 4 years, which is the norm for large players such as Amazon and FedEx. OTIF indicators for all companies remain high (from 95% to 98%), which indicates the accuracy of order fulfilment. This is a key indicator in logistics, confirming that digital technologies help to minimize errors and improve service quality [25]. Inventory Turnover Ratio also shows good results, which means effective inventory management and fast product turnover. It is also important that all companies showed a significant reduction in order fulfilments time, which confirms the effectiveness of IoT, AI and other technologies in accelerating processes. Companies such as Amazon, Maersk, FedEx have a high level of digital maturity, which indicates the deep implementation of technologies in their operational processes. High levels of transparency and traceability indicate that technologies such as Blockchain and IoT are successfully helping to track goods and information at every stage of the supply chain [26]. Adaptability also demonstrates that all companies can quickly respond to disruptions, minimizing downtime and losses. Regarding data and DTEI, data quality and DTEI remain high for all companies, confirming the successful use of data for management decision-making and supply chain optimization. This comprehensive analysis shows how supply chain digitalization can significantly improve key operational and financial metrics, increasing company efficiency. It should be clearly noted that the advantages of the developed methodology for assessing the effectiveness of digital technologies in supply chain management are its comprehensiveness, systematicity and adaptability to the realities of modern logistics and digital transformation. In

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the context of the growing complexity of global supply chains, high competition, market instability and technological challenges, companies require not only the implementation of digital solutions, but also a meaningful, justified and measurable approach to their assessment. The proposed methodology meets these needs of business and the scientific community [27]. The key advantage of the methodology is its multi-criteria nature, which allows assessing the effectiveness of digital technologies not only in financial, but also in operational, organizational and technological dimensions. It combines traditional financial and economic indicators (ROI, TCO, Payback Period) with metrics reflecting logistics efficiency (OTIF, Lead Time Reduction, Order Fulfillment Cycle Time, Inventory Turnover), as well as with new indicators of digital maturity, data quality, level of transparency and adaptability of the chain. Thus, the assessment is not limited to one aspect of digital technology implementation — it covers the full scope of their impact on supply chain management.
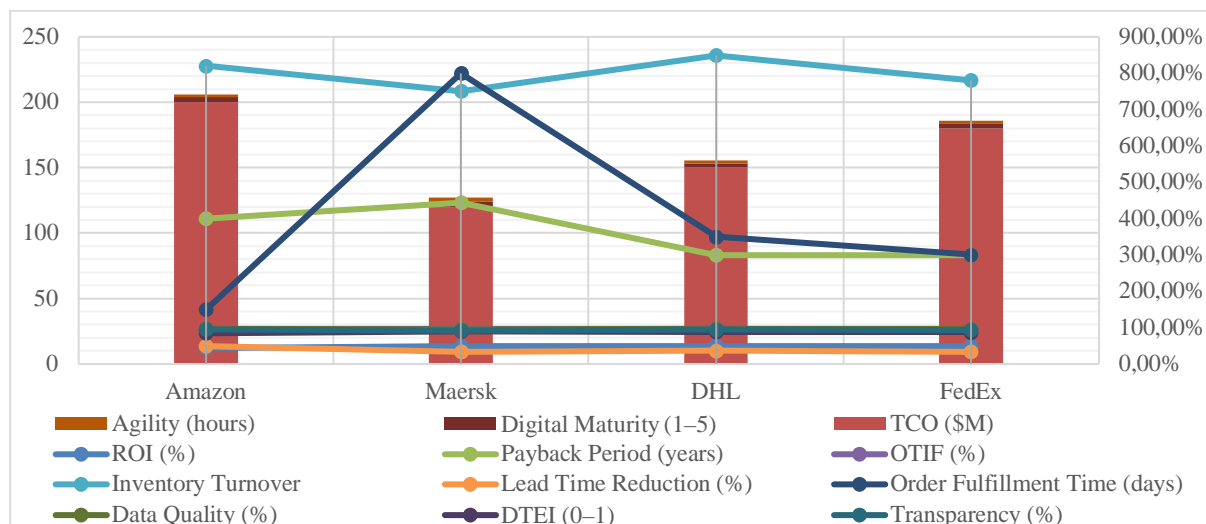

Figure 1 The key results of assessing the effectiveness of digital technologies in supply chain management of modern companies

The methodology is based on widely recognized standards, such as SCOR (Supply Chain Operations Reference), digital maturity models by Gartner, BCG, McKinsey and others, which makes it universal and comparable with international practices. This makes it possible to use it for benchmarking, assessing digital transformation in dynamics, as well as for inter-industry and inter-country comparison. The approach is adapted for companies of various sizes and levels of digitalization, allowing you to flexibly vary the depth of analysis depending on the available data and assessment goals. Special attention in the methodology is paid to data quality and the Digital Technology Efficiency Index (DTEI), which is especially relevant in the context of the rapid growth of information volumes in logistics and the need for its fast and correct processing [28]. This allows you not only to record the technical availability of digital solutions, but also to analyze how effectively they are used, what value they create, and how much they support management decision-making. The uniqueness of the methodology lies in the fact that it can be used both in retrospective analysis (to evaluate already completed digital projects) and at the planning or technology selection stage. This makes it an important strategic management tool: it can be used to compare different implementation scenarios, calculate projected payback, and select the most effective areas of digital investment. From the point of view of scientific and applied prospects of the methodology, several areas of its further development and integration into business practice can be identified. Firstly, with the development of technologies and their increased availability, new digital indicators can be built into the methodology, reflecting work with artificial intelligence, digital twins, quantum computing, and other breakthrough solutions. This requires constant updating of the model and adaptation to new technological realities. Secondly, a promising area is the inclusion of ESG indicators in the assessment system [29]. Given the transition to sustainable supply chains, digital technologies are increasingly used to monitor environmental and social parameters (e.g. carbon footprint, fair working conditions, ethical origin of raw materials). The integration of these aspects into the methodology will allow us to assess not only the economic but also the social value of digitalization. Another important vector of development is the modelling of supply chain resilience using digital indicators. For example, the adaptability index, the speed of recovery from failures, cyber resilience and fault tolerance can be made part of the overall assessment [30]. This is especially relevant in the context of global shocks, when companies are looking for ways to strengthen their logistics networks.

In addition, the methodology can be supplemented with visualization and business intelligence (BI) tools, which will open up opportunities for automating analysis, building interactive dashboards and generating reports in real time. This will enhance the practical value of the

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approach for managers, consultants and logisticians working in practice. In general, the proposed methodology offers a holistic approach to assessing the effectiveness of digital transformation in supply chains. It helps companies not only measure the effectiveness of investments, but also strategically build the digital development of their logistics infrastructure, making processes more flexible, transparent, sustainable and customer-oriented. The contribution of this study is the development of a holistic and multi-level approach to the analysis of digital transformation of supply chains, which makes it particularly valuable for solving the identified scientific and practical problems. Unlike previous studies that focused on individual technologies or local aspects of management, this approach allows us to consider transformation as a strategic and systemic process. It covers both internal mechanisms of change in companies and external factors, including market turbulence, digital maturity of industries and institutional conditions. A distinctive feature of the approach is the combination of empirical analysis, assessment of the real impact of digital solutions and conceptual understanding of the identified patterns. This allows us not only to fill the existing gap in the literature, but also to propose a practical model applicable to the assessment and implementation of digital strategies in supply management. Thus, this research approach represents a significant contribution to both scientific theory and managerial practice of digital transformation.

5 Conclusions

This study on the digital transformation of supply chain management has identified and synthesized key theoretical and practical aspects of how digital technologies influence logistics efficiency, information flow, and strategic coordination. The central outcome is the development of an integrated approach to analyzing current trends, adoption drivers, and the impact of digitalization on core logistical and strategic performance indicators. The proposed assessment framework enables structured and quantifiable evaluation of technologies in terms of transparency, flexibility, adaptability, return on investment, resilience, and supply chain maturity. The novelty of this research lies in its multi-level analysis - technological, operational, financial, and strategic - combined within a multi-criteria model. It integrates conventional performance metrics (ROI, TCO, Payback Period) with digital indicators such as data quality, digital maturity (based on SCOR, Gartner, BCG), traceability, and response speed. Another unique feature is the use of a hybrid model combining quantitative calculations and expert qualitative interpretation, enhancing applicability even under limited data conditions. Key advantages include a systemic, rather than fragmented, view of digital transformation; methodological flexibility suitable for both large corporations and mid-sized firms; and strong practical relevance. However, limitations include restricted access to reliable digital metrics, especially in less transparent sectors, and the reliance on self-reported data, which may affect objectivity. Future research should focus on cross-industry benchmarking, ESG integration, digital twins, BI-based monitoring tools, and AI-driven resilience modelling. This work thus provides a solid foundation for ongoing theoretical and practical exploration in the digitalization of supply chains.

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