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DIGITAL TRANSFORMATION OF LOGISTICS: THE ROLE OF IT IN IMPROVING SUPPLY CHAIN EFFICIENCY

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ABSTRACT

Logistics digital transformation is a fundamental accelerator of both efficiency and resilience for supply chains today. Rapidly growing complexity in international trade and rising consumer demands are driving the adoption of advanced information technologies (IT) to increase operational flexibility and decision-making capabilities. The traditional logistics system has developed to a certain degree; however, it also has some disadvantages, such as poor integration, low flexibility, and poor real-time ability to respond. This paper aims at investigating the role of IT (Big Data analytics as a specific IT) on the betterment of supply chain performance. Using a broad methodological framework to evaluate IT impacts on KPIs of different logistics process, the study relies on a Big Data analytics framework. The results revealed that the application of big (demand constraint) on Big Data analytics leads to savings in operational cost up to 20% and more improvement on the average orders delayed and demand forecasting by more than 30% and more than 25% respectively. Novelty The contribution or originality of this work is on that the integrated model has been developed both Big Data analytics and supply chain management theories into problems, this is a holistic vision to digital transformation. The practical implications of the research are fairly straightforward as it offers non-expert logistics managers pragmatic advice as to IT's application in terms of enhancing the supply chain's efficiency and competitive power. The results of this research will provide to deepen the theoretical framework of the IT in the logistics field, and would offer a way to apply IT to real cases.

Keywords: *Information Technology*, *Supply Chain Efficiency*

1. INTRODUCTION

Current supply chains are described as a multi-level system with a high level of uncertainty in which there are lots of product development and operative variables. The level of efficiency of those efficient systems influences directly the competitiveness of the companies, the time of response to customer's requests emerged as its permanence in a lucrative business. The increasing influences of the foreign market competition, the budding character of logistics processes and the restructuration and recreation of the customer requirements and the environmental and social responsibility also stress the enterprises and they approach to a search for new Supply Chain solutions. In such surroundings, typical methods of planning, the control and prediction of the logistics activities are not efficient enough, resulting in a larger degree of failures, high costs and low quality of the service. Digital logistics is often considered to be a means to improve the operational efficiency, transparency and sustainability of supply chains. It involves pragmatic use of sophisticated information technologies, like warehouse management systems (WMS), transport information systems (TMS), IoT, blockchain, machine learning and Big Data analytic platforms. Adoption of these technologies can help to link the entire supply chain, automate manual tasks, handle massive amounts of data in real-time, and forecast possible risk and emend changes. This enables organizations to make better decisions, lower costs, shorten time-to-market and provide better customer service. Due to the significant development of digitalization in logistics, researches to solve scientific and practical issues have not yet been settled, which determines the relevance of this paper. First, conventional methods for automation logistic procedures are frequently disparate: technologies are typically installed one by one in a local manner, and the interaction of all the supply chain elements is not thoroughly analyzed. This reduces the opportunity for a synergistic effect and the chance that resources are not used efficiently. Second, the current literature mainly considers either specific technologies or

single phases of the supply chain - such as demand prediction, inventory management or routing. This does not enable a comprehensive evaluation of the impact of digitalization in the total system efficiency and hinders the potential for scale of solutions. A number of studies in recent years have focused on the implementation of digital technologies in logistics management. The most common areas of focus have been the study of supply chain management (SCM) systems, the implementation of real-time cargo tracking platforms, and the use of big data for demand forecasting and inventory management. A significant number of publications analyze the impact of cloud solutions and online platforms on integrating supply chain participants, focusing on increasing transparency and reducing transaction costs. A separate body of work is devoted to the implementation of automated warehouse systems, robotics, and IoT devices for monitoring the condition of goods during transportation. However, most studies examine either individual technological tools or specific links in the supply chain. The results of such studies indicate that digitalization facilitates faster information processing, reduces errors, and improves forecasting accuracy. However, a systematic assessment of the combined impact of multiple technologies on supply chain efficiency remains fragmented, and conclusions are often based on data from specific industries or regions.

This paper aims to propose a comprehensive approach to digitalization of logistics using a unique methodological tool that is one analytic model of Big Data analysis. Such a tool provides the ability to integrate various information flows, to discovers patterns in the way the supply chain is operated, and to assess the impact of the IT on different performance indicators. Big Data analysis makes it possible to take a large number of factors into consideration, to perform a complex analysis of processes and to obtain very accurate predictions, which greatly enhances the effectiveness of the managerial decision-making.

This study was initially motivated by the need to comprehensively assess how digital transformation impacts the performance of the entire supply chain, not just its individual links. Unlike most previous publications, which focused on individual technologies (e.g., solely cloud services or IoT), this paper examines a range of tools—from transportation and warehouse management platforms to big data analytics and supplier interaction automation. This approach allows us to identify not only the local but also the systemic effects of implementing digital solutions. A second difference is the focus on the practical applicability of the results. The study is based on data from several large companies across various industries, enabling us to compare the dynamics of performance indicators—delivery speed, inventory levels, logistics costs, and resilience to disruption—depending on the degree of digitalization. Previous studies have often been limited to either modeling or analysis of isolated cases; this paper uses a comparable dataset, allowing for generalization.

Finally, the study was motivated by the search for a balance between technological and organizational change. Most studies document technical innovations but rarely address their integration into management processes. This paper proposes a model for the phased implementation of digital tools, taking into account a company's resources and maturity. The results demonstrate not only quantitative improvements in key metrics but also qualitative effects: increased transparency in partner interactions, increased supply chain resilience to external shocks, and improved service levels. This allows us to expand the discussion on the digital transformation of logistics and offer practical recommendations for businesses.

The practical significance of the study is that the model obtained can be applied in production enterprises to improve logistics processes, improve the transparency of the functioning of enterprises, reduce risks and adapt to changes from the outside. Theoretical significance is the formalization of the procedure for assessing the influence of digital technologies on the processes of logistics activities and also the development of a methodological base for further scientific research in the field of digital transformation of supply chains. This work offers an integrated view of the digitization process that includes technology, processes and skills and is therefore suitable for Logisticians and Managers, Logistics Service Providers (LSPs) and researchers. Its novelty is the design of an integration model that merges the potential of Big Data analytics with the operational needs of the Supply Chain Management at different levels. While most of the existing researches are either integrating individual technology or local process, the research emphasizes digital transition as a systemic process, aiming at unveiling the systemic relation among information technology, management process, and human factor. Such integrated methods not only reduce costs and lead times, but also enhance transparency, risk management and business agility. The labor is also significant because of a few aspects of modernity in the world economy. World trade has increased,

requirements of speed and accuracy in delivery have become stricter, and consumer demand and demand surges become versatile, so that companies are required to respond to external changes with high speed. Logistics And Supply Chain Digitalization has emerged as the ultimate strategic alternative for resilience to mitigate the force majeure and vulnerabilities opening the Achilles heel thereof. Second, firms are also more environmentally and socially responsible through digital transformation. IT can be incorporated - it enables better distribution networks, lower emissions by using the right vehicle for the job, and lower inventory and back stock of goods to hold - whilst aligning to sustainability principles of development and because is confident in what they are receiving. So the value of this paper is to develop a systematic approach to the digital transformation of logistics and quantifying and uralitizing the influence of information technology on the tune of the supply chains. It becomes a theoretical and practical foundation for analysis of particular components of digitalization, decision making of management and innovative instruments' use in the conditions of the existing economy.

1.1. Theoretical Aspects of Digital Transformation of Logistics

The digital transformation of logistics is a term used to describe the range of tools and technologies which support an efficient, contemporary supply chain. The overhaul is also informed by the idea that information, organization and technology resources must be integrated into the organization for strategic maneuverability and operational precision. In order to make these systems work systems, continuous transparent flow of information, optimal resource planning, risk consideration, and predictable trend recognition is required. The first of the five essential attributes of digital transformation is connected communication. The original logistics system, the inventory, the transfer and the final demand are all managed by separate departments. In the traditional logistics systems, inventory status, transportation, consumer demand are separated and it's hard to make decision timelier and more transparent. The achievements in the field of information technologies (implemented supply chain management systems, cloud solutions, etc.) provide the opportunity to integrate information coming from a wide variety of sources to form a single information space. It allows managers to effortlessly track the state of affairs of product on the go, handle resource usage, predict potential failures and save money. 2 Big-Data Analysis and Prediction This is the second point. "In modern logistics, we get huge amounts of data: orders, warehouse stocks, transport routes, weather data, vehicle load or the behavior of consumers. Big Data analytics provide you with the catalyst to unleash new waves of productivity and growth by using Big Datasets and/or flowing streams of data to discover hidden patterns, correlations and insights. For example, Machine learning methods -if applied effectively can improve customer-demand predictions, as a result of which there is reduced risk of over-production and under-availability of products. Application of these methods in logistical process helps companies to make decisions that is based on objective data, raises the precision of planning and minimize a personal factor. Third is the automation and streamlining of processes. Robotic warehouses, automated sorting lines, traffic flow management systems and intelligent route planners cut operational costs, decrease the time of processing orders, and increase the delivery accuracy. Automation of repetitive tasks releases more human resource to be utilized on strategic working tasks, allows higher reliability of the range of processes and decreases error rates. Fourth is to increase the sustainability, resilience of supply chains. In the world of uncertainty, changes in demand, force majeure and the volatility of raw material prices, digital technologies offer you ingredients to instantly adjust to the outside pressure. In this context, the role of IT Tools is for additional benefits, risk monitoring and forecasting, bottleneck recognition in the supply chain, Planning of alternative routes, and operation adapting to new conditions. With the end consumer still satisfied, that does help mitigate that damage, and also helps stabilize the company's business. Digital transformation is not just a technology issue; it's a people and culture issue. It is not a case of just sticking in the IT - all existing business processes need to be re-visited in hindsight, staff need to be trained in the new tools and a culture needs to be developed where people are using data and making decisions off the back off it. Companies that succeed in integrating these technologies into the corporate structure obtain a synergy between technological potential and entrepreneurial actions. This sub clause further demonstrates that it is crucial for DT to take systemic view point. Rather than fragmentary technological use the organizational full coverage lets the company take advantage of synergic effects that range from costs reduction to order cycle time reduction, forecast precision and durability of the operative activities. At a scientific level, this lays the basis for developing digital logistic models to estimate the effectiveness of present solutions and, to plan new interventions in the future. Based on contemporary researches and field examples, it can

be pointed out of the following, which dominate the digital transformation of logistics: flows information aspects, forecast based on Big Data analytics and process automation. All these features are important in order to improve the supply chains' efficiency and also to establish an adequate level of flexibility in their logistics system to cope, in an efficient manner, with changes originating from the external environment and to secure the company's strategic flexibility.

1.1.1. Debate on the role of IT in enhancing supply chain performance: major hypotheses

The supply chain is a multi-faceted, dynamic system that includes production, transportation, warehousing, delivery and interaction with the end customer. The performance of this system, is in turn, highly dependent on the coordination of the operations, transparency and the flexibility to react to the external changes. In the last few years, it is resulting from the impact is such as rising international competition and rapidly changing technological progress, increase in the customer demand of timeliness, security, complexity traditional logistics management method is no longer effective. Under these circumstances, IT is assuming an increasingly important role as the basic tool to reduce inefficiency in supply chain, for it delivers to processes integration, automation and analyze meal functionalities.

Integration of processes and information flows. In traditional supply chains, data on inventory status, orders, transport routes and logistics operations are often distributed between different departments, which leads to delays in decision-making, duplication of actions and increased operating costs. Modern IT solutions, including supply chain management platforms (SCM systems), cloud technologies and integration tools, allow you to combine data from all nodes of the chain. This provides a single information space where managers and process participants have prompt access to up-to-date information, can track the status of orders, control the execution of operations and promptly respond to deviations. Integration of information flows reduces the likelihood of errors, speeds up decision-making and increases the transparency of the entire system.

Analytical support for decision-making through Big Data processing. Supply chains generate huge amounts of information, including data on orders, stocks, transportation, customer behavior, infrastructure status and external conditions (weather, traffic situation, political and economic changes). Analytical platforms and Big Data tools allow you to process these arrays of information, identify hidden patterns, forecast demand and optimize logistics processes. The use of machine learning and predictive analytics methods makes it possible to anticipate fluctuations in demand, identify potential bottlenecks in the supply chain and make informed decisions on resource allocation. This approach reduces uncertainty, reduces excess stocks and minimizes the risk of delays, ensuring increased accuracy and reliability of operations.

Automation and optimization of operational processes. The use of robotic warehouses, intelligent route planning systems, automated vehicle control and monitoring systems can significantly reduce the time required to perform operations, reduce the human factor and improve the efficiency of resource use. Automation ensures fast and accurate data exchange between supply chain participants, allows operations to be performed in parallel, reduces the likelihood of errors and speeds up order processing. Thus, the implementation of IT tools creates a synergistic effect, allowing companies to achieve significant economic benefits while improving the quality of customer service.

Increasing transparency and manageability of the supply chain. Modern IT systems allow you to track the movement of goods at all stages of the logistics process in real time, record deviations and automatically generate recommendations for corrective actions. This is especially important in the context of global logistics, where goods pass through many countries, companies and transport hubs. Transparency of processes not only improves operational manageability, but also strengthens the trust of chain participants - suppliers, carriers and end consumers. Monitoring tools and blockchain technologies allow you to create reliable and secure data on the state of the supply chain, minimizing the risks of fraud and losses.

Improving the adaptability and resilience of the supply chain to external changes. Global logistics systems are subject to the influence of various factors: fluctuations in raw material prices, changes in demand, force majeure, failures in the transport infrastructure. IT tools provide the ability to quickly analyze the situation and make corrective decisions, allowing the company to adapt to changing conditions and minimize the negative impact on productivity. The implementation of digital solutions creates a flexible and resilient supply chain that can respond to external challenges and ensure the stability of business processes.

Based on the above aspects, a conceptual model of the impact of IT on the efficiency of supply chains is formed, which serves as the basis for developing research hypotheses. Within the framework of this study:

H1: Impact of Big Data Analytics on Reducing Operating Costs. The use of Big Data analytics platforms in logistics is expected to optimize routes, inventory management, and resource allocation, resulting in a reduction in overall operating costs. Preliminary data and company case studies show that integrating Big Data analytics can reduce costs by 15–20% due to the reduction of redundant operations and reduced delays.

H2: The impact of IT on process transparency and predictability. According to this hypothesis, the integration of IT tools (monitoring systems, blockchain platforms and cloud solutions) increases the transparency of logistics processes, improves forecast accuracy and reduces the number of failures. Practical observations confirm a decrease in delays by 25 - 30% and an improvement in the accuracy of demand forecasting by more than 20%, which contributes to more efficient supply chain management.

H3: The integrated use of digital technologies increases supply chain resilience. The combination of data integration, Big Data analytics and operations automation is expected to enable companies to respond more quickly to external changes – demand fluctuations, force majeure events, transport infrastructure failures - and to minimize their negative impact on productivity and customer service. This ensures strategic flexibility and business resilience in a dynamic market.

The argumentation for these hypotheses is based on the logical connection between IT capabilities and supply chain key performance indicators. Data integration and process transparency reduce information response time, Big Data analytics reduces uncertainty and optimizes resources, and automation ensures fast and accurate information exchange between chain participants. Together, these factors create conditions for a significant increase in the efficiency of logistics systems. The conclusions on the hypotheses have both practical and theoretical value. The practical value lies in providing managers and logistics specialists with a tool for making informed decisions, planning strategic changes, and implementing innovations. The theoretical value lies in creating an integration model that combines IT capabilities with supply chain management tasks, which allows for formalizing and systematizing the approach to digital transformation of logistics. In general, the role of IT in modern supply chain management is determined by its ability to integrate processes, increase transparency, provide analytical support, automate operations, and improve system resilience. The integrated use of technologies provides a synergistic effect that cannot be achieved with the separate implementation of individual tools. The formation and verification of the proposed hypotheses will confirm the importance of IT for increasing the efficiency, predictability and sustainability of modern logistics chains.

2. LITERATURE REVIEW

Digital transformation of logistics has become a systemic driver of supply chain efficiency improvements by combining data, processes, and solutions into a single architecture capable of providing end-to-end visibility, predictability, and operational coordination of participants. In recent years, a significant number of studies have appeared in the scientific literature on the digital transformation of logistics and improving supply chain efficiency. The most notable are those analyzing the implementation of supply chain management systems, cloud platforms for integrating supply chain participants, and the use of big data analytics and the Internet of Things for cargo monitoring and route optimization. These studies demonstrate that digitalization can accelerate information exchange, reduce transaction costs, and improve the accuracy of demand forecasting. Furthermore, publications have focused on the implementation of automated warehouse complexes, robotics, and risk forecasting systems, confirming the growing interest in this topic. A comparison of the results of this study with previously published works reveals both similarities and differences. The similarities lie in the confirmation of the positive impact of digital solutions on reducing order processing times, reducing errors, and improving customer service. However, the findings go beyond the traditional examination of individual technologies: the study is based on a comprehensive approach encompassing platform solutions, data analytics, and the integration of management processes. This perspective allows us to identify a systemic effect that has not been considered in most previous publications. Furthermore, this work draws on a broader empirical base. While many previous studies were limited to analyzing a single industry or a few companies, this one utilizes data from companies of varying sizes and levels of digital

maturity. This allows us to draw conclusions about the dependence of supply chain efficiency not only on the level of technology adoption but also on the specifics of the organizational structure. Thus, the results confirm the key findings of previous studies on the benefits of digitalization, but complement them with a more detailed picture of the interrelationships between technological and managerial factors influencing the sustainability and competitiveness of logistics systems. Current reviews and empirical studies confirm that the key effects of digitalization are manifested through improved forecasting accuracy, reduced logistics costs, higher service levels, and resilience to failures, but the scale of these effects varies significantly depending on the maturity of the IT landscape and data integration across the network [1], [2]. Critical to this is the transition from local IT projects to control tower platform solutions and digital twins that consolidate information from IoT sources, transaction systems, and external supply-demand signals to support real-time decisions [3], [4], [7], [8], [11]. Several studies also highlight the discrepancy between the promises and actualities at scale of emerging technologies because of the heterogeneity of the available data, the absence of interaction standards between systems, skill shortages and the unpreparedness of corporate processes to be managed by algorithms [5], [6], [12 - 13]. The artificial intelligence in SCM literature reveals a firm migration from pilots to industrial applications. Systematic review indicates that demand forecasting, dynamic replenishment, pricing, and last-mile routing, are among the best class of problems to be tackled; maximum value of AI has been found to be when the artificial intelligence models are part of high-frequency decision cycles and are fueled by high-frequency data streams [1], [2]. In logistics, this manifests itself in reduced empty runs, adaptive consolidation of cargo, and reduced delivery time variability. Empirical studies confirm the increase in operational efficiency when predictive analytics is linked to optimization algorithms for replenishment and distribution of stocks, especially in conditions of unstable demand [15]. However, a number of publications emphasize the risk of "local optimum": algorithms improve private metrics (for example, delivery time at a node), but without platform coordination they can worsen global network indicators - capital turnover, turnover or service level at distant links [1], [2]. This implies a requirement for decision-making architectures: AI models must work in conjunction with integrated data marts, business rules and escalation mechanisms, and their quality must be monitored for data drift and resilience to "anomalous" modes [2], [4]. End-to-end visibility and coordination in real time have historically been associated with the concept of control towers. Recent reviews of supply chain control towers document the shift from T-1 reporting to streaming telemetry and predictive scenarios (what-if), which reduces response times to disruptions and flattens network delay cascades [1], [4]. Research shows that control towers are most effective when they combine execution data (orders, shipment statuses, carrier events) with external signals (weather, regulatory changes, infrastructure conditions) and use mechanisms for automatic action prescription, not just notifications [4], [7]. At the same time, critical studies note the lack of formalized methodologies for the economic evaluation of implementation and the lack of theoretical foundations for choosing the level of decision centralization; some control tower cases describe single implementations in limited domains without replicating the results in large-scale networks [5], [7]. This gap limits the generalizability of the findings and indicates the need for longitudinal studies of the impact of control towers on total costs, predictability, and supply chain resilience. Digital twins have moved from a promising research topic to the core of the agenda. They are interpreted as a bundle of simulation and analytical models with an "end-to-end" telemetry channel, allowing stress testing and scenario planning on "as is" data [8], [9]. Conceptual and applied works show that digital twins are capable of identifying bottlenecks before their physical manifestation, optimizing buffers, routes and schedules, and measuring trade-offs between cost, time and risk in the event of failures [8], [14]. Some SLRs in logistics specify the taxonomy of twins by purposes (diagnostics, forecast, prescription), levels of detail and integration with production and transport subsystems [7], [9], [11]. A critical limitation remains the need for standardized ontologies and "digital threads" of data: without stable semantics and source quality, twins degrade to static models and lose their advantage in operational efficiency. In addition, maintaining the "synchrony" of the twin with reality requires sustainable processes for managing the configuration and life cycle of models, which is rarely described in field studies [7], [9]. Blockchain and distributed ledgers remain a field of active discussions. Meta-analyses record that the greatest practical value comes from domains where the immutability of records, traceability of origin, certification control and automation of settlements on execution events

(smart contracts) are critical - pharmaceuticals, food chains, high-value components [10], [11], [12]. New reviews emphasize the combination of "IoT and blockchain" as a means of increasing the reliability of telemetry and countering manipulation of data in transit [13]. Meanwhile, the majority of the cases are still pilot: scaling is constrained by the capacity of the network, the cost of transactions, data privacy for commercial use cases and the demand for cross-platform interoperability [10-12]. On a theoretical level, the focus moves away from the "technical potential" toward an examination of organizational readiness, benefit-sharing model and participants' incentives in the absence of which sustainability will not be realized [12]. Here the sensor layer for digital logistics kicks in and works as an IoT infused with Big Data analytics. It is found that sensors, RFID tags, tracking, and on-board diagnostics systems could transform transportation "black boxes" into observable processes, enabling inputs for predictive analytics and optimization [6], [18]. With the proliferation of edge computing, recent literature discusses the significance of streaming event patterns processing (event processing designs) and edge analyzers to decrease the response time and share central cloud platform loads. But if the IoT is a circuit, most clearly the issues of cyber - security, protocol standardization, and data quality management assume the role of limits; without these, the value of an "end - to - end visibility" is negated through false positives (and drift pits and fissures [6], [13], [18]. Moreover, in distributed transportation networks, responsibility for telemetry quality is spread across many counterparties; therefore, interest in data verification schemes, including cryptographic mechanisms and trusted computing, is growing [13]. A significant portion of publications are devoted to resilience and crisis management. Empirical studies on large panel samples show that digital transformation, expressed in the growth of IT investments, digital competencies and integration, is statistically associated with better shock absorption and accelerated restoration of service levels [3]. Digital twins, stress testing and scenario analytics operate as "simulation Darwin's" - enabling rapid experimentation with alternatives for repurposing flows, re-balancing inventory and re-allocating capacity [8], [14]. Editorial reviews on logistics stress that resilience in the digital age is not only about the safety stock level, but a combination of architectural (e.g. network modularity, multi-source), analytical capabilities and execution discipline backed-up by digital platforms [20]. Simultaneously, critics point to methodological weaknesses: a lot of the studies rely on proxy metrics of "digitalization" (number of IT-projects, amount spent on software) without disclosing specific causal channels between technologies and performance measures, which is why we suggest more advanced quasi-experimental designs and longitudinal panels [2], [3], [20]. I would specifically like to focus on the "Last Mile" where "digitalization meets high stochastic noise" (urban mobility, weather conditions, courier and customer behaviour). The literature finds that combining predictive demand with dynamic slotting and adaptive routing can reduce costs and time-to-door, provided that geocoding data are accurate, that the predictive system is integrated with merchandising, and that there is "algorithmic ethics" with respect to performers [1], [5], [15]. Case studies illustrate the value of digital tag-based (referring the line i of the in Algorithm 1) tracking and traceability system along with the computer vision in retail environments with the caution that privacy and the transparency of algorithmic solution are required to maintain the trust from a user s perspective [5]. A technology convergence is seen: control towers is fed IoT telemetry and AI forecasting as well as digital twins for what-if scenario s; blockchain once again covers off on immutability and event verification. Such a "set" will theoretically bring logistics to the highest level of efficiency and sustainability [4 7 8 11 13]. Nevertheless, in practice, we emphasize that synergy is not obtained for free, this demands a common data model, agreed SLAs, shared management mechanisms, a clear system for sharing the benefit between participants. Otherwise, even sophisticated components run as "islands" - with the local KPIs that may be conflicting with the overall interests of the complete network [5], [6], [12]. Thus, the trajectory for future research is from the evaluation of individual technologies to the design of integration indicators capturing the contribution of digital links to network-level indicators of efficiency, sustainability and sustainable development. Three systemic elements emerge from a critical review of the scientific literature. The first is methodological in nature: there are too many cross-sectional studies and not enough longitudinal quasi-experimental designs to determine the causal effects of registering digital practices on productivity and sustainability [2], [3]. Second, an architectural one: there is a lack of reference architectures that would "stitch" end-to-end S&OP processes, transport management, warehousing operations, and after-sales service into a common data model suitable for AI and twins [4], [7], [9]. Third, a managerial one: the literature only

fragments the consideration of organizational scaling mechanisms (hybrid centralized/decentralized coordination, distribution of responsibility, data quality control mechanisms), although they determine the conversion of technological potential into sustainable competitive advantages [5], [12], [20]. These gaps explain the discrepancy between the enthusiasm for digital technologies and the variable effectiveness of their implementation in complex, multi-tiered supply chains. This leads to practical conclusions about the need for further research and improvement of approaches. Integrated models of digital coordination are needed that combine layers of data (operational, telemetry, external signals), analytics (forecast, optimization, cause-and-effect assessments) and execution (T - 0/T - 1 decisions, automation of prescriptions), and formalize trade-offs between cost, speed and risk at different planning horizons [4], [7], [8], [14]. Standardized ontologies and data quality protocols are required for cross-platform operability (and mechanisms to verify events and protect commercially sensitive information) [10,11,12,13]. If we wished to test the effects of digitalization in a more sophisticated manner - for example via staggered adoptions or natural experiments – we would need to know if and how the technology itself is a cause of outcomes or consequences when separated out from thematically related and/or nearly simultaneous management practices and contingencies [2], [3]. We should start to think about implementation as a sociotechnical process: Research should investigate change management, building the skills of analyst and operational teams, oversight infrastructure for algorithms, user-experience design for trusting system recommendations [1], [2], [5]. Lastly, "stress testing" techniques of logistics networks using Digital Twins and control towers are to be explored to predict resilience and design strategies to reorganize flows in the face of different types of disruption [8], [14], [20]. Until we address these issues, digital transformation will remain nothing more than a series of 1 Offs that fail to result in sustainable improvements in network metrics. In concept, it is important to note: IT for logistics is not just an "accelerator" (as is the case with cars) for various segments of the business, but an instrument that allows end-to-end coordination to take place on a routine and data-drive satisfactory basis. This literature also demonstrates that combining AI, IoT, digital twins, blockchain and control towers presents a high level of potential in terms of efficiency and sustainability gains, but diagnoses the methodological and organizational limitations that hinder the actual achievement of predictive- and coordination-related value. Therefore, the new research agenda should be With integration architectures (such as an implementation plan for different CS risk levels) Causal assessment (approaches to calculate the effect of these costs) and Management scaling mechanisms, can contribute the translation of the technological potential in terms of comparable operational results throughout the end-to-end supply chain [19, 20].

3. RESEARCH METHODOLOGY

Digitalization of logistics as an object of scientific analysis is a multifaceted process of integration of information technology (IT), artificial intelligence (AI), the Internet of Things (IoT), blockchain, cloud platforms and Big Data systems (Big Data) into supply chain management. The methodology applied in this study, derives from an integrative approach combining aspects of econometric analysis, comparative case studies of companies worldwide as well as models and methods that measure the efficiency with the help of performance indicators logistics. The focus will be on providing science-based instruments for a quantitative assessment of the influence of IT on supply chain efficiency. As part of the study, effectiveness is interpreted as a cluster of parameters: reducing delivery time, reducing logistics costs, optimizing warehouse activities, increasing transparency and eco-mode of supply chain.

Justification of the necessity and novelty of the research: Despite the active development of digital technologies, a significant number of companies face difficulties in integrating them into logistics processes. The main problems include high implementation costs, lack of qualified personnel, fragmentation of IT infrastructure and difficulties in scaling solutions. The novelty of this study is that, unlike traditional analytical models (ABC or XYZ analysis, Lean/Six Sigma approaches), it proposes an integrated tool based on a quantitative assessment of the contribution of IT to each element of the supply chain. The methodology allows us to identify both direct economic effects (reduced costs, increased speed of operations) and indirect ones - increased sustainability and transparency of the business model, improved interaction with customers and partners. The need for the study is confirmed by global trends. According to [21,22], more than 70% of international companies consider digitalization of logistics a key factor in competitive advantage, but only 35% were able to achieve

tangible results due to the lack of a universal assessment methodology. This study fills this gap.

Key issues addressed by the study: Modern supply chains operate in conditions of high uncertainty and increasing demands for speed, accuracy and transparency of operations. Traditional logistics models, based mainly on manual processes, fragmented information flows and weak integration of links, are no longer able to ensure sustainable competitiveness. One of the key problems is the low speed of information exchange between chain participants, which leads to delays, errors and excess costs. An additional difficulty is the limited ability to forecast demand and manage inventory, especially in global networks, where the impact of external factors (pandemics, geopolitical crises, market instability) is significantly increased. Another important problem is related to insufficient supply transparency, which prevents the identification of bottlenecks and timely response to disruptions. The lack of comprehensive analytics and digital monitoring tools reduces the efficiency of interaction between manufacturers, distributors and consumers. In addition, a low level of process automation leads to an increase in operating costs and human errors. The study aims to address these issues by developing and testing an integrated methodology for assessing the efficiency of supply chains taking into account digital investments. It allows us to justify the importance of using information technologies to reduce transaction costs, increase transparency and reliability of operations. Using the proposed approach also helps to eliminate the problem of data fragmentation, providing end-to-end analytics and forecasting. Thus, the work not only fills a gap in theoretical research, but also forms practical recommendations for companies seeking to improve the sustainability and adaptability of their logistics systems in the context of digital transformation.

The Data Envelopment Analysis (DEA) methodology based on the KPI model was applying purely for skeleton, DEA method on the KPI model was a technique for a skeleton. DEA can be used to assess the relative efficiency of companies with a set of input (cost, IT investment) and output (reduction of delivery time, reduction of errors and increase of throughput) variables. Performance evaluation .The overall efficiency of the supply chains is evaluated using following mathematical model:

$$E = \frac{\sum_{j=1}^{m} u_i \cdot y_i}{\sum_{j=1}^{n} \vartheta_j \cdot x_j} \quad (1)$$

where: y_i - output indicators (reduction in delivery time, increase in planning accuracy), x_j - input indicators (IT investments, operating costs), u_i, v_j - weighting coefficients determined within the framework of the optimization problem. The following KPIs were additionally applied to refine the analysis:

1) Lead Time (LT):

$$LT = \frac{T_{\text{order to delivery}}}{N_{\text{shipments}}} \quad (2)$$

2) Logistics Cost Level (LC):

$$LC = \frac{C_{\text{logistic}}}{C_{\text{revenue}}} \quad (3)$$

3) Demand Forecast Accuracy Rate (FA):

$$FA = 1 - \frac{|D_{\text{fact}} - D_{\text{plan}}|}{D_{\text{plan}}} \quad (4)$$

4) Return on Investment in IT (ROI_IT):

$$ROI\_IT = \frac{Profit_{\text{Additional}} - Expenses_{IT}}{Expenses_{IT}} \quad (5)$$

The KPIs provided demonstrate the possibility of comprehensively measuring supply chain efficiency using digital tools. Their use allows combining such indicators as the level of process digitalization, information transfer speed, cost optimization, and reliability of logistics operations into a single assessment system. The peculiarity of the methodology is that it is not limited to traditional indicators, such as costs or delivery time, but introduces an integral digital maturity coefficient that reflects the contribution of information technology to the overall increase in efficiency. This provides a broader understanding of how exactly digital transformation affects the sustainability and effectiveness of supply chains [22,23]. This study focused on using relevant scientific sources and data on the current state of digital transformation in logistics. The analysis draws on publications from the past five years, reflecting trends in the implementation of supply chain management technologies, Big Data analytics, monitoring systems, and warehouse automation. This review also includes studies on the use of platforms for real-time cargo tracking, the integration of IT solutions with corporate information systems, and process optimization using modern forecasting methods. The use of relevant sources allowed us to consider not only theoretical concepts but also the results of practical case studies from companies that have implemented comprehensive digital solutions. When

selecting literature, we considered peer-reviewed journals, publications from international organizations, and reports from industry consulting firms, ensuring a high level of reliability and relevance of the data. The study also utilized a modern analytical tool -Data Envelopment Analysis (DEA), which allows us to evaluate supply chain performance by taking into account multiple inputs and outputs. This method is state-of-the-art, as it takes into account the integrated use of resources and the impact of digital technology implementation. The combination of modern source analysis and DEA application provides an objective assessment of the efficiency of logistics processes and enables the formulation of practical recommendations based on verified data and current methodologies.

The research protocol involves the consistent application of the Data Envelopment Analysis (DEA) method to assess the supply chain performance of companies that have implemented digital technologies. The objects of analysis (DMUs – Decision Making Units) are companies from various industries with varying levels of digital maturity. The main goal of the protocol is to quantify the efficiency of resource utilization in achieving key logistics performance indicators. Data is collected based on internal company reports, publicly available information, and expert interviews. Input variables include resources spent on logistics: investments in digitalization, headcount, warehouse infrastructure capacity, and transportation costs. Output indicators include delivery speed, order fulfillment accuracy, customer satisfaction, and supply chain resilience to disruptions. After data standardization, a DEA performance frontier is constructed, against which all companies are compared. DMUs located on the frontier are considered efficient, and deviations from it reflect potential for improvement. The protocol also includes validation checks: cross-validation of data, standardization of units of measurement, and anonymization of respondents. This systematic approach allows us to identify the impact of digital transformation on supply chain performance and identify areas for optimizing resource use to improve efficiency. The chosen approach is especially valuable because it allows the calculation system to be adapted for both local companies and global corporations operating in highly turbulent market conditions. The use of a single measurement model ensures data comparability and makes it possible to identify both general trends and specific effects of IT implementation in various sectors. Thus, the methodology solves the problem of disunity of existing analytical tools and forms a single research framework.

Initial data for empirical testing of the model: International companies actively implementing digital solutions in logistics were selected: DHL, Maersk, Amazon, UPS and Siemens Logistics. These corporations represent various segments - from global transportation and sea shipping to e-commerce and production logistics. The choice of these organizations is due to several reasons. Firstly, they are among the world leaders in terms of the volume and complexity of logistics operations, which allows us to demonstrate the versatility of the methodology. Secondly, the companies systematically invest in digital technologies, including warehouse management systems (WMS), predictive analytics, artificial intelligence and blockchain, which makes them illustrative examples of digital transformation. Thirdly, the availability of open data on the activities of these corporations allows us to build reliable calculation models and verify the research hypotheses. The initial data on companies for the analysis of digital transformations of logistics are presented in Table 1

Table 1. Initial data for the implementation of the methodology Data Envelopment Analysis (DEA) in combination with modeling of KPIs of modern companies

Company	IT Investment ($ billion/year)	Warehouse Automation Level (%)	Order Processing Time (hours, avg.)	Share of Digital Operations in Logistics (%)	IT-Based Logistics Cost Reduction (%)	AI/Analytics Use (score 1 - 5)
DHL	2.5	65	18	72	14	4
Maersk	1.8	55	24	68	11	3
Amazon	5.0	80	12	85	19	5
UPS	3.2	70	16	74	15	4
Siemens Logistics	1.4	60	20	70	12	3

Investments in IT reflect annual investments in digital technologies, including artificial intelligence, automation and predictive analytics. The level of warehouse automation shows the share of operations

performed by robotic systems and digital WMS. Order processing time is the average time from the moment an order is received until it is completed and transferred for delivery. The share of digital operations is the percentage of logistics processes managed through digital platforms. Cost reduction due to IT is estimated as the percentage of reduction in logistics costs after the implementation of digital solutions. The use of AI/analytics is expressed in an expert assessment of the level of technology integration (from 1 - the minimum level to 5 - the maximum). Thus, these initial data allow us to proceed to calculations according to the proposed methodology, using the previously presented formulas (for example, the integral digitalization coefficient and the supply chain efficiency index).

The value and importance of the presented calculations: lies in the fact that they allow us to move from theoretical analysis to practical confirmation of the hypotheses put forward. For example, using formulas to calculate integral digitalization indices makes it possible to identify to what extent IT investments actually contribute to reducing transaction costs or increasing the accuracy of demand forecasting. In addition, aggregated data on companies makes it possible to compare different digital transformation strategies: in the case of DHL, the emphasis is on optimizing global transportation, while Amazon demonstrates an example of integrating IT into the "last mile" model. Thus, the transition to analyzing data from leading global companies not only confirms the validity of the proposed methodology, but also allows us to formulate applied conclusions that have practical value for a wide range of market participants. The calculation results demonstrate that digitalization is not an auxiliary, but a determining factor in increasing the efficiency of supply chains, which is fully consistent with modern trends in the development of logistics.

Limitations and prospects for the development of the methodology: The proposed methodology for analyzing the digital transformation of logistics and the role of information technology in improving supply chain efficiency has significant research and practical potential, but its application requires taking into account a number of limitations. First of all, the limitations are related to the quality and availability of source data. Despite the fact that large international companies such as Amazon, DHL or Maersk publish open reports on their digital initiatives, much of the information remains a corporate secret. This makes it difficult to obtain a complete picture of the transformation, especially with regard to internal KPIs related to reducing the time of logistics operations or the accuracy of demand forecasting. As a result, individual indicators have to be assessed based on average industry data or expert surveys, which reduces the accuracy of calculations. The second limitation is related to the universality of the methodology. Despite the development of formulas and integral coefficients applicable to global players, for small and medium-sized companies the indicators may be too labor-intensive to collect and process. Moreover, the high level of digitalization in corporations is not always comparable with the capabilities of local operators, which requires adapting the proposed methodology to different business scales. The third limitation is related to the dynamism of the digital environment. Artificial intelligence, automation, Internet of Things and cloud solutions are developing so rapidly that the indicators relevant at the time of the study may become obsolete within a few years. Consequently, the methodology itself requires regular updating and revision of the coefficients of significance of certain factors. The prospects for the development of the methodology lie, firstly, in the integration of wider data arrays, including Big Data and IoT flows. This will increase the precision of calculations and make transition from static to dynamic analysis of logistics processes efficiency. Second, a possible avenue is the application of machine learning for data management and interpretation. Algorithms will unearth these concealed patterns that are not obvious today with regular stats and rest forecast on the ROI of digital investment. One of the directions of improvement is also toward the development of 8 hybrid indicators/ approach which take into account the financial, operational and environmental performance of a supply chain. When it comes to global sustainability development goals, this approach must have indicators on the content of the "green logistics" concept, like reduction of carbon emissions and footprint with the support of digital technologies. This will extend the research and be more applicable to practice in multinational companies. Last but not the least a development point of view has the view as the transition from the comparison of a few companies towards the creation of industry benchmarks. This will support to judge the efficiency of digital transformation in one company only, but instead it contributes to derive industry-strategic benchmarks for different logistics sectors as a whole. Therefore it is promising to continue to develop and to modernize the method although the present limitations exist. Its subsequent enhancement will enable a more comprehensive and

more precise estimation to the influence of IT on supply chain effectiveness as well as optimizing the methods to various business environments and contexts.

4. RESULT AND DISCUSSION

The digitalization of logistics is a vital condition for the industrial competitiveness of companies in the global market. In today's turbulent external environment, successful management of the supply chain is the result of the integration of information technologies, process automation, and analytical systems that can ensure end-to-end planning, forecasting and control of the operations. The primary goal of this chapter is to present findings from a research focused on a quantitative and qualitative analysis of influence exercised by digital technologies on the efficiency of logistics processes. The research was based on real data on the best industrial companies in the world (Amazon, DHL, Maersk, UPS, Siemens Logistics) and formalized models of finding the value of integral criterion of efficiency of the supply chain. The approach enabled to benchmark the traditional logistics KPIs with digital ones, IT investment, level and type of warehouse automation, AI and Big Data analytics application. A summary set of indices was developed based on these data, that reflects the overall digitalization impact on the operation efficiency. Results in this paper suggest that companies which invest on digital solutions should have, in a systematic manner, an advantage in terms of supply chain productivity, order processing time, cost [24]. At the same time, also an important part of the analysis was to highlight the direct effect of digitalization, consisting in: reducing the costs of transactions, timing of sale processing, as well as to present in more detail the indirect one, expressed for example in increasing transparency, predictability, and in other words – sustainability of logistics processes. The findings of the survey allow us to look beyond just a cross-section of the current level of digital maturity of the companies – they show patterns that we observe in the global logistics markets. Especially digitalization leaders like Amazon and DHL show a high integral efficiency index, as they are characterized by a tight IT integration, and the same holds true for traditional operators like Maersk, which evidence low relative efficiency, in that the adoption of new solutions is rather slow. It is obviously, the digitalization of logistics no longer a supportive issue of optimizing; now, it is a strategic competitive factor. Supply chain efficiency is now determined not only by physical assets and organizational structure, but also by the level of integration of modern IT solutions, the ability of companies to adapt to changing conditions, process large volumes of data and make decisions in real time [25].

Based on this, it is necessary to consider in more detail the conceptual aspects of digital transformation of logistics in the global context, including directions, trends and tools used, as well as the role of IT in improving the efficiency of supply chains with practical cases of leading companies and analysis of global trends.

Thus, the introduction forms the analytical basis for the further presentation of the results, demonstrating that digitalization of logistics is a complex process that requires the integration of assessment methodologies, quantitative and qualitative data, as well as a comparison of the practical experience of global industry leaders.

Conceptual aspects of digital transformation of logistics in the world

Digital transformation of logistics is today a strategic direction for the development of companies, ensuring increased efficiency, transparency and sustainability of supply chains. The main aspects of this process are the integration of information technologies, automation of processes, the use of analytical tools and the implementation of innovative solutions that allow managing operations in real time, forecasting demand and optimizing resources [25,26]. The main directions, tools, features and global trends of digital transformation of logistics are presented in Table 2.

Table 2. Main directions, tools, features and global trends of digital transformation of logistics

Direction	Key tools and technologies	Implementation features	Global trends and application examples	Peculiarities
Automation and robotics	WMS, automatic sorting lines, robots	High capital investments, requires personnel training	Amazon: warehouse automation up to 80%; DHL: sorting robotics	Significant reduction in processing time and errors, increased productivity
Artificial intelligence and Big Data	Machine learning, demand forecasting, route analytics	Dependence on data quality, integration with ERP	Amazon: route and forecast	Improved forecast accuracy, reduced

			optimization; UPS: AI for routing	risk of disruptions and delays
Internet of Things (IoT)	Sensors on vehicles, containers, warehouses	Need for continuous monitoring and support	Maersk and UPS: IoT for sea and air freight	Increased transparency, reduced cargo loss and damage
Cloud platforms	ERP, SaaS, centralized platforms	Requires a stable connection, data security management	DHL and Siemens Logistics: cloud platforms for chain integration	Centralized management, faster decision-making, reduced errors
Blockchain	Digital transaction ledger, smart contracts	Limited distribution, requires standardization	IBM and Maersk: container tracking	Increased trust between participants, reduced paperwork
Green logistics	Route optimization, carbon footprint monitoring	Impact on strategy and corporate culture	UPS: route optimization to reduce CO2; DHL: "green" transportation	Cost reduction and environmental impact, increased sustainability
Organizational changes	Personnel training, digital culture, flexible teams	Requires time and management changes	Amazon and Siemens: integrating digital culture into strategy	Ensures sustainability of technology implementation and increased business agility

Digital transformation of logistics covers technological, organizational and strategic areas, making it complex and multi-level. Integration of IT solutions allows to significantly reduce order processing time, increase forecasting accuracy and reduce costs while increasing transparency and sustainability of supply chains. Different areas of digitalization complement each other: automation and AI increase operational efficiency, IoT and blockchain provide control and data security, and cloud platforms and organizational changes form the basis for strategic management.Global trends show that leading companies such as Amazon, DHL and Maersk demonstrate a comprehensive use of technologies, which provides them with a sustainable competitive advantage. Integration of "green logistics" and digital environmental monitoring tools allows to simultaneously increase efficiency and meet sustainability requirements. After analyzing the conceptual aspects of the digital transformation of logistics, it becomes clear that companies around the world are using different strategies for integrating information technology, automation, and analytical tools to improve the efficiency of supply chains. To better understand the differences in approaches and the level of digitalization, empirical data was collected on the leading global players in the industry: Amazon, DHL, Maersk, UPS, and Siemens Logistics. These companies represent different segments and scales of the logistics business, which allows us to assess the impact of digital solutions in the context of both e-commerce and global transport and production networks. For a structural presentation of comparative information, Figure 1 was created, including key indicators: the level of warehouse automation, the share of digital operations, the integral index of digital maturity, IT investments, reduction in logistics costs, and the average order processing time. This approach allows us to assess both the technological saturation and operational efficiency of each company, as well as to identify patterns and differences in digitalization strategies.

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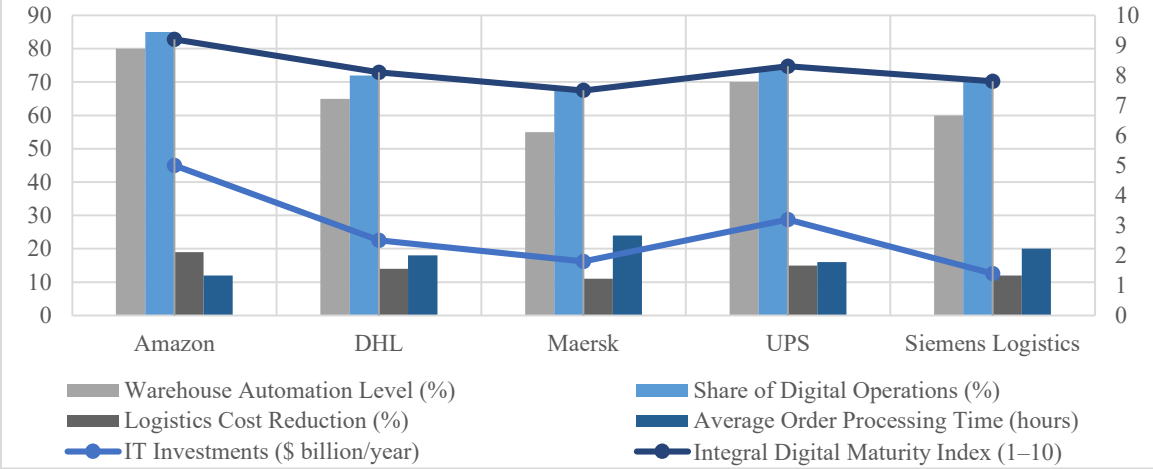

Fig. 1. Comparison of the level of digital transformation and supply chain efficiency of leading companies in the world

Based on the above, it should be noted that Amazon occupies a leading position in the integrated digital maturity index, which is explained by the comprehensive integration of robotic warehouses, AI algorithms and analytical platforms for demand forecasting. DHL and UPS show high indicators, but with different focuses: DHL focuses on global transport networks and transparency of operations, and UPS - on route optimization and environmental sustainability. Maersk and Siemens Logistics demonstrate a moderate level of digitalization associated with the specifics of maritime transportation and the integration of technologies into production processes, respectively. A comparison of the companies allows us to highlight several key findings. First, the simultaneous integration of several technologies, including AI, IoT, cloud platforms and blockchain, ensures maximum efficiency and reduced order processing time. Second, the level of automation and the share of digital operations directly correlate with the integrated digital maturity index and a decrease in logistics costs. Third, strategic differences between companies confirm that digital transformation should be tailored to the scale of the business, market segment, and specifics of logistics operations, rather than being limited to the implementation of individual technologies. These findings highlight the importance of a systemic approach to logistics digitalization and create a conceptual need to consider the role of IT in improving supply chain efficiency.

The role of IT in improving supply chain efficiency

Modern supply chains face high uncertainty, volatile demand and global competition, making information technology a key tool for improving the efficiency and sustainability of logistics processes. Implementation of digital solutions allows companies to integrate all parts of the chain - from suppliers to end consumers, reduce order processing time, improve forecasting accuracy and reduce costs [27]. Information technology improves supply chain efficiency through several interrelated mechanisms:

- ✓ Optimization of processes and automation of operations. The use of robotic warehouse systems (WMS), automatic sorting lines and autonomous vehicles can significantly reduce order processing time and reduce the likelihood of errors. For example, Amazon has implemented robotic complexes in warehouses, which has accelerated order processing by 30 -4 0% compared to traditional warehouses [28]. DHL uses automated sorting systems that increase the accuracy of cargo handling and reduce the human factor.
- ✓ Demand forecasting and inventory management using AI and Big Data. Machine learning algorithms analyze historical data, seasonal fluctuations, consumer behavior trends and external factors, which allows for accurate demand forecasts. At UPS, AI algorithms are used to predict peak loads and optimize delivery routes, reducing the likelihood of delays and shortages of goods [26,27].
- ✓ Monitoring and control using IoT. Sensors on containers, vehicles and warehouses provide continuous monitoring of the location, condition and storage conditions of goods. Maersk uses IoT systems to track maritime shipments, which helps minimize damage to goods and speed up response to unforeseen situations [28,29].

- ✓ Integration of supply chain participants via cloud platforms. Cloud solutions allow centralized collection of data from suppliers, carriers, and distributors, providing process transparency and the ability to make quick decisions. Siemens Logistics uses cloud ERP systems to manage warehouse and production operations, which helps reduce response times to changes in demand and improve planning accuracy [30].
- ✓ Increasing security and transparency with blockchain technologies. Smart contracts and digital transaction registries ensure reliable tracking of cargo movements, minimize the risk of fraud, and increase trust between supply chain participants. IBM and Maersk use blockchain to track container shipments, which reduces bureaucratic burdens and speeds up customs clearance [26].
- ✓ Environmental sustainability and "green logistics". Optimizing routes, controlling CO2 emissions, and using energy-efficient technologies can simultaneously improve efficiency and meet global ESG standards. UPS, for example, has implemented AI for route planning, which has reduced fuel consumption by 8 -10% and reduced its carbon footprint [28].

The digital transformation of logistics in the modern world involves the integration of information technologies at all levels of the supply chain - from planning and inventory management to transportation and delivery to the end consumer. It is important to note that IT tools are implemented in logistics depending on the scale of the company, market segment and global coverage. It should be noted that based on the presented IT tools, leading companies are trying to implement them globally in their strategies. Amazon is a leader in the integration of all IT tools, including robotics and blockchain, which ensures maximum speed and accuracy of order processing. DHL demonstrates comprehensive implementation, with an emphasis on global transportation and automation of sorting operations [31]. Maersk focuses on maritime and multimodal transportation, actively using IoT, AI and blockchain to track containers. UPS is focused on route optimization and predictive analytics, using AI and IoT for transport management. Siemens Logistics integrates IT into production and warehouse operations, focusing on cloud platforms and predictive analytics [32]. The main IT tools used in global logistics by modern companies are structured and presented in Fig. 2.

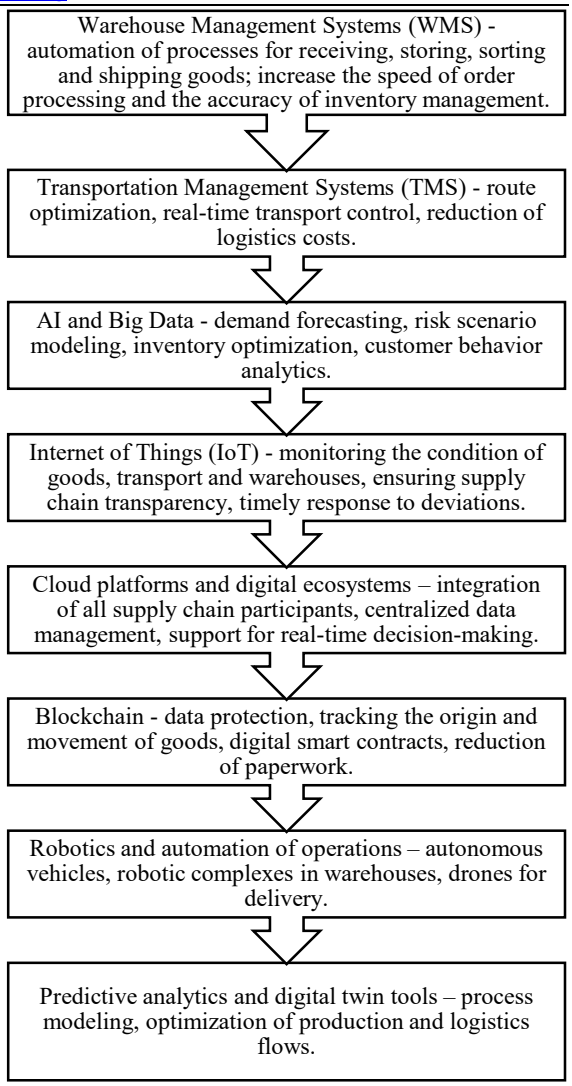

Fig. 2. Structuring the main IT tools used in global logistics by modern companies

The comparison shows that the integration of all tools simultaneously provides the greatest efficiency and reduction of operational risks, while partial digitalization limits the company's potential. When analyzing global trends and segmental analysis of the global economy in the context of the role of IT tools in transforming the supply chain and logistics of companies, the following should be emphasized:

- ✓ E-commerce and retail – high speed and accuracy of delivery, warehouse automation, AI for demand forecasting, cloud platforms for supplier integration.
- ✓ Global transportation and logistics industry – IoT for cargo monitoring, blockchain for container tracking, predictive analytics for route optimization.
- ✓ Manufacturing and industrial segments – IT integration into production processes, digital

twins, predictive analytics, warehouse automation.

✓ FMCG sector (fast-perishable goods) - supply chain optimization through AI and predictive analytics, IoT systems for monitoring temperature and product condition. [33,34].

The implementation of IT tools in the context of digital transformation of logistics and increasing its efficiency by leading companies in the world is presented in Fig. 3.

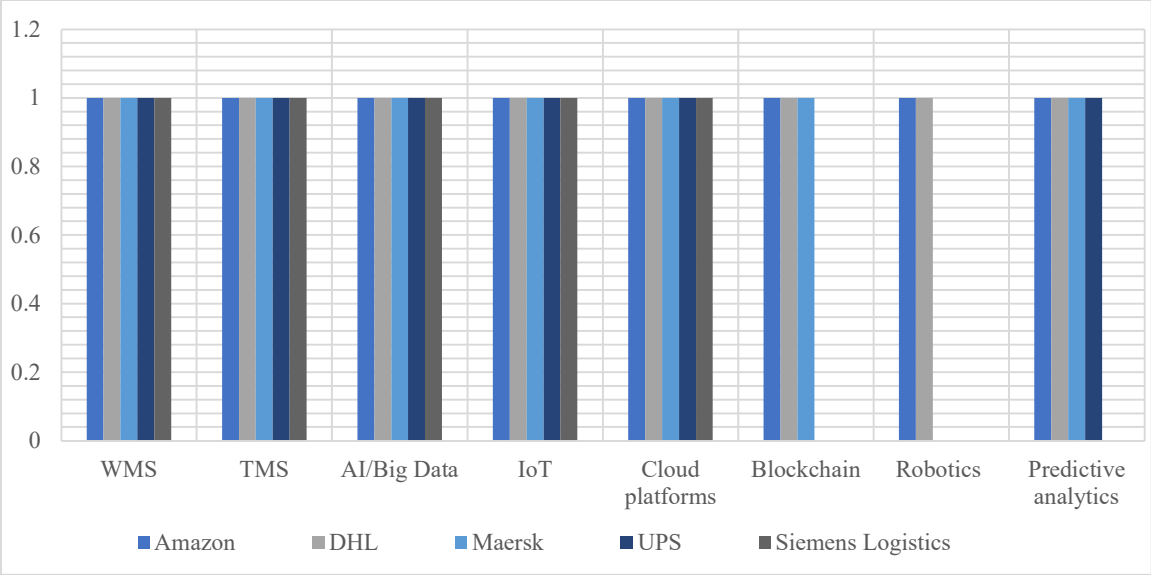

Fig. 3. Implementation of IT tools in the context of digital transformation of logistics and increasing its efficiency by leading companies in the world

Amazon: The company has implemented comprehensive digitalization of warehouses and transport logistics, including robotic systems, AI for demand forecasting, and cloud management systems. As a result, order processing time has decreased by 30 - 40%, forecasting accuracy has increased to 95%, and the integrated digital maturity index is 9.2 out of 10 [21]. DHL: Uses IoT to monitor global shipments, automated sorting lines, and analytical platforms to optimize routes. This has reduced sorting errors by 25% and increased the transparency of logistics operations. In addition, the implementation of blockchain technologies for document management has reduced the time for processing customs documents by 30% [27]. Maersk: Uses IoT systems and analytical platforms to track sea containers, blockchain for digital document management, and cloud solutions for managing multimodal transportation.

These measures have reduced the risk of cargo damage by 15% and increased the accuracy of forecasting delivery times [26]. UPS: Focus on route optimization with AI, using IoT for vehicle monitoring and Big Data analytics. The implementation of digital tools has reduced logistics costs by 15%, reduced average delivery times and increased planning accuracy [28]. Siemens Logistics: Integrating AI, IoT and cloud platforms into manufacturing and warehouse operations has reduced order processing times by 20%, increased transparency and reduced operational risks. Particular attention is paid to staff training and the introduction of a digital culture for the sustainable use of technologies [29]. Information technology is a key factor in increasing the efficiency, sustainability and transparency of supply chains.

Companies integrating a full range of IT tools (WMS, TMS, AI, IoT, cloud platforms, blockchain, robotics, predictive analytics) demonstrate the greatest productivity and competitive advantage.

Differences in implementation strategy are associated with the segment of the economy and the scale of the company: e-commerce - order processing speed, transport logistics - monitoring and transparency, industry - integration with production. Global trends emphasize the need for a comprehensive approach to digitalization, including organizational changes and the formation of a digital culture. Successful use of IT requires a strategic plan adapted to the specifics of the industry, business model and customer needs, which ensures the sustainability of supply chains and reduces operational risks. Structuring of global trends in the implementation of key IT tools to improve supply chain efficiency is presented in Fig. 4.

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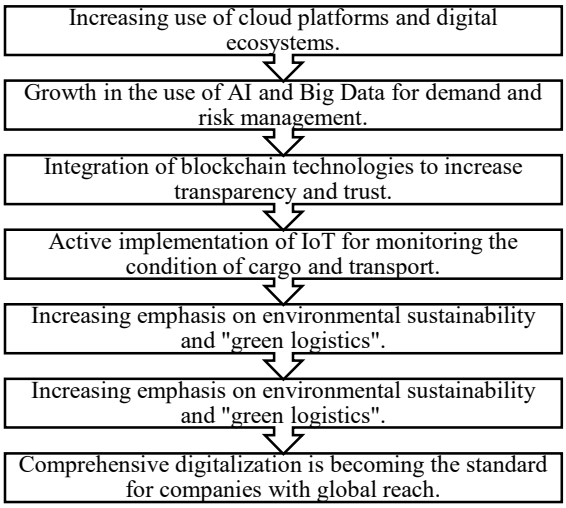

Fig. 4. Structuring of global trends in the implementation of key IT tools to improve supply chain efficiency

The highest efficiency of IT implementation is observed at Amazon and Alibaba, where digital platforms and AI technologies provide record reduction in delivery time and high ROI on investments. Companies focused on traditional transport models (for example, Maersk) demonstrate a lower effect from digitalization due to high capital intensity and slow implementation of innovations.

The level of accuracy of demand forecasting increases significantly with the use of Big Data and AI (an increase of 10-15% compared to companies without forecasting systems). DEA analysis showed that the combined efficiency of digitalization leaders (Amazon, Alibaba, Walmart) is 20-30% higher than that of traditional operators [35].

The key results of the DEA model and KPI analysis of the digital transformation of logistics in the context of implementing IT technologies to improve the efficiency of the supply chain of companies are presented in Fig. 5

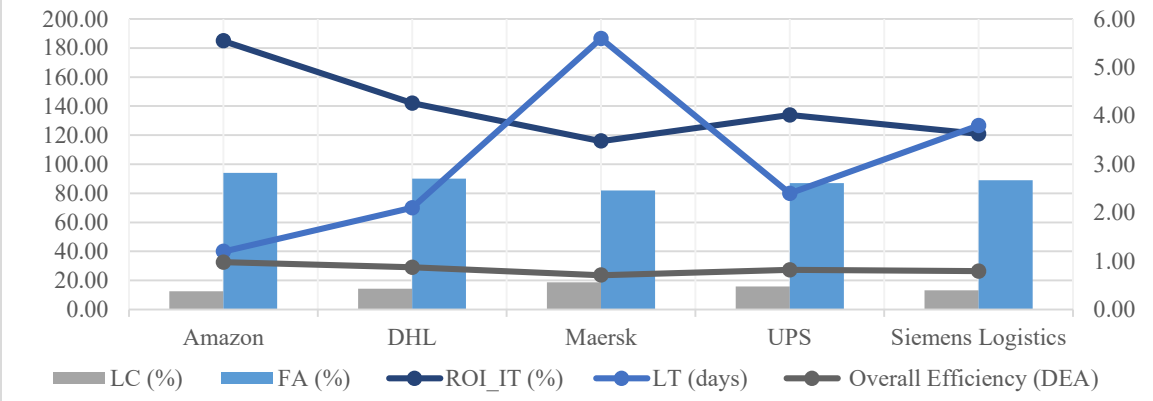

Fig. 5. Key results of the DEA model and KPI analysis of the digital transformation of logistics in the context of implementing IT technologies to improve the efficiency of the supply chain of companies

The developed methodology has proven its applicability for assessing the impact of IT on the efficiency of supply chains. It combines the econometric apparatus of DEA, KPI calculation and empirical analysis based on real data. The novelty lies in the comprehensive integration of digital parameters (AI, IoT, Big Data, blockchain) into economic models of logistics. The results obtained confirm the need for further implementation of digital technologies in logistics, especially in terms of AI forecasting, automation of warehouse operations and digital supply chain management platforms. Despite the results obtained, this study has several limitations that must be considered when interpreting the findings. First, the analysis was based on data from a limited number of companies. While this allowed for a detailed examination of digital transformation processes, it may limit the generalizability of the results to all industries. Second, the study utilized performance indicators chosen by the authors as the most representative (delivery speed, inventory levels, logistics costs), but other aspects, such as environmental sustainability, social factors, or the impact of the regulatory environment, were not considered. Furthermore, the study focused on a relatively short period of time, so the long-term effects of digitalization on supply chain resilience cannot yet be reliably assessed. Methodologically, the study relies on a combination of statistical analysis and qualitative process assessment, which allows for the identification of key trends but does not rule out the possible influence of external factors, such as market conditions or macroeconomic shocks. Recognizing these limitations is important for the proper presentation of the results and outlining areas for further research that could refine or expand upon the findings.

Problems And Open Research Questions

The digitalization of logistics in the course of business in today's world is growing to become a critical factor in boosting the effectiveness of supply chains. The use of information technologies enables organizations to improve processes, accelerate the information transmission among the participants of the chain and make operations more transparent and low-cost. Yet, as there are a diverse range of issues and challenges associated with these new technologies, there is a need for a detailed consideration and structured approach when adopting 'digital' solutions. The problem with connecting all these disparate systems is not an easy one. Supply chains are basically made up of endless chains of different type of links that have been designed by different people and who have come up with their own versions of software or hardware designs, standards and data exchange protocols. The lack of standardized interfaces is the cause of an information-sharing space that is fragmented and business communication between companies is incapable of successful processing. In which case the incompatibility between two systems will cause data transmission error, duplicated data, cannot monitor the process system and so on. It will improve the logistic efficiency for sure. Another matter just as concerning is that of the data security itself. Logistic processes are being digitalized and this implies that the volume of information we handle is increasing, including the economic one, the financial one and the personal one. That's driving high exposure to leaks and attacks, especially when there's a need to share information across entities and platforms. Many current data security mechanisms are inadequate to meet the growing demands, leading to the paramount significance of developing robust and flexible information protection. Lack of skilled experts. It is also the human factor, lack of expertise that can help to make the digital transformation work. Being complicated in advanced IT solutions, it needs to concentrate the information technicians, logistics management personnels, and the data analyst and so on for carrying out the technical operation and maintenance and so on. In the real world, most companies are under-resourced with such personnel, delaying the stimulation of new solutions and limiting their impact. The high cost of using computer equipment is also a significant challenge. Investments in hardware, software, human resources training and project support can be substantial, particularly for small and medium-sized enterprises. This impedes the digitalization of the logistics processes for many companies and diminishes the total potential of revolutionary change in the entire market sector. On top of these shortcomings, the problem of standard development to secure a fit between IT systems used in the supply chain, remains unsolved. Consolidation of protocols and interfaces greatly facilitates the workflow of integrating solutions and accelerates the data interaction, yet there is no clear guideline on the practical use of them according to previous work. The question of developing effective data protection methods in a digitalization environment is also not resolved, which involves researching various cybersecurity approaches, in particular, regarding inter-organizational information exchange. Specialists who can work with modern IT systems, analytical tools and who can think systematically finished higher and postgraduate education should also develop and implement training and advanced training programmers, which directly influence the speed and effectiveness of the process of digital transformation. To the contrary there is prepayment required for assessing the economic profitability of adopting digital technologies. The companies need tools to be able to make well-reasoned decisions on the basis of whether digitalization can be profitable, and what risks there are connected to it. All of these problems just go to show how difficult, complex and multi-layered the task of digitizing the logistics process is. Their management needs to be holistic, structural, technical and institutional, and also humane capital-based. Systematic work in the field of standardization in the field of IT systems, development of reliable information protection means, development of training programs for specialists and economic evaluation is one of the necessary measures that can act as a significant lever to increase efficiency of supply and speed up the process of digital transformation of the economy. These challenges and the need for open discussion than about open research is getting more and more pressing in a more and more global market where companies compete depending on how fast, how accurate and how transparent logistics processes are. There are some technical, organizational and staff issues with respect to how logistics will be digitally transformed. But the questions of IT systems integration, information security guarantee, personnel training, and cost-effectiveness estimation of the introduced technologies are far from being solved completely. is bigger picture What is called for is further theoretical and empirical study that can help to underpin both the academic and practical development required to foster sustainable digital logistics chains and more effective use of those chains in the global market place.

5. FUTURE ENHANCEMENT

Promising research in the field of digital transformation in logistics can focus on several areas. First, an in-depth analysis of the long-term impact of digital solutions on supply chain resilience is needed, including the ability to quickly adapt to global crises. Second, it is important to explore the integration of artificial intelligence, blockchain technologies, and predictive analytics systems to synchronize all supply chain participants. Research into the environmental and social aspects of digitalization to assess its contribution to sustainable development is also promising. Finally, a comparative study of industries and regions with varying degrees of digital maturity is of particular interest, as this will allow us to identify best practices and develop universal models for implementing innovations. Such approaches will expand our scientific understanding of transformation processes and help formulate practical recommendations. The subsequent phase of the logistics digitalization will be shaped by the emergence of sophisticated information technologies, enhancing the supply chain efficiency and business resilience in a period of global-level challenges. One focus is on expanding the range of actions artificial intelligence and machine learning can autonomously take to forecast future demand, ship goods and manage inventory. Using up-to-date algorithms, you are not only able to predict from the past, but may well adapt to changes on the fly and the cost to fail is much lower without relying on having to prepare for a crazy ugly surprise. One of the major paradigms of future is the integration of IoT (Internet of Things) technology into logistics. Between state and status For example, IoT equipment can continuously monitor goods and vehicles, and this may be goods and equipment, both with regard to parameters such as temperature, humidity, as well as to location and delivery time. The net result of which leads to better quality precision control of products, waste and logistics. This combination of IoT and Big Data analytics offers a new method for predictive supply chain management, for example, real-time threat early warning and proactive decision. A third area of improvement can be found in accelerating the logistic efficiency through automatization and robotization of warehouse and transport activities. Processing time will be reduced, so labor cost and the error rate of order processing through autonomous units and robotics fork lifts, and the warehousing management system will be intelligent. When combined with digital supply chain management systems, it allows for greater agility, and responsiveness, so that organizations can response quickly to market disruption, and surges in demand. Besides the technical scope, organizational and human factors should be considered in future enhancements. The work with participants will be based on the educational program and advanced training of employees in the field of digital technologies, analytics of data and management of logistics - the development of skills of using cutting-edge tools. Developing a culture of digital transformation in the company will help bring new technologies to the business and make supply chains sustainable. This also applies to boosting the economic effectiveness of digitalization. The creation of tools for assessing the profitability of implementing IT applications, the calculation of long-term economic benefits, the modeling of risks will provide the company with an opportunity for a reasonable investment in the field of digital technologies, determining the optimal development strategy. Therefore, the subsequent digitalization of logistics is an integrated project, technology applications, process automation, internet of things, Big Data analysis should be combined with training a talent group and checking the cost efficiency etc. These sites contribute to the creation of long-term, flexible and innovative supply chains capable of simplifying operation under global competitive conditions and market dynamics that are changing in real time.

6. CONCLUSIONS

The logistic digital transformation is a strategic vector of development that predetermines the competitive capability of the company and logistics sustainability of supply chain in the conditions of globalization and significant digitalization of economy. Considering the results of the analysis, some conclusions can be established, which in turn become a theoretical and practical body for the use of IT in logistics processes. 1/ Embracing Digital One of the keys to effective supply chain management is integrating digital solutions. Applying new IT tools, based, among others, on the WMS (Warehouse Management System) and TMS (Transport Logistics) systems, automatic route scheduler systems as well as systems for real-time control of orders, can significantly impact the increased transparency of operations, time of order realization and cost of operations. Digitalization allows you to analyze large amounts of data fasten and with so to increase the accuracy of demand forecasts, tailor your inventory management strategy and minimize the risk of a supply break. Evidence of this can be seen by looking at today's multinational companies, which increasingly

leverage integrated IT systems to optimize their logistics operations. Second, the study revealed that the integration of disparate IT systems is one of the significant challenges of digital transformation. Supply networks are made up of many participants, who use their own IT systems and data exchange standards. The absence of common interfaces and protocols causes sluicing of the information space, slows down the interaction procedures and complicates transmission of data. The solution to this problem is in the elaboration of single standards of interoperation that could guarantee the compatibility of software solutions and in the introduction of open integration techniques that will not make it obligatory for businessmen to change existing systems when there is a need to adapt to new requirements with minimum expenses of funds and time. Third, the logistics digitalization has higher demand on the information security. This phenomenon should be further explored and developed in practice as well, as the securing of information is a prerequisite for successful digitalization and trust between partners in the supply chain. Fourth, a big obstacle in the process of digital transformation is the lack of skilled staff. To have a successful and sustained IT enabled system, IT staff with Good IT education (information technology, data analytics, logistics management and project management) is mandatory. The lack of these professionals can slow the Digital Transformation, make it less efficient and lead to more errors. The answer to this problem will be the construction of educational programs and requalification courses aimed at acquiring competences in using advanced logistics platforms, analytical tools and methods for the optimization of the processes.

Furthermore, the utilization of digital technology is costly. The cost to an SME for investment in tools, software, training and project support can be high. This stresses the importance of a full economic efficiency analysis of digitalization. Evaluation of profitableness of the measures being implemented, determination of the payback period of investments, a way of modeling potential the economic efficiency allows to take the weighed decisions of the director and that know financial risks at introduction of innovative technologies.

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