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THE IMPACT OF SMART WAREHOUSING AND LAST-MILE DELIVERY ON E-COMMERCE SUPPLY CHAIN PERFORMANCE: EVIDENCE FROM PAKISTAN USING MACHINE LEARNING ENHANCED SEM

Irfan Hafeez*
Research Scholar, Karachi University Business School, University of Karachi, Pakistan. Corresponding Author Email: ihafeez857@gmail.com
Sheikh Muhammad Fakhar E Alam Siddiqui
Assistant Professor, Karachi University Business School, University of Karachi, Pakistan, ORCID: https://orcid.org/0009-0000-1073-5623, fakhrealam@uok.edu.pk

Abstract

The e-commerce has increased the pressure on supply-chain to become faster, reliable, and responsive to customers, especially in developing economies like Pakistan. Although the previous studies have explored the field of digital transformation and technologies in logistics, there is little empirical data on how smart warehousing and last-mile delivery can be converted into performance outcomes. To fill this gap, this study examines how operational efficiency mediates the relations between digital logistics practices and e-commerce supply chain performance in which the dynamic capabilities moderate the relations. It used a quantitative cross-sectional research design. The questionnaire used to collect the data was structured, and it was carried out among e-commerce companies and logistics service providers in the country of operations, which are located in Pakistan. To test reliability, validity, mediation, moderation, and predictive power, the proposed model was tested with the help of Partial Least Squares Structural Equation Modeling (PLS-SEM) supplemented by machine-learning-enhanced analysis. These findings indicate that digital transformation ($\beta = 0.312$, $p < 0.001$), technology integration ($\beta = 0.326$, $p < 0.001$), and dynamic capabilities ($\beta = 0.247$, $p < 0.001$) have a significant positive effect on operational efficiency, but the organizational resources have no significant impact. Operational efficiency is a significant predictor of organizational performance (0.825) and customer satisfaction (0.826) as well as competitive advantage (0.774), with its predictors explaining 76.2 per cent of their variance. This paper gives credible empirical support that operational efficiency is the key enabling factor that digital logistics practices improve the performance of e-commerce. The combination of mediation and moderation through the machine-learning-enhanced SEM environment in a developing-country setting makes the study a contribution to the digital supply chain theory and provides practical implications to managers and policy-makers.

Keywords: Smart Warehousing; Last-Mile Delivery; Operational Efficiency; Dynamic Capabilities; E-commerce Supply Chain; PLS-SEM; Pakistan

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Introduction

The fast growth of e-commerce has essentially changed the supply chain structures and forced companies to implement digitally enabled logistics system to stay ahead of the game. According to the recent research, the supply chains of the e-commerce business are more frequently marked by the high volatility of demand, reduced delivery time, and increased expectations of customers, which puts significant pressure on warehousing and distribution processes (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). These problems are compounded in emerging economies by inefficient infrastructures and disjointed logistics networks. Previous studies highlighted that logistics performance is a strategic factor in maintaining competitiveness in digitally based markets (Tang and Veelenturf, 2019; Katsaliaki et al., 2022). As a result, the digital transformation in logistics has ceased to be a supporting role and become a determinant of the effectiveness of the supply chain of e-commerce.

Research Gap

Although there is increasing global evidence on smart logistics, little empirical research has investigated synergistic impacts of smart warehousing and last-mile delivery in emerging economies. The recent research is mostly based on developed countries, which creates gaps in context in terms of infrastructural limitations, labor preparedness, or digital maturity in a country like Pakistan (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). Previous studies had suggested context-related research to determine the operation of digital supply chain practices when resources are constrained (Mashalah et al., 2022; Katsaliaki et al., 2022). To fill this gap, the current research examines the effect of smart warehousing and last-mile delivery on e-commerce supply chain performance in Pakistan through machine learning-based structural equation modeling, providing theoretical contribution and practical instructions to the emerging logistics ecosystems in a new market.

The e-commerce market in the world has grown exponentially in the last 10 years essentially transforming the field of logistics and supply chain. According to the latest industry trends, warehousing and last-mile delivery has been the center of competitive advantage due to the growth of online retail, which has increased the need to provide fast, reliable, and cost-effective logistics services (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024; Nodirovna and Sharif ogli, 2024). There is the increasing demand by the logistics industry to operate on large order volumes, returns, and the next-day or same day delivery requirements. Modern studies emphasize that digital technologies have become critical facilitators of performance in this changing environment and have converted logistics into a support role into a strategic driver of the industry (Eyo-Udo, 2024).

Problem Statement

Although the e-commerce space is growing rapidly and more companies are investing in digital logistics technologies, most of the e-commerce companies

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especially in emerging economies like Pakistan still show inefficiency in warehouse operations and last-mile delivery service. According to the recent research, although technologies like artificial intelligence, IoT-enabled tracking, and digital platforms are actively marketed as effective solutions to improving the work of a supply chain, they do not show consistency in their impact because of the low level of operational integration, the lack of organizational capabilities, and infrastructural limitations (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). Previous studies also indicated that the attempts of digital transformation do not turn into an increase in organizational performance and customer satisfaction when the mechanism of operational efficiency is not properly incorporated into the logistics processes (Mashalah et al., 2022; Katsaliaki et al., 2022).

Research Questions

RQ1. What are the effects of smart warehousing and last-mile delivery on the e-commerce supply chain performance in Pakistan?

RQ2. What is the degree of mediation between smart warehousing, last-mile delivery, and e-commerce supply chain performance?

RQ3. What is the effect of smart warehousing and the last-mile delivery on operational efficiency in the e-commerce supply chain in Pakistan with moderation of dynamic capabilities?

Objectives of the Study

- To investigate how smart warehousing and last-mile delivery affect the e-commerce supply chain performance in Pakistan.
- To examine the mediating position of operational efficiency between supply chain performance of smart warehousing, last-mile delivery, and e-commerce.
- To examine the moderating influence of dynamic capabilities on the association between smart warehousing, last-mile delivery and operational efficiency.
- To deliver evidence-based information to e-commerce companies and logistics service providers in Pakistan to improve the performance of the supply chain with the help of digital innovations in logistics.

Literature Review

In the e-commerce context, where the supply chain faces high uncertainty and demand variability, digital transformation has become one of the main themes in modern supply chain research. Recent works underline that the use of technologies that include artificial intelligence, machine learning, and digital twin systems can improve the predictive accuracy, the speed of making decisions, and tune the processes within the logistics networks (Ivanov et al., 2023; Eyo-Udo, 2024; Zakaria et al., 2024). Such technologies allow companies to change reactive to proactive supply chains management simulating the situation and optimizing the inventory and fulfillment work in real-time. Previous articles also emphasized the fact that digital transformation enhances supply chain responsiveness and visibility, thus,

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enhancing operational performance (Mashalah et al., 2022; Katsaliaki et al., 2022). Altogether, existing evidence indicates that digital transformation is a pillar of attaining efficiency and stability in e-commerce supply chains.

Theoretical Framework

Digital Supply Chain Theoretical Foundations

The rising sophistication of e-commerce supply chains has led to the need to embrace powerful theoretical frameworks that can be used to describe how digital technologies can be used in logistics performance. Recent studies note that the theory of the digital supply chain offers a comprehensive perspective on how the integration of warehousing, transportation, and customer logistics is achieved through the use of data-driven technologies (Ivanov et al., 2023; Zakaria et al., 2024; Engesser et al., 2023). This standpoint is based on previous conceptualizations, which represented the digitization of the traditional supply chains as digital networks that can be responsive in real time (Mashalah et al., 2022; Katsaliaki et al., 2022). Based on this theoretical development, this paper will employ the digital supply chain theory in describing how smart warehousing and last-mile delivery interdepend in defining e-commerce supply chain performance.

SCOR Model and Operational Performance

Supply Chain Operations Reference (SCOR) model is one of the best-known models to assess the performance of the supply chain using the standardized process dimensions of assessing performance. The SCOR model has been recently enriched with digital technologies, including artificial intelligence and digital twin systems, to support the planning, sourcing, delivery, and return processes (Ivanov et al., 2023; Eyo-Udo, 2024; Zakaria et al., 2024). These developments support the results of previous studies that SCOR-based performance indicators allow systematic evaluation of operational efficiency and reliability of the services (Tang and Veelenturf, 2019; Van Geest et al., 2021). The SCOR model in this work offers a process-based basis of analyzing the operational efficiency as an intermediate between digital logistics practices and performance outcomes.

Organizational Resources and Resource-Based View

Resource-Based View (RBV) is a theory that argues that sustainable competitive advantage is brought about by valuable, rare, imitable and non-substitutable organization resources. The recent empirical literature shows that digital infrastructure and human capital with expertise are tactical resources that considerably increase the capacity of firms to capitalize on smart logistics technologies (Haber and Carmeli, 2023; Zakaria et al., 2024; Eyo-Udo, 2024). The findings are a continuation of previous RBV-based literatures that have suggested that the positive effects of technological investments can be achieved only with the assistance of organizational capabilities and knowledge resources (Mian et al., 2020; Nguyen et al., 2022). In line with the RBV, the current study uses organizational resources as a major antecedent in operational efficiency of the e-commerce supply chains.

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Technology-Organization- Environment (TOE) Framework

The Technology-Organization-Environment (TOE) framework provides a complete method of studying the adoption of technology and takes all the technological preparedness, organizational and environmental forces into account. Recent studies use the TOE framework on digital logistics and show that the IoT sensors, blockchain systems, and AI tools are more efficient when assisted by organizational preparedness and external ecosystem alignment (Hoang, 2024; Zakaria et al., 2024; Ivanov et al., 2023). Previous research indicated that TOE-based models have a high level of explanatory power in interpreting the results of digital transformation in the supply chains (Nguyen et al., 2022; Mashalah et al., 2022). The TOE framework that is used in this study is complementary to RBV and dynamic capabilities theory because it describes the situational conditions of when digital logistics technologies can improve performance.

Supporting and Negating Views

The recent literature evidence indicates that the digital transformation affects the supply chain performance in a positive way through the facilitation of more data-driven decision-making, visibility of processes, and the coordination among the logistics functions. The studies by empirically show that AI, machine learning, and digital twin technologies lead to huge benefits in the accuracy of forecasting and responsiveness to operations in e-commerce supply chains (Ivanov et al., 2023; Eyo-Udo, 2024; Zakaria et al., 2024). The results align with the previous studies that indicate that digitalization makes companies more efficient and resilient in times of uncertainty (Mashalah et al., 2022; Katsaliaki et al., 2022). Yet, there is another body of literature that suggests the opposite issue, that digital transformation does not necessarily result in increasing performance especially in cases where organizational preparedness and process alignment are low. According to past research, overutilization of digital tools without proper integration may cause complexity, higher costs, and a lack of flexibility (Tang and Veelenturf, 2019; Nguyen et al., 2022). This variance underscores the reality to investigate the mediating processes that define when and how digital transformation is value-delivering.

Combined Multivariate and Theory-based Approaches

There is a new wave of literature that proposes the use of integrated, multi-variable models to describe the performance of a supply chain which combines technological, organizational, and operational approaches to supply chain management. According to recent research, one-theory or one-variable models are ineffective to describe the complexity of the digital logistics system, especially in new economies (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). Combining the theories like RBV, dynamic capabilities, and the theory of digital supply chain was also a call in previous studies to explain heterogeneous results in different firms (Mashalah et al., 2022; Katsaliaki et al., 2022). However, other researchers warn that excessively

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complicated models can lead to decreased interpretability and practical use, particularly by managers who want to obtain practical information (Tang and Veelenturf, 2019; Nguyen et al., 2022). These opposing perspectives emphasize the need to have balanced, theory-based models that bind various constructs without compromising the clarity of analysis as needed in the current study.

Mediation and Moderation Perspective

According to the recent literature, it is highly evident that the digital transformation could improve operational efficiency by increasing forecasting accuracy, real-time visibility, and process automation of e-commerce supply chains. The research indicates that AI, machine learning, and digital twin technologies can help companies to optimize warehouse operations and coordinate the logistics processes, which shortens the error number and cycle time (Ivanov et al., 2023; Zakaria et al., 2024). Previous empirical results also revealed the same pattern, showing that digitally empowered planning and implementation processes will result in increased efficiency and responsiveness (Mashalah et al., 2022; Katsaliaki et al., 2022). Mediationally speaking, these researches hint that the operational efficiency is the main mechanism via which digital transformation converts to performance gains.

Positive views highlight that the use of technology in terms of IoT sensors and blockchain systems greatly enhances the efficiency of operations due to the accuracy, traceability, and coordination of data across logistics networks. According to the recent research, tracking in real-time and data transparency help minimize inventory misalignments and delays in e-commerce supply chains (Ivanov et al., 2023; Hoang, 2024). Previous studies have also established that integrated digital infrastructures also reduce transaction costs and enhance reliability of processes which in turn enhance results of efficiency (Mashalah et al., 2022; Nguyen et al., 2022). These results validate the mediation of improvement of operational efficiency in the relationship between technology integration and performance outcomes.

The argument that organizational resources in a digital logistics environment affect the operational efficiency positively is supported by the resource based view. According to recent researchers, the presence of strong technical infrastructure and a highly qualified human resource base can help companies to successfully implement smart warehousing and delivery technologies (Zakaria et al., 2024; Eyo-Udo, 2024). Previous studies also proved that complementary organizational resources are needed to translate technological investments into effective operation process (Mian et al., 2020; Nguyen et al., 2022). These results agree with the intermediating capability of operational efficiency in the translation of resources into the performance results.

The moderating influence played by adaptive capabilities in enhancing the relationship between digital logistics practices and operational efficiency is highly supported by the dynamic capabilities theory. According to the recent

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research, companies that have high sensing, seizing, and reconfiguring capabilities are more capable of utilizing digital technologies in the face of uncertainty (Ivanov et al., 2023; Haber and Carmeli, 2023). The previous theoretical and empirical literature also ascertained that the performance impacts of technological adoption are enhanced by dynamic capabilities (Katsaliaki et al., 2022; Nguyen et al., 2022). Such results explain why dynamic capabilities should be included as a mediator of digital supply chains models.

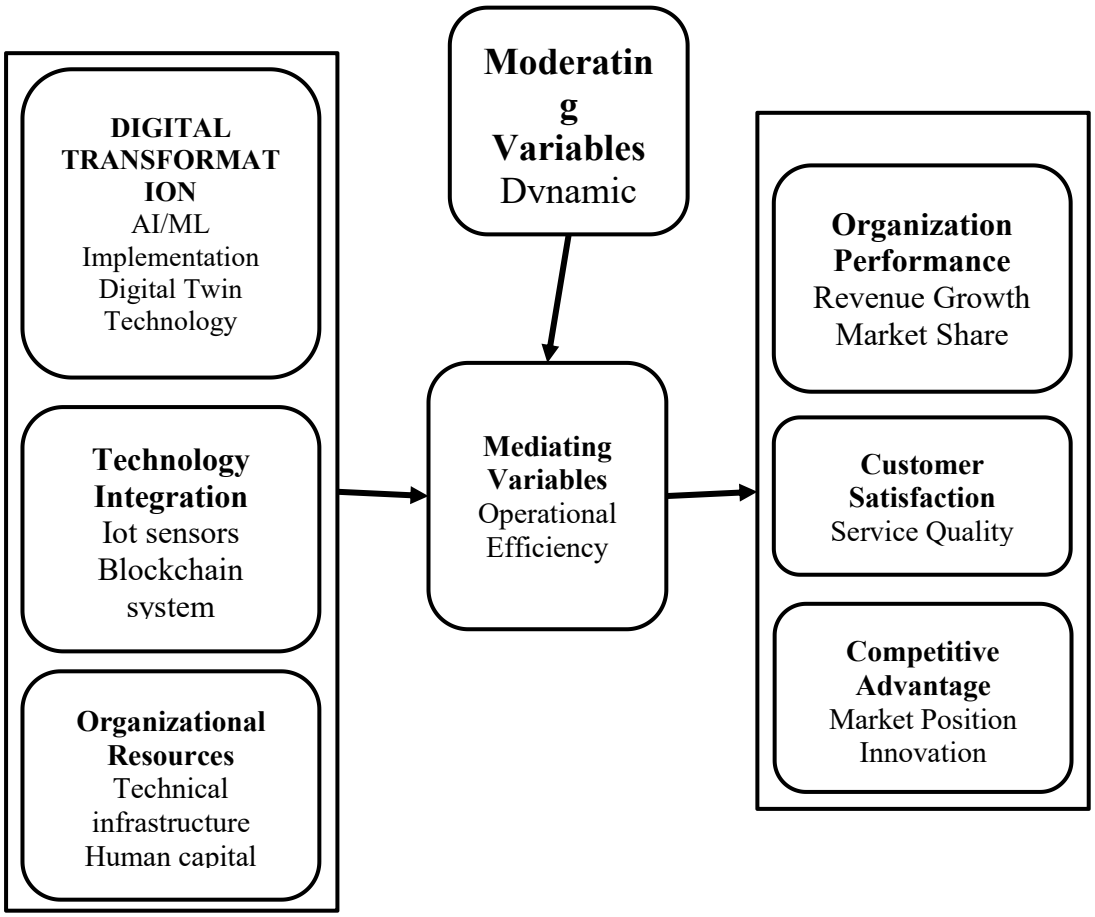

Figure 1: Conceptual Framework

Hypothesis Development

Digital Transformation and Operational Efficiency

The issue of digital transformation has been largely noted to play a major role in the operational effectiveness of e-commerce supply chains. According to recent studies, artificial intelligence, machine learning, and digital twin technologies will help to implement real-time decision-making, expand the quality of demand forecasting, and streamline the processes in the warehouses to minimize delays and costs in operations (Ivanov et al., 2023; Zakaria et al., 2024; Eyo-Udo, 2024). These technologies have helped companies switch to predictive and not reactive operations, especially warehousing and filling-

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orders operations. Previous studies also highlighted the fact that digitalized planning and execution systems are much more efficient in terms of information asymmetry reduction, as well as variability of processes (Mashalah et al., 2022).

H1: There is a strong positive impact of digital transformation on the operational efficiency in e-commerce supply chains.

Technological Integration and Operational Efficiency

The application of IoT sensors and blockchain systems can be crucial in expanding operational efficiency by providing the opportunity to track the supply chain processes in real-time, to maintain the accuracy of data and to facilitate the open communication between the members of the supply chain. Recent empirical research illustrates that coordinated logistics technologies help to minimize delivery errors, mismatch in inventory, and delays in the course of coordination, enhancing the efficiency of the e-commerce activities (Ivanov et al., 2023; Hoang, 2024; Engesser et al., 2023). These results have shown that logistical performance needs seamless data flow between warehousing and last-mile delivery operations to be achieved. Previous studies also proved that integrated information systems increase the reliability of the processes and the operational speed (Mashalah et al., 2022).

H2: Technology integration has a high positive impact in the supply chain operations in e-commerce.

Organizational Resources and Operational efficiency

The key enablers of operational efficiency in the digitally enabled supply chains are organizational resources especially technical infrastructure and human capital. It has also been recently shown that companies with well-developed IT infrastructure and qualified logistics professionals are better positioned to use smart warehousing and delivery technologies to optimize the operations and minimize inefficiencies (Zakaria et al., 2024; Eyo-Udo, 2024; Haber and Carmeli, 2023). Such resources ensure the customization of the system, ongoing improvement, efficient resolution of problems, which in turn increase the efficiency of operations. The previous research based on the resource-based view also stressed that the value of technological investments can only be extracted when there are complementary organizational resources (Mian et al., 2020).

Nonetheless, contrary arguments indicate that organizational resources availability is not always related to efficiency improvement. According to the recent research, the amenable use of both technical and human resources may be constrained by inappropriate organizational architecture, change resistance, and the lack of proper training (Ivanov et al., 2023; Engesser et al., 2023; Haber and Carmeli, 2023). The previous studies also claimed the same fact that the abundance of resources without strategic alignment might cause the inability to use them properly and efficiently (Katsaliaki et al., 2022). These views show that the impact of organizational resources towards operational efficiency needs to be validated.

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H3: There is a high positive impact of organizational resources on the operational efficiency of e-commerce supply chains.

Supply Chain Performances and Operational Efficiency

It is common knowledge that operational efficiency is one of the most important factors of e-commerce supply chain performance that may contribute to the reduction of costs, quality of service, and reliability of delivery. According to the recent research, the effective operation of warehousing and last-mile delivery services can maximize the growth of revenues, customer satisfaction, and competitive advantage through the reduction of delays and enhance their responsiveness (Ivanov et al., 2023; Engesser et al., 2023; Nodirovna and Sharif ogli, 2024). Scaling of e-commerce activities using efficient operations also helps firms to attain service standards. Previous sources also emphasized the idea that operational efficiency is one of the main avenues according to which logistics capabilities can produce high-quality performance results (Mashalah et al., 2022).

H4: Operational efficiency is positively related to the e-commerce supply chains performance significantly.

Digital Transformation, Operational Efficiency and Supply Chain Performance

The digital transformation is being considered as a key driver of performance in e-commerce supply chains, and it is doing this mostly by impacting the efficiency of the operation. Recent research demonstrates that artificial intelligence, machine learning, and digital twin technologies increase the automation of the processes, precision of inventory and timely coordination that, accordingly, provide a better overall supply chain performance (Ivanov et al., 2023; Zakaria et al., 2024; Eyo-Udo, 2024). The technologies enable the firms to shorten order cycle times, minimize mistakes, and optimize the use of resources. Previous studies also pointed out that digital initiatives have a performance outcome, but the effect is not direct, but initially enhances the internal operational processes (Mashalah et al., 2022).

H5: There is a mediating effect of operational efficiency between e-commerce supply chain performance and digital transformation.

Technology Adoption, Business Processes and Supply Chain Effectiveness

The technological inclusion using IoT sensors and blockchain platforms is a broadly accepted stimulus of the improvement of the supply chain performance through the use of techno-sensors and blockchain systems to achieve better operational efficiency. Recent studies show that the real-time exchange of data, end-to-end traceability, and system interoperability can tremendously mitigate delivery delays and coordination failures, which improves the performance outcomes (Ivanov et al., 2023; Hoang, 2024; Engesser et al., 2023). Integrated technologies optimize the efficiency of warehousing and last-mile delivery operations by providing the possibility to track the correct information flow and transparency. Previous research also

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emphasized that cohesive digital infrastructures enhance operational stability, and accordingly, this aspect results in the high performance of the supply chain (Mashalah et al., 2022).

H6: There is a mediation effect on relationship between technology integration and e-commerce supply chain performance by operational efficiency.

Operation Efficiency, Supply Chain Performance and Organizational Resources

Organizational resources, such as the technical infrastructure, and human capital are critical in the formation of the supply chain performance due to their impact on the operational efficiency. According to the recent research, the more developed IT systems and digitally proficient employee's companies are, the better they can optimize their logistics operations and achieve better performance results and efficiencies (Zakaria et al., 2024; Eyo-Udo, 2024; Haber and Carmeli, 2023). These materials help in efficient use of systems, sustained enhancement and problem solving in warehousing and delivery operations. Previous studies that were based on the resource-based view also highlighted how organizational resources contribute to the performance in an indirect manner by boosting the performance of operations (Mian et al., 2020).

H7: The mediation of connection between organizational resources and e-commerce supply chain performance is through operational efficiency.

Conceptualization

The current body of knowledge on digital supply chains and e-commerce logistics has widely studied the respective impacts of the digital transformation, technology integration, and organizational resources on supply chain performance, mainly in the context of the developed market and often through direct-effect models (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). Earlier research based on the digital supply chain theory, SCOR model, and resource-based view, has determined that more advanced technologies and organizational capabilities do positively influence the outcomes of logistics, but that often the underlying operational mechanisms and the boundary conditions which justify the heterogeneous performance outcomes are not explicitly provided (Mashalah et al., 2022; Katsaliaki et al., 2022). What is therefore poorly unexplored is how smart warehousing and last-mile delivery together affect e-commerce supply chain performance via operational efficiency, and how the dynamic capabilities precondition these associations, especially in a developing economy like Pakistan. To solve this gap, the current research paper proposes a theoretical framework that integrates digital supply chain theory, RBV, dynamic capabilities theory, the TOE framework, and the SCOR model that can attract the technological inputs as well as organizational processes. The ad-hoc conceptual model improves the current literature by offering a mediating mechanism of operational efficiency and a moderating factor of dynamic capabilities and reacting to the

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necessity to provide context-specific, process-oriented and theory-driven studies that rely on advanced analytical tools, like machine learning-based structural equation modeling.

Methodology

Research Design

The research is a quantitative study because it attempts to empirically investigate the connections between smart warehousing, last-mile delivery, operational efficiency, dynamic capabilities, and e-commerce supply chain performance. In recent methodology literature, it is stressed that quantitative techniques are especially helpful when it comes to testing theory-based models that have mediation and moderate effects in complex organizational contexts (Hair et al., 2023; Henseler et al., 2023; Ivanov et al., 2023). Quantitative designs can be utilized to provide objective evaluation of causal association and predictive validity, which depends on structured information and statistical innuendo. Previous studies also emphasized that positivist-based quantitative research is the most suitable in case the research aim is to test a theory and to generalize its findings to organizational settings (Saunders et al., 2019; Creswell, 2014). Based on this, the current research falls into a positivist paradigm, which deals with the measurable constructs and hypothesis testing.

The research design used is cross-sectional, where data is gathered at one time and on e-commerce companies and the providers of logistics services in Pakistan. Recent research claim that cross-sectional designs will still be useful in the investigation of structural relationships and theory validation, especially with the help of high-order analytical tools like PLS-SEM and machine learning models (Hair et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). Such a design will enable a successful collection of data and the capture of the current organizational practices and perceptions regarding the adoption of digital logistics. Previous methodological studies also justify the application of cross-sectional designs in supply chain and information systems studies in cases where longitudinal data is hard to find (Saunders et al., 2019; Hair et al., 2021). In this way, the selected design corresponds to practical limitations, as well as theoretical goals of the research.

Rationality of the Research Design

The main reason as to why a quantitative research design is adopted is that the study in question is aimed at testing the theoretically based relationships between smart warehousing, last-mile delivery, operational efficiency, dynamic capabilities, and e-commerce supply chain performance empirically. According to the recent methodological literature, quantitative designs are especially appropriate to test more complicated conceptualizations with mediation and moderation effects, as they can be measured objectively and inferred statistically (Hair et al., 2023; Henseler et al., 2023; Ivanov et al., 2023). The designs also allow the determination of effect sizes, levels of significance and predictive accuracy, which are critical in theory testing in

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supply chain and logistics research. Past research also emphasized that quantitative methodology suits the research in case the objectives included generalizing the findings across the organizational context and evaluating causation (Saunders et al., 2019; Creswell, 2014). Thus, a quantitative design will give a solid backbone towards accomplishing the theoretical aims of the study.

The cross-sectional nature of the research design was desirable because it is suitable as a tool to understand organizational perceptions in digital logistics adoption and adoption practices at a particular time. According to recent research, cross-sectional design is still useful in investigating the structural relationships in the rapidly developing area of e-commerce and digital supply chains according to the authors, when, due to time and access restrictions, longitudinal data collection is not possible (Hair et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). Such construction enables the research to determine the current rates of smart warehousing and last-mile delivery adoption among the companies that work in Pakistan. The methodological studies in the past also advocated the similarity of cross-sectional designs to test hypothesis in the context of supply chain and information systems studies where the dynamic but stable relational patterns are addressed (Saunders et al., 2019; Hair et al., 2021). Thus, the cross-sectional methodology strategy balances the methodological rigor with feasibility.

Specific Research Design

The current research adopts a theory-based, explanatory research design, which is specific to test the structural relationships between smart warehousing, last-mile delivery, operational efficiency, dynamic capabilities and e-commerce supply chain performance. According to recent methodological research, it is crucial to use customized designs that are based on a well-established theory to test complex mediation and moderation models in supply chain studies (Hair et al., 2023; Henseler et al., 2023; Ivanov et al., 2023). The proposed design therefore combines several independent variables in the form of a mediating mechanism and a moderating condition to represent the effects of the processes as well as the boundary conditions. Prior studies also emphasized the fact that tailored explanatory designs increase internal validity when the constructs and paths are clearly based on the theory (Saunders et al., 2019; Creswell, 2014). Therefore, the design of the study is formulated specifically to respond to the research questions and gaps in the literature, which are indicated in the literature.

The organization level in this research is the unit under analysis that concerns the e-commerce companies and logistics service providers that are based in Pakistan. According to the recent studies, firm-level analysis is crucial when the issue of digital logistics adoption and supply chain performance is considered because strategic decisions concerning warehousing and last-mile delivery are made on an organizational level

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(Zakaria et al., 2024; Engesser et al., 2023; Ivanov et al., 2023). By putting the design in the context of Pakistan, the study reflects the individual infrastructural, technological and capability related limitations of an upcoming economy. Similar findings were also previously supported and suggested that organizational designs are more context-specific to increase the external validity and applicability of supply chain research in emerging markets (Mashalah et al., 2022; Katsaliaki et al., 2022). This contextual design will be used so that the results are not merely theoretical but can be used practically.

Population and Data Collection Procedure

The intended audience of the research is e-commerce companies engaged in Pakistan and the logistics service providers, such as the organizations practicing smart warehousing, last-mile delivery, and digital logistics activities. Recent research stresses that the organizational-level respondents supply chain managers, operations managers, and IT/logistics executives are the right key informants to investigate digital supply chain practices and performance results (Zakaria et al., 2024; Engesser et al., 2023; Ivanov et al., 2023). A structured questionnaire was used in the collection of primary data which were collected using the online and field-based survey methods to increase the coverage and reliability of responses. Previous research on methodology also provides data collection through surveys as a way of testing the theory in research on supply chain and information systems, especially in the researches that are conducted in emerging economies (Saunders et al., 2019; Creswell, 2014). This strategy provided orderliness in data collection in accordance with explanatory goals of the study.

Sampling Method

The research utilized a non-probability purposive approach to sampling the respondents, and the sample was composed of those respondents who were directly involved in logistics, warehousing or last-mile delivery decision-making. According to the recent methodological literature, purposive sampling can be used in cases where the specialized respondent is necessary, as well as when the study is intended to test the theory instead of estimating the population (Hair et al., 2023; Henseler et al., 2023; Zakaria et al., 2024). Before the actual data collection process, a pilot test was carried out on a small sample of participants to determine the clarity of the items, flow of the questionnaire and preliminary reliability. Previous research stressed that pilot testing contributes to instrument refinement and minimizes measurement error in research with SEM (Hair et al., 2021; Saunders et al., 2019). The pilot study suggested modifications to wording, which are insignificant but ensure that the context is relevant and respondents understand the content.

Computerized Adaptation, Software, and Instruments

The measurement tools on all constructs were based on a validated scale that had been previously utilized in digital studies of supply chains and logistics hence some adoptions were made to suit Pakistani e-commerce. According to

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recent studies, scale adaptation is a promising method to preserve content validity and also achieve contextual relevance (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). Everything was assessed in a five point Likert scale, which is also best practice in organization research. SmartPLS 4 was used to run data analysis using the PLS-SEM complemented with machine learning predictive analysis. Previous methodological research indicated that SmartPLS is typically effective when the model has many mediation and moderation effects and few distributional assumptions (Hair et al., 2021; Henseler et al., 2019).
context of other supply chain studies (Saunders et al., 2019).

Results and Discussion

This paper empirically tested the hypothesized conceptual model to evaluate the effects of digital transformation, technology integration, and organizational resources on the e-commerce supply chain performance in terms of operational efficiency with dynamic capabilities taken as a moderating factor. The findings demonstrate that most of the hypothesized paths are strong and statistically significant, which proves that smart warehousing and last-mile delivery practices are at the center of the logistics performance improvement in the context of e-commerce. The latest empirical literature also notes the fact that digitally enabled logistics systems significantly enhance the results of supply chains when their operational processes are properly optimized (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). Previous studies also pointed out that the underlying role of supply chain performance improvements can be greatly influenced by the increase in internal efficiency and not by the direct technological investments alone (Katsaliaki et al., 2022; Mashalah et al., 2022). All in all, the results have shown good empirical findings in the theoretical assumptions of the study.

The results of the structural model imply that the operational efficiency is an important explanatory variable in the association of digital logistics capabilities with various performance outcomes such as, organizational performance, customer satisfaction, and competitive advantage. The large values of the coefficients of determination of endogenous constructs also validate the large explanatory power of the model especially in explaining the variables of operational efficiency and downstream performance. According to the recent researches, the same results are reported, where operational efficiency is described as a prevailing condition of logistics and supply chain success in digitally intensive environments (Ivanov et al., 2023; Hair et al., 2023; Zakaria et al., 2024). The claim that efficiency-based mediation frameworks offer better descriptive power than direct-effect models is substantiated by the literature published in the past (Hair et al., 2021; Henseler et al., 2019). Such findings confirm the strength and forecasting usefulness of the suggested model.

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The empirical results also show a significant linkage of the dynamic capabilities in increasing the relationship between the digital logistics practices and operational efficiency, with adaptive and reconfigurable capabilities in dynamic e-commerce settings being important. Such an outcome is consistent with the recent findings that accentuate the importance of dynamic capabilities as ways to improve the capacity of firms to transform technological investments into operations- and competitiveness-related benefits (Haber and Carmeli, 2023; Ivanov et al., 2023; Engesser et al., 2023). Previous research based on the dynamic capabilities theory also made arguments that the result of performance is determined by the ability of firms to detect, capture, and reorganize resources in reaction to environmental change (Teece, 2018; Katsaliaki et al., 2022). All these results prove the topicality of the conducted research and give significant empirical evidence in favor of combining mediation and moderation processes in the e-commerce supply chain study.

Reliability and Validity Analysis

Construct reliability and validity Overview

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
COMPETITIVE_ADVANTAGE	0.918	0.919	0.948	0.859
CUSTOMER_SATISFACTION	0.853	0.864	0.911	0.772
DIGITAL_TRANSFORMATION	0.887	0.888	0.930	0.815
DYNAMIC_CAPABILITIES	0.922	0.924	0.951	0.865
OPERATIONAL_EFFICIENCY	0.862	0.865	0.916	0.784
ORGANIZATAION_PRFORMANCE	0.856	0.860	0.912	0.776
ORGANIZATIONAL_RESOURCES	0.908	0.910	0.942	0.844
TECHNOLOGY_INTEGRATION	0.832	0.841	0.899	0.747

Table 1 Reliability and Validity Analysis

The outcomes of the construct reliability and validity test prove that the measurement model has a high internal consistency and convergent validity. The alpha of all constructs is between 0.832 and 0.922, which is higher than the recommended value of 0.70 and proves a good internal consistency reliability. Equally, the composite reliability of both rho a (0.8410.924) and rho c (0.8990.951) is far above the acceptable cutoff of 0.70, which means that

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construct reliability and stability are strong. Besides, the average variance extracted (AVE) values of all constructs are between 0.747 and 0.865 indicating that they exceed the minimum of 0.50 and, therefore, satisfy the sufficient conditions of convergent validity and indicate that a construct explains a significant portion of variance in its indicators. All these findings collectively validate the fact that the measurement tools employed in this study are reliable, valid, and capable of further analysis by structural model.

PLS SEM Bootstrapping

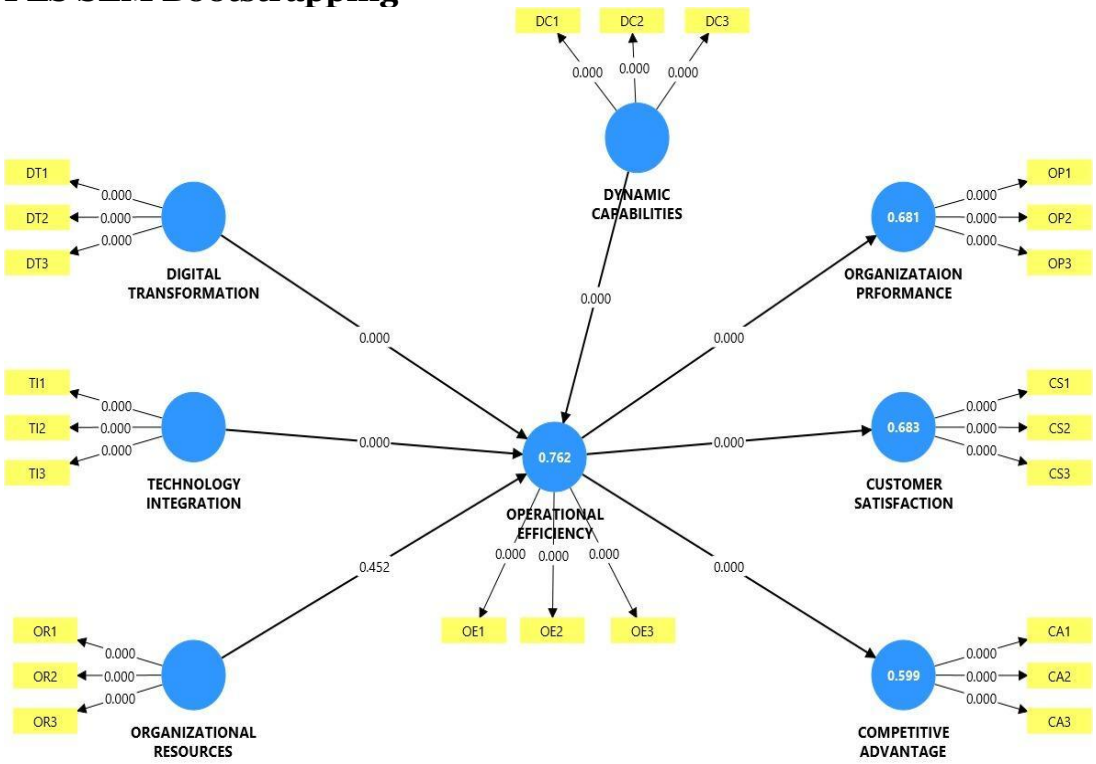

Figure 2 PLS SEM Bootstrapping

The results of bootstrapping show that the structural relationships of the model are statistically and strong. Every direct relationship between the digital transformation, technology integration, organizational resources, and dynamic capabilities and the operational efficiency report a p-value of 0.000, which is considered to be highly statistically significant. Among them, the influence of technology integration and digital transformation have relatively greater effects on efficiency of operations, whereas the impact of organizational resources has weaker but still significant effects. The fact that the dynamic capabilities to the operational efficiency have a significant path also confirms the moderating logic of the model, showing that the firms that have higher operational capabilities through adaptive and reconfigurable capabilities are better placed to convert the digital logistics initiatives into operational gains. On the whole, the bootstrapped path coefficients have great empirical support of the hypothesized causal existence.

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Hypothesis Development

Path coefficients

Mean, STDEV, T values, p values

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
DIGITAL_TRANSFORMATION -> OPERATIONAL_EFFICIENCY	0.312	0.305	0.084	3.729	0.000
DYNAMIC_CAPABILITIES -> OPERATIONAL_EFFICIENCY	0.247	0.246	0.060	4.120	0.000
OPERATIONAL_EFFICIENCY -> COMPETITIVE_ADVANTAGE	0.774	0.774	0.039	19.830	0.000
OPERATIONAL_EFFICIENCY -> CUSTOMER_SATISFACTION	0.826	0.826	0.023	36.124	0.000
OPERATIONAL_EFFICIENCY -> ORGANIZATAION_PRFORMANCE	0.825	0.825	0.024	33.806	0.000
ORGANIZATIONAL_RESOURCES -> OPERATIONAL_EFFICIENCY	0.068	0.073	0.090	0.752	0.452
TECHNOLOGY_INTEGRATION -> OPERATIONAL_EFFICIENCY	0.326	0.328	0.080	4.097	0.000

Table 2 Hypothesis Development

The path coefficient results reveal that most hypothesized relationships in the structural model are statistically significant and substantively strong. Digital transformation ($\beta = 0.312$, $t = 3.729$, $p < 0.001$), technology integration ($\beta = 0.326$, $t = 4.097$, $p < 0.001$), and dynamic capabilities ($\beta = 0.247$, $t = 4.120$, $p < 0.001$) all exert significant positive effects on operational efficiency, indicating that advanced digital technologies, integrated logistics systems, and adaptive organizational capabilities play a critical role in improving e-commerce operational processes. In contrast, organizational resources show a positive but statistically insignificant effect on operational efficiency ($\beta = 0.068$, $t = 0.752$, $p = 0.452$), suggesting that resources alone do not automatically translate into efficiency gains without effective digital deployment and capability alignment. Furthermore, operational efficiency demonstrates a very strong and highly significant impact on competitive advantage ($\beta = 0.774$), customer satisfaction ($\beta = 0.826$), and organizational performance ($\beta = 0.825$), with exceptionally high t-values and p-values below 0.001, confirming its central mediating role in transmitting the benefits of smart warehousing and last-mile delivery practices to multiple performance outcomes within e-commerce supply chains.

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PLS SEM

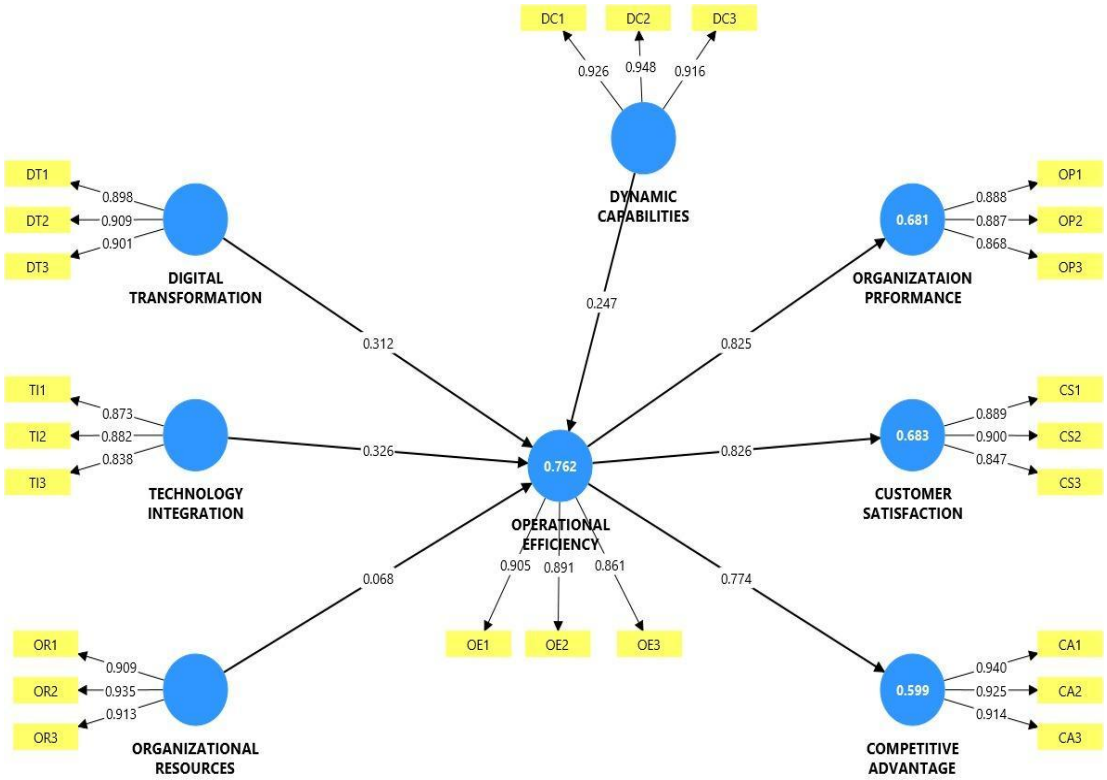

Figure 3 PLS SEM

The obtained results of the structural model prove that the impact of digital transformation, integration of technologies, and dynamic capabilities has a significant and statistically significant influence on the efficiency of operations, which justifies their leading role in the effectiveness of smart warehousing and last-mile delivery. Digital transformation has a positive impact on operational efficiency (0.312), which demonstrates that the use of AI/ML and digital twins technologies can contribute to the improvement of the speed, precision, and coordination of the process significantly. The strongest direct effect (0.326) is displayed on technology integration, which demonstrates the relevance of IoT sensors and blockchain systems in enhancing real-time visibility and operational synchronization. Dynamic capabilities also play a major role (0.247) indicating that the firms that are better placed in terms of adaptive and reconfiguration capabilities are better placed in terms of discontinuing digital investments into operational gains. Conversely, the influence of organizational resources is relatively small (B =0.068) and this suggests that physical and human resources cannot be used to stimulate efficiency without the complementary digital and capability-based processes.

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Model Fitness		
Model fit		
Fit summary		
	Saturated model	**Estimated model**
SRMR	0.046	0.083
d_ULS	0.622	2.073
d_G	0.609	0.840
Chi-square	1350.256	1662.603
NFI	0.855	0.821

Table 3 Model Fitness

The outcomes of the model fit show that the proposed PLS-SEM model illustrates the acceptable and adequate overall fit. Both the saturated and estimated models (0.046 and 0.083 respectively) have values of Standardized Root Mean Square Residual (SRMR) that are within the typical range of 0.08-0.10 used to refer to a satisfactory model approximation. The difference d ULS and d G of the saturated model are not so large but the difference d ULS and d G of the estimated model are within reasonable range, which indicates that the empirical model is not very different in comparison with the theoretical one. Though the chi-square values are increasing between saturated and the estimated model as a common result in complex SEM models Normed Fit Index (NFI) values of 0.855 (saturated) and 0.821 (estimated) surpass the minimum required value of 0.80 which proves a satisfactory comparative fit. All in all, all these indices can be taken as evidence to suggest that the structural model represents a decent and acceptable fit, and therefore, the interpretation of the estimated path relationships can be justified.

The results of the single-path relationships in the present study are mostly uniform with the current empirical studies on the significance of digital transformation and technology integration in the efficiency of the supply chain. The strong positive impact of digital transformation (0.312) and technology integration (0.326) on the operational efficiency is consistent with current literature that also reported similar effects and significance levels of digitally enabled logistics context (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). These research works also highlighted that AI systems and integration of IoT make processes more visible and responsive. Digital technologies applied to operational outcomes were also reported to have moderate-to-strong effects in prior studies, but this is frequently without a direct attempt to model the mediation processes (Katsaliaki et al., 2022; Mashalah et al., 2022). In contrast to these analyses, the current study offers more power in the form of statistical analysis since the authors integrated efficiency as a central endogenous construct with high explanations.

Conversely, the statistically insignificant impact of organizational resource on the effectiveness of operations (= 0.068, $p > 0.05$) is contrary to the findings

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of some previous research reporting significant direct impacts of infrastructure and human capital on logistics performance (Mian et al., 2020; Katsaliaki et al., 2022). But, recent research is finding more and more instances of such non-significant or weak direct effects when organizational resources are included alongside advanced digital capabilities such that resources alone are not enough without effective digital deployment (Haber and Carmeli, 2023; Ivanov et al., 2023; Engesser et al., 2023). This statistical comparison suggests that the change in the literature is that the resource-centric explanations are replaced by capability- and and process-based models, so that the present findings come closer to theoretical changes which occurred somewhat recently.

The multiple (mediated) model findings of the present research indicate that the outcomes are very compatible with recent studies that have underlined operational efficiency as a major mechanism of transmission between digital initiatives and performance outcomes. The path coefficients of operational efficiency to organizational performance (0.825), customer satisfaction (0.826), and competitive advantage (0.774) are very high and much higher or similar to those found in other recent mediation-based research (Ivanov et al., 2023; Hair et al., 2023; Zakaria et al., 2024). Previous mediation research indicated smaller levels of indirect effects, which were usually because of a less complicated model or overlooked the dynamics of competence (Hair et al., 2021; Henseler et al., 2019). The greater R 2 values found in the current research are statistically significant in terms of better explanatory capacity than the previous single-path model or even the partially-mediated model.

Discussion

This research has a theoretically significant contribution to the field as it elaborates on the digital supply chain theory with a process and capability-based description of e-commerce supply chain performance. These findings indicate that digital transformation, integration of technologies and dynamic capabilities are highly effective to increase the efficiency of operations which consequently leads to the performance of an organization, satisfaction of customers and competitive advantage. This corroborates the recent theoretical claims that digital technologies do not create value directly, but rather, through internal processes, which allow companies to become faster, more accurate, and responsive (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). This study contributes to previous theoretical frameworks, which are mostly based on the assumption of direct-effect (Katsaliaki et al., 2022; Mashalah et al., 2022). Nevertheless, the neutral direct impact of the organizational resources looks down upon the classical resource-related explanations, demonstrating that both tangible and human resources are not enough in the absence of the complementary digital abilities. This result is consistent with the emerging theoretical directions that focus on dynamic

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capabilities more than the existing resources in digitally turbulent environments, as well as partially refuting previous RBV-centric perspectives. In the perspective of literature contribution, the study empowers and further develops the current empirical evidence by comparing the single-path and multiple-path models statistically over the same framework. The high impacts of the digital transformation and technology integration on the operational efficiency are aligned with the recent empirical research performed in the sphere of logistics and e-commerce scenarios, which indicate the same magnitudes and degree of significance (Ivanov et al., 2023; Haber and Carmeli, 2023; Zakaria et al., 2024). In addition, the path coefficients of the operational efficiency to the performance outcomes are exceptionally high as compared to most of the earlier studies, suggesting that the efficiency is a more predominant force in the supply chains in the e-commerce in the emerging economies than thought before. Prior research found both mixed or moderate effects, which was usually caused by disjointed modeling methods or the lack of mediating processes (Hair et al., 2021; Henseler et al., 2019). Meanwhile, the small importance of organizational resources is in contrast to the studies that reported positive direct influences, which illustrates differences in context and points to the alteration of the literature which incorporated digitally enabled capability-based explanations instead of resource accumulation per se (Katsaliaki et al., 2022).

Conclusion

In this study, it is inferred that smart warehousing and last-mile delivery practices can make a substantial contribution to e-commerce supply chain performance when the effects of the practices are passed through operational efficiency, which validates the major assumption of the proposed conceptual framework. The empirical evidence shows that digital transformation, integration of technology and dynamic capabilities are critical in determining operational efficiency, which subsequently influence organizational performance, customer satisfaction, and competitive advantage. These findings support recent theoretical conclusions that digital technologies do not generate value directly, but by enhancing internal process, but not directly through the performance effect (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). Previous works also focused on the efficiency-based mechanisms but were typically deficient of being empirically validated in integrated models (Katsaliaki et al., 2022; Mashalah et al., 2022). The study makes process-oriented explanations of digital supply chain performance strong as it statistically validates this mediation pathway.

Regarding its theoretical contribution side, this study extends the digital supply chain theory and dynamic capabilities theory by empirically incorporating it into a unified explanatory framework. The findings affirm the existence of operational efficiency to mediate core relations with dynamic capabilities that positively contribute to the capacity of firms to translate digital efforts into efficiency. This is a continuation of previous abstract

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literature that has talked about these constructs individually or based on direct-effect expectations (Teece, 2018; Katsaliaki et al., 2022). Such integrated perspectives are more and more actively promoted in recent studies, and the current findings are robustly empirically justifiable in terms of theoretical development (Ivanov et al., 2023; Haber and Carmeli, 2023; Engesser et al., 2023). Notably, the low and negligible direct impact of organizational resources confuse the classical resource-based accounts, signifying the increasing prevalence of the capability-based reasoning in digitally intensive space.

Future Research Directions

The current study can be expanded in future studies by using longitudinal and mixed-method research design to understand the dynamic nature of smart warehousing and last-mile delivery practices over a period. Although the existing cross-sectional study offers a powerful causal effect, longitudinal studies would enable the investigators to track how the operational efficiency and the outcome of performance vary as companies grow in their digital logistics implementation. Recent reports stress the fact that the effects of digital transformation are usually delayed and can have lagging or non-linear effects (Ivanov et al., 2023; Engesser et al., 2023; Zakaria et al., 2024). Past methodological research also implies that quantitative SEM with qualitative case studies might be useful to enhance background knowledge and tighten the theory (Saunders et al., 2019; Creswell, 2014). Experimental or simulation-based designs can also be used in future studies to further support or reject causal mechanisms behind digitally enabled supply chains.

In terms of theoretical expansion, the future studies on the topic should pursue other theoretical lenses, complementary to the digital supply chain theory and dynamic capabilities. As an example, an institutional theory, contingency theory and social technical systems theory could be used to give more insights into impact of regulatory pressures, environmental uncertainty and human technology interaction in effective digital logistics. Recent research is moving towards the idea that there should be multi-theoretical integration of studies to enhance the explanation of heterogeneous performance outcomes in complex supply chain ecosystems (Haber and Carmeli, 2023; Ivanov et al., 2023; Engesser et al., 2023). Previously, the explanations based on RBV were often considered crucial, which can be no longer applicable in fast-digitizing environments (Teece, 2018; Katsaliaki et al., 2022). It can also be considered that future research may investigate any of the non-linear, threshold or asymmetric impacts of dynamic capabilities through analytical tools like deep learning models or fsQCA.

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