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The nexus between digital supply chain and sustainability: An empirical study in pharmaceutical companies in Jordan

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This study focuses on the impact of the digital supply chain, including digital suppliers, digital manufacturing, and digital logistics, on sustainability outcomes in pharmaceutical companies in Jordan. Quantitative data were collected through a questionnaire distributed to a sample of 226 managers of pharmaceutical companies in Jordan. The questionnaire measures perceptions, attitudes and experiences related to digital supply chain adoption and sustainability performance. Structural equation modeling (SEM) was used as an analytical framework to study the relationships between digital supply chain and sustainability outcomes. The hypothesized relationships were tested using confirmatory factor analysis and path analysis techniques within the SEM framework. The results indicate a positive relationship between digital supply chain adoption and sustainability performance in pharmaceutical companies in Jordan. Based on the results, several recommendations were proposed for pharmaceutical companies in Jordan to enhance their sustainable performance through digital supply chain initiatives. This research contributes to the existing literature by providing empirical evidence on the relationship between digital supply chain practices and sustainability outcomes in the pharmaceutical industry, especially in the context of Jordan.

1. Introduction

The concept of sustainability has recently emerged as a vital and critical element in responding to concerns related to climate change, resource depletion, and social justice (Abbate et al., 2024). In essence, sustainability, as explained by the United Nations Brundtland Commission in 1987, is based on fulfilling the obligations of the present without affecting the ability of generations to fulfil their future obligations. Ruggerio (2021) emphasized that achieving global sustainability requires the combined efforts of everyone, including individuals, communities, and governments, to reduce activities that harm the environment and affect individual and social well-being. Accordingly, many regulatory initiatives have emerged aimed at promoting social responsibility, reducing the harmful environmental footprint, and supporting the economic prosperity of enterprises (Amaral et al., 2020). In addition, many countries have tended to amend their policies to be more sustainable through tax cuts to adopt sustainable approaches, methods of dealing with solid waste, and abandoning fossil coal in power generation (Zeemering, 2021).

In the contemporary business environment, the traditional supply chain has witnessed fundamental changes represented by the integration of digital technologies into all its stages and operations. This development has led to the emergence of the digital supply chain as a dynamic approach that ensures data-driven decision-making across supply chain processes from raw material suppliers to end consumers (Lee et al., 2022). The essence of a digital supply chain is to make the most of Industry 4.0 technologies such as AI and IoT to improve resilience across the chain and provide valuable insights to decision-makers

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(Ivanov &Dolgui, 2021). Haddud and Khare (2020) stated that the combination of supply chain activities and modern technologies allows real-time monitoring, automation of operations, reduction of costs, and improvement of quality, all of which are reflected in customer satisfaction. On the other hand, Rahamneh et al. (2023) stressed that the digitization of the supply chain facilitates communication between chain partners, which increases trust and enhances transparency to confront turmoil in the business environment.

The pharmaceutical industry has recently found itself under increasing pressure to shift towards sustainable practices to reduce the environmental concerns of its activities and enhance its social commitment. At the same time, the emergence of digital technologies as a powerful force in the modern supply chain management landscape has created opportunities for these companies to achieve efficiency and support innovation. However, the extent to which digital supply chain initiatives contribute to sustainability outcomes in the context of pharmaceutical companies in Jordan remains largely unexplored. The distinct components of the Jordanian pharmaceutical sector, which include regulatory stringency, value chain complexity, and ethical considerations, have further complicated and ambiguous the relationship between the integration of digital technologies within the supply chain and sustainability initiatives. Hence, there was a need to conduct empirical research that interprets and explains the relationship between the digital supply chain and sustainability in pharmaceutical companies in Jordan.

By delving deeper into the interaction between the digital supply chain and sustainability goals, this research seeks to provide insights into the opportunities and potential challenges that pharmaceutical companies in Jordan may face. The research findings also contribute to the academic literature on the relationship between supply chain management and sustainability in light of digital transformation, with a focus on putting forward a set of practical recommendations to enhance sustainability practices in the pharmaceutical sector. Ultimately, the research aims to inform evidence-based decision-making and promote a more sustainable and resilient pharmaceutical industry in Jordan and beyond.

2. Literature Review

2.1 Digital supply chain

The digital supply chain is a relatively recent concept that has been discussed in academic circles to define its comprehensive concept and application approach. However, several opinions have emerged that explain the digital supply chain. Weerabahu et al. (2023) believe that this concept expresses the merging of physical and digital processes resulting in a new and dynamic supply chain ecosystem. According to Liu et al. (2024), the digital supply chain is considered the outcome of the transformational revolution of businesses towards the intensive use of technology, as it is based on the automation of the transfer of materials and products from raw material suppliers to consumers through manufacturing processes. This definition is based specifically on digital systems for manufacturing companies, including digital twins and the Internet of Things. Nasiri et al. (2020) expressed that a digital supply chain integrates digital technologies and information systems to enhance visibility, coordination, and collaboration across the supply chain network. It involves the use of electronic data interchange (EDI), Internet-based communications platforms, and digital analytics to improve efficiency, responsiveness, and customer service.

Although there are different perceptions about the concept of the digital supply chain, the dimensions of its measurement centered on the automation of traditional supply chain stages and processes. Rahamneh et al. (2023) reported that the main dimensions for measuring the digital supply chain are digital suppliers, digital manufacturing, and digital logistics.(1) Digital suppliers are supply chain partners that use digital technologies to communicate and interact with the rest of the supply chain. These suppliers use digital portals to determine the timing and quantity of orders, collaboration platforms to enhance interaction between partners, and predictive analytics to provide insights that contribute to improving strategic effectiveness (Sharma & Joshi, 2023). (2) Digital manufacturing is based on investing in machines and robots based on Industry 4.0 technologies in the manufacturing and packaging process. The most prominent technologies used in "smart manufacturing" include 3D printing, digital twinning, and the Internet of Things to obtain high-quality products at the lowest cost (Ivanov &Dolgui, 2021). (3) Digital logistics is the actual application of digital technologies in inventory management and transportation to and from storage locations. The most popular digital technologies in this field include GPS, blockchain and RFID tools used to improve the efficiency of logistics resources (Choudhury et al., 2021).

2.2 Sustainability

Over the years, scholars and authors have extensively discussed the concept of sustainability, each offering their perspective on the concept. According to the economic perspective, sustainability refers to the pursuit of environmental balance by ensuring that resource consumption remains within minimum limits and waste generation is within the Earth's carrying capacity (Mandpe et al., 2023). Dietz (2023) stated that sustainability from a sociological perspective involves enhancing the ability of individuals to live fulfilling lives by ensuring access to education, health care, economic opportunities and political freedoms. Triple Bottom Line (TBL), the popular concept of sustainability, defines sustainability as achieving economic prosperity, environmental care, and social justice simultaneously through the synergy between the 3Ps (people, planet, and profit) to create value across all dimensions (Loviscek, 2020).

The general concept of sustainability consists of three main dimensions. (1) The environmental dimension, which forms the heart of sustainability and aims to protect the ecosystem from the harmful environmental effects of humans. According to this dimension, achieving sustainability requires focusing on preserving biodiversity, reducing greenhouse gas emissions, and investing in renewable energy (Feroz et al., 2021). (2) The social dimension is based on achieving well-being for individuals and future generations. This dimension also includes a commitment to social responsibility and achieving social justice and inclusion through the provision of basic services to individuals to enhance their resilience, for example, education and healthcare (Govindan et al., 2021). (3) The economic dimension considers the link between the environmental and social aspects of sustainability through achieving economic prosperity within the minimum natural resources. This dimension includes policies to promote responsible production based on recycling, innovation and entrepreneurship to reach a green economy (Vardar, 2024).

2.3 Digital supply chain and sustainability

The digital supply chain is considered one of the main ways to enhance sustainability results, especially since most organizations' operations are based on providing raw materials, storing, and transporting their products to consumers. This positive impact on sustainability can be demonstrated by increasing organizational efficiency and responding quickly to changes in the turbulent business environment by adopting the innovation model (Dais et al., 2022). Sedky (2023) stated that integrating digital technologies, including process automation and predictive analytics, into traditional supply chain operations contributes to improving the use of resources and reducing waste in a way that reduces the harmful environmental impact.

Contemporary digital technologies play as enabling factors that help engage in sustainable activities, as emphasized by Pal (2023), as these technologies play an essential role in organizational learning and leadership support to adopt a more sustainable approach. Moreover, the digital supply chain is one of the contemporary trends to adopt a collaborative approach to the use of resources and transparent coordination between chain partners. This effective cooperation and communication contribute to reducing energy consumption and reducing greenhouse gas emissions by reducing travel time (Praveenadevi et al., 2023). On the other hand, it helps simplify logistical operations and increase social commitment to preserving depleted resources (Ning & Yao, 2023).

On the other hand, Nguyen et al. (2023) indicated that adopting a digital transformation approach, especially in supply chain activities, enhances the ability to prepare sustainability reports and transparently disclose the results of related regulatory indicators. Joshi and Sharma (2022) considered the digital supply chain to be an inevitable outcome of social and governmental pressures toward a sustainable global economy based on increased investment in renewable energy and ethically responsible resources. In general, investing in digital supply chains is appropriate to support the stability and sustainable growth of societies by harnessing the facilities of digitalization to improve the efficiency of operations and drive innovation. Accordingly, the model shown in Fig. 1 can be proposed to empirically verify the impact of the digital supply chain on sustainability.

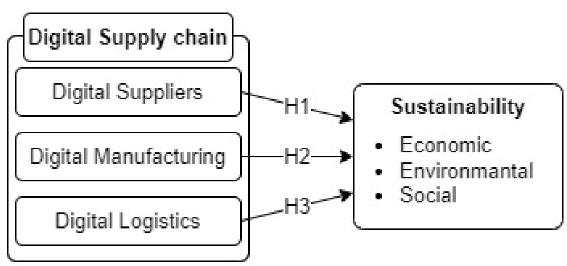

Fig. 1. Conceptual Framework

Depending on the theoretical discussion and the proposed research model, the hypotheses that are investigated in this research can be prepared as follows:

Hypothesis 1 (H1): Digital suppliers positively impact sustainability.

Hypothesis 2 (H2): Digital manufacturing positively impacts sustainability.

Hypothesis 3 (H3): Digital logistics positively impact sustainability.

3. Methodology

3.1 Research design

Investigating the impact of the digital supply chain on sustainability in pharmaceutical companies in Jordan requires a robust research design that enables the results to be generalized. A positivist design is considered appropriate in this case because of its ability to deal with quantitative data and verify the validity of hypotheses (Al-Ababneh, 2020). Furthermore, a cross-sectional approach was used in the data collection process. In contrast to the longitudinal approach, Maier et al. (2023) stated that the cross-sectional approach allows data to be collected from a research sample over a specific period in order to overcome research limitations.

3.2 Population and sample

The current research population consists of employees at senior and middle management levels in pharmaceutical companies in Jordan, particularly pharmaceutical manufacturing companies. According to the Pharmacists Syndicate and the Directorate of Companies Control, there are 15 companies in Jordan specializing in pharmaceutical industries [http://www.johealth.com/links.asp?category=172]. Therefore, the research includes all these companies to ensure diverse and unbiased viewpoints are obtained. However, the temporal and spatial limitations of the research made it difficult to implement a comprehensive survey. Hence, a purposive sample was used to collect primary data for the research from managers related to the supply chain of those companies, with a minimum of 200 respondents according to the recommendations of Ezeugwa et al. (2022).

To achieve the highest response rate, the research instrument was distributed to 270 managers in pharmaceutical manufacturing companies during the period from February 19 to March 28, 2024. The responses received via email were 237. A review of these responses revealed that they included 11 responses with a repeating pattern or with incomplete information that were removed from the final research sample. Accordingly, the final sample included 226 responses, representing 83.7% of the total sent, which is a high response rate and meets the requirements for sufficient sampling (Barber & Janson, 2022). Fig. 2 shows the demographic analysis of the final sample, including gender, age group, and qualifications variables.

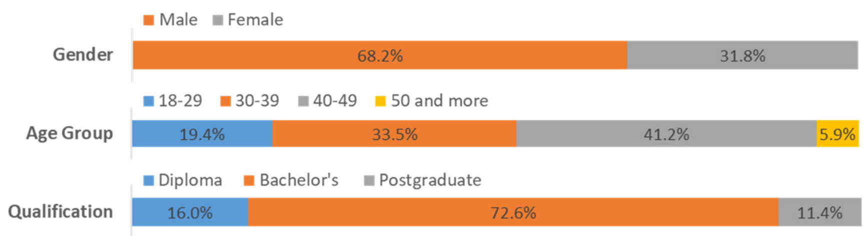

Fig. 2. Demographic profile of the sample

3.3 Measures

To investigate the impact of the digital supply chain on sustainability, we relied on quantitative data collected using a structured survey. This survey was designed after reviewing the relevant literature and translating it into Arabic through the back translation method. According to Klotz et al. (2023), this method aims to transform the survey items into a language that the target population understands while maintaining its accuracy and ability to measure the research variables objectively. Moreover, Google Forms were used in the emailing process for ease of communication and compatibility with environmental considerations. The survey initially included an informed consent form to emphasize voluntary participation and a mechanism for handling data confidentiality.

The survey included a section dedicated to demographic data and two sections measuring key research variables. In the sections that included items for the key variables, respondents were asked to rate the items according to a five-point Likert scale, with a minimum limit (1) strongly disagreed and an upper limit (5) strongly agreed.

The digital supply chain scale included 12 items borrowed from Rahamneh et al. (2023). Together, these items form three first-order constructs, including digital suppliers (4 items), digital manufacturing (4 items), and digital logistics (4 items). Similarly, 12 items were used to measure sustainability according to AL-Zyadat et al. (2022). These items were divided into three first-order constructs: economic dimension (4 items), environmental dimension (4 items), and social dimension (4 items).

3.4 Analytical methods

In this research, analytical techniques based on structural equation modeling (SEM) were employed, along with inferential statistics. Before proceeding with the analysis, the construct validity and reliability of the model were verified using confirmatory factor analysis (CFA). CFA aims to determine the degree of compatibility between the proposed theoretical model and the model based on observed data to enhance the possibility of generalizing the results (AlBrakat et al., 2023). Inferential statistics were based on means and standard deviations to evaluate the adoption degree of digital supply chain and sustainability in pharmaceutical manufacturing companies in Jordan. Furthermore, correlation coefficients were used to check multicollinearity between independent constructs. On the other hand, goodness of fit indicators were used to determine the extent to which the structural model can analyze the cause-and-effect relationship between the research variables (Alshura et al., 2023). In addition, path coefficients were extracted that show the order of the impact of digital supply chain constructs on sustainability.

4. Findings

4.1 Measurement model assessment

According to structural equation modeling (SEM), confirmatory factor analysis (CFA) is a proactive step to determine how well the model measures variables (Marsh et al., 2020). CFA is used to compare the theoretical model with the observed one through correlation indices between observed constructs (factors) and their latent constructs (Goretzko et al., 2024). The validation and reliability values of the measures for testing the impact of the digital supply chain on sustainability are presented in Table 1.

Table 1
Result of Validity and Reliability

Constructs	Items	Loadings	AVE	MSV	√AVE	CR
Digital Suppliers	**DS1:** The company uses digital technology to continually evaluate supplier performance against KPIs.	0.715	0.522	0.448	0.722	0.813
	DS2: The company digitally monitors the financial stability and regulatory compliance of its suppliers to avoid human bias and downtime risks.	0.637				
	DS3: The company is investing in digital tools to enhance cross-collaboration and predictive planning activities with suppliers.	0.758				
	DS4: Through digital platforms, the company integrates the efforts of suppliers whose goals align with its overall vision and prioritizes them in the evaluation process.	0.772				
Digital Manufacturing	**DM1:** The company invests in digital technology to create virtual representations and simulations of physical manufacturing processes.	0.739	0.547	0.493	0.739	0.828
	DM2: The company uses robots and sensors to evaluate the quality of the final product and identify potential defects.	0.725				
	DM3: The company applies virtual reality and augmented reality technologies in product design and development.	0.813				
	DM4: The company uses digital technologies to enhance production equipment connectivity, maintenance scheduling and early warning of faults.	0.674				
Digital Logistics	**DL1:** The company leverages digital technologies in warehouse automation to optimize space utilization and increase its capacity.	0.703	0.504	0.429	0.710	0.802
	DL2: The company applies digital technologies to optimize the route and track deliveries in real time.	0.614				
	DL3: The company uses digital logistics to predict and mitigate potential risks in the supply chain.	0.766				
	DL4: The company invests in digital technology to forecast customer demand and align production and inventory levels accordingly.	0.748				
Economic Dimension	**ECD1:** The company seeks to reduce the costs of purchasing natural materials in their raw form (used for the first time).	0.753	0.556	0.389	0.746	0.833
	ECD2: The company replaces traditional production and lighting machines with environmentally friendly machines to reduce energy costs.	0.795				
	ECD3: The company applies occupational safety measures to reduce financial fines resulting from work-related injuries.	0.682				
	ECD4: The company reduces the costs of recycling and investing waste through training courses for its employees.	0.748				
Environmental Dimension	**END1:** The company has taken urgent and appropriate measures to reduce harmful air emissions.	0.731	0.566	0.373	0.752	0.839
	END2: The company invests heavily in waste recycling and wastewater reclamation systems.	0.782				
	END3: The company follows international recommendations aimed at preventing the use of harmful and dangerous toxic materials.	0.719				
	END4: The company is making great efforts to reduce noise and environmental accidents harmful to the biological environment.	0.776				
Social Dimension	**SOD1:** The company pays great attention to engaging its employees with long-term and effective health care programs.	0.657	0.542	0.401	0.736	0.825
	SOD2: The company helps its employees find nearby accommodation suitable for a decent human life.	0.797				
	SOD3: The company provides convenient transportation for employees from the place of residence to the workplace.	0.724				
	SOD4: The company continuously seeks to improve the standard of living of its employees and achieve their well-being.	0.760				

The results of Table 1 demonstrate the values of the indicators extracted as a result of applying CFA. The results indicate high levels of correlation between the observed variables and the latent constructs, as the loadings ranged between 0.614 and 0.813, indicating that they exceeded the minimum of 0.50 (McNeish & Wolf, 2023). On the other hand, the amount of variance explained by the latent constructs was appropriate according to the average variance extracted (AVE) index, which was between 0.504 and 0.566. Baharum et al. (2023) stated that values of AVE exceeding the minimum threshold of 0.50 are an indication of the convergent validity of the model used.

Regarding discriminant validity, the results indicated that the values of maximum shared variance (MSV) were lower than the values of AVE, which calls for considering the latent constructs to express themselves according to what was reported by Lesia et al. (2024). This result was confirmed by the values of the square root of AVE that exceeded the correlation coefficients between the latent constructs. These indicators call for the model to be considered as meeting the conditions of discriminant validity (Cheung et al., 2023).

The results also included McDonald's Omega coefficients used to check composite reliability (CR). The results showed that these values were between 0.802 and 0.839, exceeding the minimum threshold mentioned by Steenkamp and Maydeu-Olivares (2023). Accordingly, the model for measuring the impact of the digital supply chain on sustainability was characterized, according to the results of the current research, with appropriate validity and reliability.

4.2 Descriptive statistics

The descriptive statistics in this research provide valuable insights into the characteristics of data related to components of digital supply chain and sustainability. Specifically, the mean, one of the measures of central tendency, enables the determination of the convergence degree of views on the research variable, while the standard deviation, one of the measures of dispersion, helps to visualize the map of the spread and disparity of views (Anderson et al., 2020). Moreover, correlation coefficients show the intensity and direction of the relationship between variables, along with checking for multicollinearity (Temizhan et al., 2022). Table 2 lists the results of the extracted descriptive statistics for the components of digital supply chain and sustainability.

Table 2
Mean, Standard Deviation, and correlation

Constructs	Mean	SD	1	2	3	4	5	6
1 Digital Suppliers	3.75	0.899	1					
2 Digital Manufacturing	3.61	0.915	0.441	1				
3 Digital Logistics	3.74	0.867	0.482	0.459	1			
4 Economic Dimension	3.51	0.925	0.624	0.598	0.627	1		
5 Environmental Dimension	3.64	0.881	0.611	0.652	0.691	0.650	1	
6 Social Dimension	3.72	0.903	0.637	0.553	0.566	0.681	0.608	1

It is clear from Table 2 that the descriptive statistics related to the variables vary. The digital supply chain variables were mostly at a high level, with digital suppliers (M= 3.75, SD= 0.899) ranked first, followed by digital logistics (M= 3.74, SD= 0.867). However, digital manufacturing (M= 3.61, SD= 0.915) was ranked third and last with a moderate level. On the other hand, the sustainability variables were at a moderate level, except for the social dimension (M= 3.72, SD= 0.903), which ranked first with a high level, while the environmental dimension (M= 3.64, SD= 0.881) ranked second and economic dimension (M= 3.51, SD= 0.925) ranked third, both at a moderate level. The results also indicated a moderate positive correlation between the variables, as the correlation coefficients between the variables of digital supply chain and sustainability ranged between 0.553 and 0.691. Moreover, the correlation coefficients between the digital supply chain variables were between 0.441 and 0.482, which confirms that they are free from multicollinearity as they did not exceed the threshold of 0.80 (Shrestha, 2020).

4.3 Structural model assessment

To determine the relationship between variables and verify hypotheses, structural equation modeling was used (SEM). This technique is considered pioneering in testing complex relationships between variables, as it allows researchers to compare theoretical models with experimental ones to draw realistic conclusions based on primary data (Thakkar, 2020). SEM involves two basic steps. The first is to extract goodness-of-fit indicators, as shown in Fig. 3, to evaluate the degree of fit of the observed data with the theoretical model. The second is to determine the relationship and test hypotheses by extracting the impact coefficients between the independent and dependent constructs of the research.

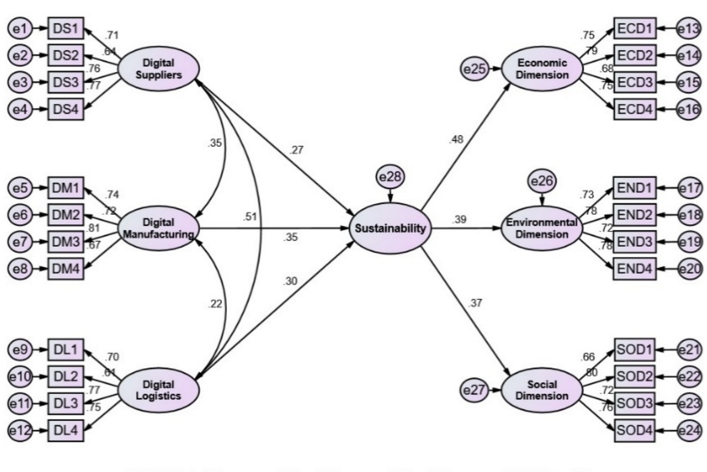

Fig. 3. Structural Model for the Impact of Digital Supply Chain on Sustainability

The results of Fig. 3 demonstrate that the parsimonious indicator measured by the chi-square ratio (CMIN/DF) was 2.473, which is less than the maximum threshold of 5 (Khairi et al., 2021). For incremental fit indices, in particular TLI and CFI, were 0.931 and.0.946, respectively. This result confirms that these indicators were appropriate as they exceeded the minimum of 0.90 (Garnier-Villarreal & Jorgensen, 2020). Furthermore, the absolute fit indicator using the root mean square error of approximation (RMSEA) was within acceptable limits, with the upper ceiling not exceeding 0.08 (Schuberth et al., 2023). Accordingly, the structural model used in the research was considered highly efficient and the results extracted for the path coefficients shown in Table 3 are reliable and generalizable.

Table 3
Result of path coefficients

			B	β	S.E.	t-value	P-value
Digital Suppliers	→	Sustainability	0.281	0.266	0.073	3.84	0.02
Digital Manufacturing	→	Sustainability	0.374	0.354	0.067	5.58	0.000
Digital Logistics	→	Sustainability	0.316	0.303	0.069	4.58	0.004

Table 3 reveals the results of the path coefficients used to identify the relationship between digital supply chain components and sustainability. The results confirmed the acceptance of all hypotheses that considered digital suppliers, digital manufacturing, and digital logistics to have a positive impact on sustainability. However, it indicates a difference in the effect size, as digital manufacturing ($B= 0.374$, $\beta= 0.354$, $t= 5.58$, $P< 0.001$) ranked first, followed by digital logistics ($B= 0.316$, $\beta= 0.303$, $t= 4.58$, $P< 0.01$), and then digital suppliers ($B= 0.281$, $\beta= 0.266$, $t= 3.84$, $P< 0.05$) ranked last.

5. Discussion

The research results indicate that adopting digital supply chain practices has emerged as a potential positive solution to address sustainability challenges in pharmaceutical companies in Jordan. Digital suppliers leverage emerging technologies and information systems to enhance engagement, streamline purchasing processes, and improve supply chain visibility. Pal (2023) emphasized that with the adoption of digital platforms for managing and collaborating with suppliers, organizations could achieve greater transparency, traceability and compliance with ethical sourcing standards. This collaboration contributes to reducing the risk of supply chain disruptions, ensuring product quality and safety, and promoting ethical business practices across the supplier network. In addition, digital suppliers can also facilitate the adoption of sustainable sourcing practices, such as sourcing raw materials from renewable sources or implementing fair labor practices, thus enhancing the environmental and social sustainability of supply chains as emphasized by Dais et al. (2022).

By digitizing manufacturing processes, for example, 3D printing and robotics, organizations can achieve greater efficiency, flexibility and quality control, leading to reduced waste, improved resource use and enhanced product innovation (Nguyen et al., 2023). Furthermore, digital manufacturing enables products to be customized to meet specific patient needs, optimize production schedules, and reduce time to market. This not only enhances the economic viability of pharmaceutical manufacturing in Jordan, but also contributes to environmental sustainability by reducing energy consumption, lowering emissions, and conserving resources. Furthermore, digital logistics includes the use of digital technologies such as RFID, GPS, and cloud computing to improve transportation, warehousing, and distribution processes in the supply chain. Ning and Yao (2023) noted that leveraging real-time data and analytics helps organizations improve delivery routes, reduce transit times, and improve inventory management, leading to lower carbon emissions, reduced fuel consumption, and enhanced operational efficiency.

6. Recommendations and Conclusion

Based on the current research results, several recommendations can be made to decision makers in pharmaceutical companies in Jordan. First, it is recommended that pharmaceutical companies in Jordan invest in capacity development and training programs to enhance employees' digital technology skills. This includes training them in the use of digital supply chain technologies, data analysis, and sustainability practices, to ensure they take full advantage of digital tools in promoting sustainability. Second, pharmaceutical companies in Jordan must collaborate with suppliers, customers, regulators and other stakeholders in order to advance sustainability goals. These companies should establish collaborative partnerships with stakeholders to jointly develop and implement sustainability initiatives, share best practices, and address common challenges. Third, appropriate investment in technology infrastructure is key to enabling digital transformation in the supply chain of pharmaceutical companies. This includes modernizing IT systems, adopting cloud platforms, implementing IoT devices, and ensuring data security and privacy to support the seamless integration of digital technologies into supply chain operations. Fourth, compliance with regulatory requirements and industry standards is essential to ensure ethical and responsible behavior at pharmaceutical companies. These companies should follow developments in legislation related to sustainability, supply chain transparency, and ethical sourcing practices, and proactively adjust their operations to fully comply with these regulations.

Overall, investing in the digital supply chain, including digital suppliers, digital manufacturing, and digital logistics, plays an important role in enhancing sustainability in pharmaceutical companies in Jordan. By using digital technologies to enhance transparency, efficiency and innovation in the supply chain, pharmaceutical companies can achieve greater environmental, social and economic sustainability. However, achieving the success of these initiatives requires cooperation, investment and commitment from all stakeholders, including pharmaceutical companies, suppliers, regulators and consumers. Therefore, we must work together and increase research to explore the full potential of digital supply chain management in promoting sustainability in the pharmaceutical industry in Jordan and beyond.

7. Limitations and Future Research Directions

Besides the importance of the results achieved by the research into the impact of the digital supply chain on sustainability in pharmaceutical companies in Jordan, it is not without some limitations that must be taken into account in future research. First, this study was applied in a specific context represented by pharmaceutical companies in Jordan, which may affect the possibility of generalizing the results to other industries or other regions. Future research could provide comparative studies based on different industries or regions which would help clarify the impact dynamics between variables when the context changes. Second, this research was based on a cross-sectional design that captures the impact of the digital supply chain and sustainability over a specific period. Therefore, it is difficult to track impact over time and change as new technologies emerge. Future research can address this limitation by applying longitudinal studies that contribute to identifying long-term trends and patterns of the causal relationship between the digital supply chain and sustainability.

Third, the research relied on self-reported quantitative data which may result in response bias and imprecision. Therefore, qualitative research methods can be applied in future studies such as interviews to provide deeper insights based on experiences and expertise on the application of digital supply chain activities and their implications for sustainability goals. Last but not least, the current research relied on an experimental measure specifically directed to employees at the upper and middle management levels of pharmaceutical companies, which may lead to errors in understanding and measurement. Therefore, future research could incorporate the perceptions of other stakeholders across the digital supply chain, such as suppliers, regulators, and consumers, to ensure a comprehensive understanding of all aspects of the digital supply chain that may lead to improved pharmaceutical sector sustainability.

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