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The Role of Digital Transformation on Sustainable Supply Chain Performance in The Manufacturing Sector of Pakistan

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A B S T R A C T

Purpose- The major objective of this research is to explore how digital transformation affects sustainable supply chain performance in Pakistan's manufacturing sector. Specifically, it examines the impact of digital collaboration, intelligence optimization, agility, and responsiveness, as well as end-to-end transparency across the entire supply chain for sustainability.

Study Design/Methodology/Approach - A quantitative research design combined with a deductive method was employed. A structured questionnaire was used to collect data from 125 respondents in Pakistan's manufacturing sector between May 2, 2024, and May 20, 2024. The survey utilized a five-point Likert scale, and statistical techniques such as regression analysis and Pearson's correlation coefficient were used to analyze the collected data.

Findings- The study found a strong relationship between digital transformation and sustainable supply chain performance. Key factors included digital collaboration, which improved communication and cooperation, and AI/ML-driven optimization, which enhanced demand planning, inventory control, and process efficiency. End-to-end transparency fostered trust and accountability across the supply chain. While agility positively influenced sustainable performance, other factors were not statistically significant, indicating potential additional influences.

Practical Implications- The findings suggest that manufacturing practitioners should adopt digital tools to improve their supply chain operations. Policymakers are encouraged to implement supportive policies and legislation to promote digitalization. The results imply that digital collaboration, intelligent optimization, and full transparency can significantly enhance sustainable supply chain performance, thereby contributing to social welfare, environmental sustainability, and economic growth.

Originality/Novelty - This study is original in its focus on the relationship between digital transformation and sustainable supply chain performance within the context of Pakistan's manufacturing sector. It highlights the importance of digital collaboration, AI-driven optimization, and transparency in achieving sustainability goals, offering new insights into the drivers of sustainable supply chain practices.

Keywords: Digital transformation, Sustainable supply performance, Digital collaboration (DC), Agility and Responsiveness, Intelligent optimization, End-to-End Transparency

1 | INTRODUCTION

Pakistan's manufacturing industry is about to undergo an enormous shift as it is going to prepare to adopt digital transformation and incorporate it into supply chain management procedures. This development has great potential to improve the performance of a sustainable supply chain, which is essential to contemporary manufacturing processes. In the Digital transformation context, the combined impact of supply chain diversity and digital transformation on resilience, Fu et al. (2020) emphasizes the significance of combining these effects. Gao et al. (2024) underscores the necessity of gaining a more profound comprehension of the correlation between sustainable performance and digital supply chain transformation. Furthermore, Liang et al. (2022) investigate the intricate connection between supply chain management and digital transformation in manufacturing companies and emphasize how supply chain features can help or impede digital transformation initiatives. (Joshi & Sharma, 2022) emphasize that while talking about the influence of Industry 4.0 technologies on supply chain digital transformation, it is important to take into account particular technical developments in the manufacturing sector.

The basis of Supply chain, economy, environment, and society is influenced by many critical variables, including digital collaboration, intelligent optimization, and end-to-end transparency, agility, and responsiveness. With the help of research, it is clear that the application of green supply chain management (GSCM) techniques improves economic and environmental performance leading to enhanced operational performance (Green Jr et al., 2012). Information sharing, supply chain visibility, collaboration, and agility are some of the factors that impact greatly the performance of a supply chain thereby resulting in greater returns and competitiveness (Baah et al., 2021). The COVID-19 pandemic has brought into sharp focus the need for strong and socially responsible supply networks capable of responding to global disruptions (Sajjad, 2021). Additionally, empirical research has shed light on several components related to sustainable supply chain performance which are linked with Blockchain adoption and digital transformation. Di Silvestre et al. (2020) said blockchain is a technology innovation experiencing widespread acceptance in manufacturing among other industries. Saqib and Zhang (2021) underline that sustenance can only be assured where there is visibility in the supply chain. Umar et al. (2022) adopt an approach using Green Supply Chain Management techniques to evaluate how Industry 4.0 affects economic and environmental performances whilst Saqib's study provides insights on potential impacts for Pakistan's manufacturing industry.

To comprehend digital transformation effects on sustainable supply chain performance during this time when Pakistan's manufacturing sector addresses these complexities, it becomes necessary to thoroughly analyze recent studies.

1.1 | Problem Statement

There is a noticeable Knowledge gap in terms of digital collaboration, agility and responsiveness, intelligent optimization, and end-to-end transparency as well as Combine impact on supply chain resilience and sustainable performance (Ning & Yao, 2023). Many manufacturing companies in Pakistan face challenges integrating digital technologies into their supply chains. This includes issues related to the adoption of new technologies, interoperability of systems, and alignment with existing processes (Kim et al., 2024). This transition has the potential to significantly affect how well networks for sourcing raw materials, components,

and final products perform over time. Similarly, however, most empirical research focuses on how businesses operating in this industry can enhance their sustainability performance through supply chain digitalization; several gaps exist regarding what is known about implications for sustainable performance of these firms' supply chain due to these digital transformation variables (Rehman Khan et al., 2022). There is often a lack of comprehensive data on how digital transformation directly impacts sustainable practices. Studies need to assess how digital tools influence environmental, social, and economic aspects of sustainability within supply chains.

This calls for an examination of the opportunities and challenges related to the integration of digital collaboration, agility and responsiveness, intelligent optimization, and End-to-End transparency at different levels of manufacturing processes from raw material procurement to finished product distribution within the Pakistani manufacturing supply chain, as well as possible applications of such technology in improving various link functions (Shatta, 2024).

Therefore, it is important to consider how specific characteristics of the Pakistani supply chain are affecting Industrial transformations driven by digitalization to sustainability. Also discussed are Industry 4.0 technologies to SCDT where emphasis is put on understanding its implications, especially on digital collaboration (Govindan et al., 2020). In addition, Pakistan's production sector cannot be overlooked without considering other factors such as transparency and agility among others, which serve as key determinants.

2 | LITERATURE REVIEW

Recently, the issue of improving the effectiveness, openness, and ecological friendliness of supply chain management using digital transformation has attracted much attention (Shatta, 2024). In Pakistan's manufacturing industry where supply chain management is crucial, understanding this role of creating sustainable performance needs to be emphasized.

2.1 | Sustainable Supply Chain Performance

Sustainable supply chain performance refers to the ability of a chain to serve customers with goods and services efficiently but in such a way that is environmentally aware, socially, and economically responsible. This means that every step of the supply chain from acquiring raw materials to disposing and recycling products must use sustainable approaches. Sustainable supply chain performance has several elements such as reduction in carbon emissions, waste minimization, assurance of fair labor standards, ethical procurement of materials, and community involvement among others (Govindan et al., 2020). When sustainability becomes a priority brand reputation gets enhanced, supply chain is more resilient and less risky while simultaneously enhancing environmental and societal well-being. Over the last ten years, there has been an observable shift from traditional methods to sustainability-driven approaches in managing the supply chain (Narimissa et al., 2020). It is necessary to identify additional dimensions or characteristics of sustainability beyond the economic, environmental, and social variables to measure sustainable supply chain performance effectively. Organizational theories that explain drivers have an impact on research on sustainable supply chain management.

2.2 | Social Performance in Sustainable Supply Chain

The relationship between supply chain management and social performance has received a lot of attention already. Yawar and Seuring (2017) present the idea of corporate social performance (CSP) in the context of

supply chains, stressing the significance of tackling social issues, acting responsibly, and being aware of the results down the supply chain. In addition to tackling challenges related to social, Croom et al. (2018) said that socially responsible supply chain management strategies can enhance the efficiency of the operation and bring positive and social impact.

Nath and Agrawal (2020) explain that implementing social sustainability in the supply chain. Necessitates the use of methodical processes, like internal policy drafting and adept supplier relationship management. In addition to that, Hussain et al. (2019) stress that because social sustainability is now becoming a more important concern, supply chain managers should identify and minimize their social consequences on communities. Furthermore, by performing an empirical examination into the effects of green warehousing, ethics, social values, and logistics optimization on supply chain management, Agyabeng-Mensah et al. (2021) show the relationship between social values and sustainability results. Furthermore, by conducting an empirical investigation into the effects of green warehousing, ethics, social values, and logistics optimization on supply chain sustainability and economic performance.

2.3 | Economic Performance in Sustainable Supply Chain

A vital component of the sustainability and success of an organization is its economic performance. Numerous studies have looked into the connection between numerous variables and economic success in a range of industries. Giralt Escobar et al. (2017), for instance, stressed how important it is to incorporate environmental factors into port management to enhance economic performance. They illustrated how improved environmental performance may result in lower expenses and more involvement from stakeholders, which eventually benefits businesses financially.

Wagner (2010) also covered the beneficial relationship between business sustainability performance and economic performance. According to the study, a firm's economic success can benefit from its social and environmental performance. Furthermore, Liu et al. (2021) emphasized the significance of striking a balance between economic and environmental performance in sectors like iron and steel. To optimize overall enterprise performance, they suggested adopting environmental protection practices.

2.4 | Environmental Performance in Sustainable Supply Chain

Environmental performance is one of the significant factors influencing financial outcomes and corporate success. Much research has indicated that environmental performance significantly impacts corporate performance; this result is concluded by both static and dynamic panel data (Elsayed & Paton, 2005). This emphasizes how necessary it is to take the environment into account when evaluating a firm's overall success. Even if better environmental performance can increase business success, the policy of environmental regimes may also have a negative impact on business performance, highlighting the complex link between environmental regulations and economic outcomes (Lanoie et al., 2011). Furthermore, a study on the topic (Yurdakul & Kazan, 2020) found that eco-innovation has a positive effect on cost reduction, resource conservation, pollution avoidance, and recycling. All of these factors directly affect economic performance.

2.5 | Digital Transformation

The fast-growing digital economies have emphasized the importance of digital transformation in enabling firms to sustainably compete with rapidly changing markets. Nevertheless, it is important to understand that outcomes of these disruptive shifts go beyond individual companies and they stretch into environmental,

societal, and institutional domains. As a result, numerous new studies on various aspects of the literature have been published in the past few decades (Kraus et al., 2021). Digital Business Transformation is at the forefront of remaking industries by breaking down barriers between people, businesses, and technology which has ushered in an innovation wave in products, services, and operational efficiencies. Therefore, this paradigm shift demonstrates why organizations must completely embrace digital transformation as an essential tactic for thriving during the era of digitization.

2.6 | Digital Transformation in the Manufacturing Sector

Digital Transformation in manufacturing refers to the complete review of industrial processes with digital tools to make them smooth, and productive and encourage innovation within the entire production supply chain. This disruptive route involves multiple technological advancements and operational changes which seek to generate major shifts within conventional industrial practices. Research on digital transformation in manufacturing has exploded thus highlighting its growing importance and impact. Several studies show how digital technologies influence different aspects of manufacturing such as sustainable development, green initiatives, low-carbon development, and technological innovation among others. Müller et al. (2018) point out why there is a need to understand the dynamics surrounding Industry 4.0 technology adoption in the manufacturing sector. Ren et al. (2023); and Lyu et al. (2023) discuss how digital transformation enables green and low-carbon transitions within the manufacturing industry through technology innovation and structural optimization.

2.7 | Research Models and Hypothesis Development

The association between digital transformation and sustainable supply chain performance shows that digital technology is a critical enabler of sustainability within diverse organizational processes across companies. Modern technologies enabled by the use of cutting-edge technologies and digital solutions can enable businesses to achieve better results in terms of sustainability through effectiveness in resource allocation, optimizing procedures, and enhancing transparency and traceability throughout the supply chain. This win-win relationship has gained considerable attention in current literature that reflects the evolving debate about digitalization versus sustainability.

A study conducted by Lerman et al. (2022) reveals that digital transformation greatly influences the environmental performance of their supply chain. It stresses the importance of digital transformation in sustainable supply chain management. It also demonstrates that there is a need for the aforementioned process to take place digitally, to enable sustainability in supply chain management.

2.8 | Digital Collaboration

There have been many studies on the association between supply chain performance and digital collaboration. Supply chain cooperation enhances collaborative advantage leading to better company performance according to Cao and Zhang (2011) findings. Business partners achieve higher levels of performance as well as synergy through this kind of cooperative advantage. Besides that, Zhou & Wang (2021) showed how they were positively impacted by digitalization: Supply Chain Flexibility Sustainable Performance Collaborative Knowledge Generation.

Digital technology adoption boosts communication within the firm regarding sourcing, production, and distribution activities, thereby improving supply chain performance (Srivastava et al., 2024). Additionally, Li et

al. (2023) who showed that while cooperation promotes resilience and robustness, digitization directly increases supply chain resilience confirmed these findings. Similarly, Zhou et al. (2023) pointed out that customer collaboration mediates the relationship between digitalization and financial/service performance in logistics firms. Furthermore, sharing data has been shown to improve supply chain performance, visibility, agility, and collaboration (Baah et al., 2021). This highlights the role of information sharing in enhancing cooperation and efficiency in the supply chain as well.

2.9 | Agility and Responsiveness

The key skills of agility and responsiveness are critical to the overall performance of the supply chain. Responsiveness, on the other hand, refers to how quickly or flexibly a company responds to customer needs and market changes; on the other side; agility refers to the ability of a supply chain to respond quickly and effectively to the changes and uncertainties it encounters. The interaction between responsiveness to agility and supply chain performance has received much attention from researchers. The literature reviewed by Gligor and Holcomb (2012) on logistics and supply chain agility emphasized the importance of agility in achieving supply chain performance. In addition, information sharing has been highlighted as an important factor in ensuring better supply chain visibility, collaboration, flexibility, and ultimately supply chain efficiency (Baah et al., 2021).

2.10 | Intelligent Optimization

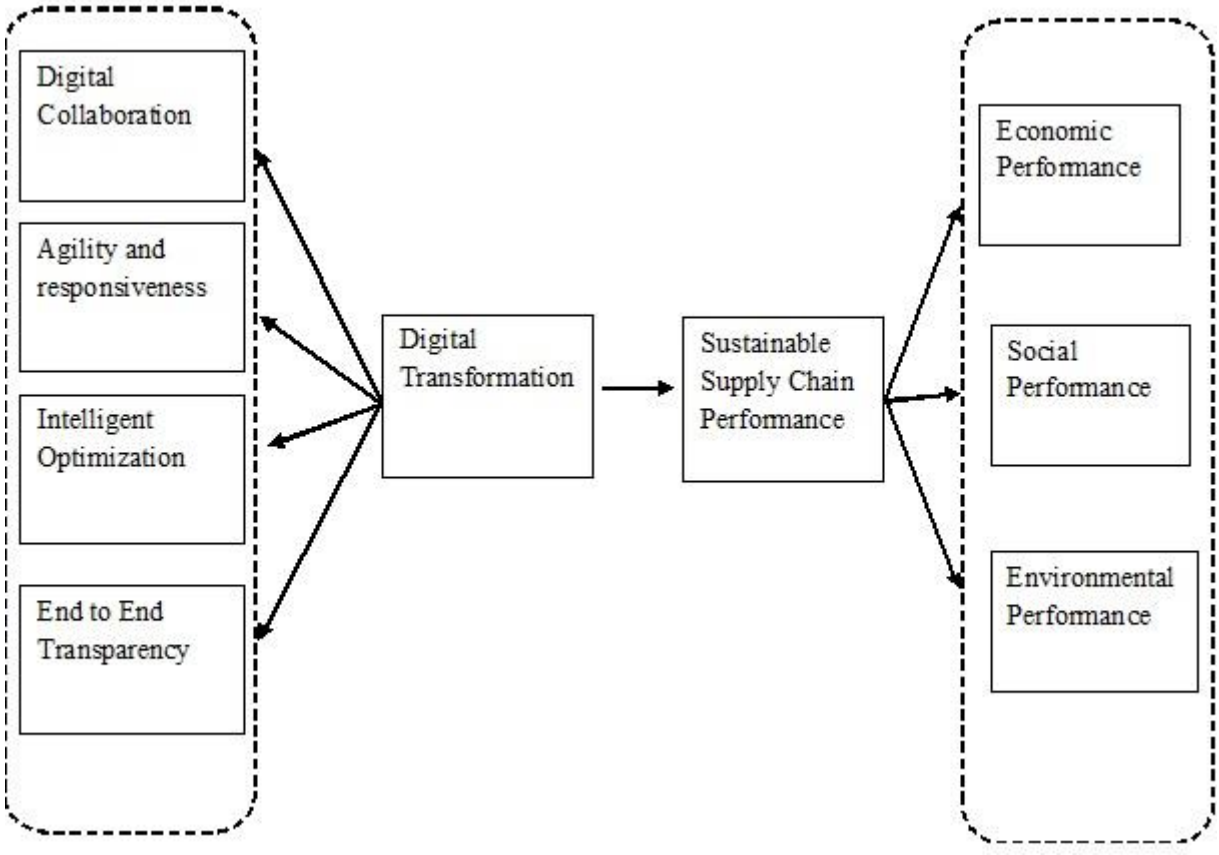
Intelligent optimization is one way to enhance this along with other innovative technologies such as AI and machine learning as hinted by Mohsen (2023). Artificial intelligence can be used to identify inefficiencies within a company's operations hence helping them estimate demand much better, improve their logistic systems additionally increase the efficiency of data analysis (Mostaghel et al., 2019). According to Mostaghel et al. (2019), the quality of these services depends on how intelligent your system is in matching its supplier capability with what customers desire most so that it becomes easier to make innovations. Moreover, Fatorachian and Kazemi (2021) also pointed out that resilience together with agility throughout the whole value chain is essential for better performance through facilitating efficient risk management.

2.11 | End-to-End Transparency

There has been a lot of talk recently about how transparency can affect supply chain performance. The principle of End-to-End transparency is that you can see the network of business enterprises involved in the production/supply chain from edge to edge. Several studies have been conducted on transparency and its impact on supply chain performance. Morgan et al. (2018) developed a measure of supplier visibility based on concepts such as supply chain visibility and traceability, which reflects the importance of transparency in modern supply chain management thinking. Discussing the role of transparency in sustainability initiatives, Kashmanian (2017) explored elements that companies can use to improve supply chain transparency. Sim et al. (2022) also touched upon this subject when they talked about how blockchain technology is used to improve traceability in the pharmaceutical supply chain from source to patient.

Figure 1

Conceptual Model



3 | METHODOLOGY & DESIGN

3.1 | Population & Sample

The current study is based on a quantitative research design to analyze the role of digital transformation on the performance of sustainable supply chains in Pakistan's manufacturing industry.

The primary research data was collected using a questionnaire. The purpose of the study was to collect the opinions of participants who are currently working in different sectors of manufacturing. A total sample size of 125 participants was selected. To increase the reach of the survey various platforms were selected. The survey was collected through Google form to get maximum response. The survey is shared through several social media sites, such as WhatsApp, LinkedIn, and reference-based Professional.

The questionnaire was designed using a five-point Likert scale. To guarantee timely and pertinent data acquisition, the data-collecting process was conducted over a predetermined period. This time frame was selected to provide respondents enough time to participate while guaranteeing that the data gathered was up-to-date and representative of current viewpoints in the sector. All data was collected on Google form, after gathering the data, statistical analysis, including descriptive analyses, reliability tests, regression analyses, and correlation analysis, was carried out through SPSS software.

4 | RESULTS and ANALYSIS

Table 1

Reliability (Cronbach's Alpha)

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.890	.892	5

A measure of internal consistency reliability called Cronbach's Alpha evaluates how closely linked a collection of objects is to one another. It is frequently used to assess the validity of scales or questionnaires in the domains of psychology, education, and other subjects. Values above 0.7 are generally regarded as satisfactory. In our measurement, it is 0.890, indicating a good degree of internal consistency between the scale's items.

Table 2

Descriptive Statistics

	N	Mean		Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic	Std. Error
DC	125	3.51	0.08	0.88	-0.464	0.217	-0.074	0.431
AG	125	3.5	0.07	0.73	-0.496	0.217	0.993	0.431
IO	125	3.57	0.07	0.79	-1.029	0.217	1.617	0.431
EE	125	3.46	0.07	0.75	-0.343	0.217	0.482	0.431
SSCP	125	3.52	0.06	0.72	-0.793	0.217	0.991	0.431

Important statistics are shown for each variable (DC, AG, IO, EE, and SSCP) in the descriptive findings. The views of respondents towards various conceptions are revealed by these measurements. Prominently, the average ratings for DC, AG, IO, EE, and SSCP are approximately 3.5, indicating a moderate degree of concurrence or discord. Standard deviations, which show consistency in responses, range from 0.06 to 0.08 and show relatively low variability around the mean values. Within each construct, the distribution shapes and patterns are further shown by the values of skewness and kurtosis. The distributions of DC, AG, and SSCP show a modest positive skewness, whereas the distribution of IO is the most positively skewed, indicating a more prominent peak towards lower scores. On the other hand, EE has the lowest kurtosis and skewness, indicating a distribution that is most similar to normal. These results provide complex insights.

Table 3

Regression Model Summary

Model		R Square	Adjusted R Square	Std. Error of the Estimate
1	817[a]	.668	.657	0.421

The correlation coefficient (0.817) shows that the dependent variable (sustainable supply chain performance) and the predictors (digital collaboration (DC), agility and responsiveness (AG), intelligent optimization (IO), and end-to-end transparency (EE)) have a strong positive association. With an R square value of 0.668, the model accounts for roughly 66.8% of the variance in SSCP. This suggests a suitable match. The number of predictors in the model is taken into consideration by the modified R square (0.657), which verifies that the model explains approximately 65.7% of the variance in SSCP. The average separation between the observed values and the regression line is indicated by the standard error (0.4214). A more favorable fit is indicated by a lower value.

Table 4

ANOVA Results

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	42.536	4	10.634	59.884	<.001[b]
	Residual	21.132	119	0.178		
	Total	63.668	123			

a. Dependent Variable: SSCP
b. Predictors: (Constant), EE, DC, AG, IO

The variance described by the model is shown by the sum of squares resulting from the regression (42.536). This high score indicates that the predictors account for a significant portion of the variability in SSCP. The variation not described by the model is indicated by the sum of squares of the residuals (21.132). A well-fitting model is shown by a lower value as compared to the regression sum of squares. The entire variability in the SSCP data is represented by the total sum of squares (63.668). By dividing the sum of squares by the degrees of freedom (df), one can find the mean square. The regression's mean square (10.634) shows how much of the mean variation each predictor explains. The regression model is very significant, as evidenced by the F value (59.884) at the significance level ($p < .001$). This indicates that a sizable amount of the variance in SSCP is explained by the Predictor factors taken together.

Table 4

Coefficient

Variable		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	0.489	0.21		2.328	0.022
	DC	0.314	0.058	0.383	5.402	<.001
	AG	0.045	0.076	0.045	0.589	0.557
	IO	0.251	0.073	0.277	3.457	<.001
	EE	0.253	0.068	0.264	3.74	<.001

a. Dependent Variable: SSCP

The findings of the regression analysis are shown in the coefficient table. SSCP and digital collaboration have a strong and favorable association. Keeping all other variables equal, the unstandardized coefficient of 0.314 shows that SSCP rises by 0.314 units for every unit increase in Digital Collaboration. According to the significance threshold (< 0.001) and the high t-value, there is statistical significance in this association. Digital Collaboration is a highly significant predictor of SSCP, as indicated by the standardized coefficient (Beta) of 0. 383. The association between SSCP and responsiveness and agility is good but not statistically significant. A slight positive link is suggested by the unstandardized coefficient of 0.045, but the high p-value (0.557) suggests that this impact is not statistically significant. This suggests that the study's measurements of responsiveness and agility had little bearing on SSCP. Here is a significant and positive correlation between SSCP and Intelligent Optimization. Keeping all other variables equal, the unstandardized coefficient of 0.251 shows that SSCP rises by 0.251 units for every unit increase in Intelligent Optimization. The statistical significance of this link is confirmed by the t-value and significance level (< 0.001). According to the standardized coefficient (Beta) of 0.277, SSCP can be strongly predicted by Intelligent Optimization. Additionally, there is a strong and positive correlation between SSCP and End-to-End Transparency. With all other variables held constant, the unstandardized coefficient of 0.253 shows that for every unit increase in End-to-End Transparency, SSCP increases by 0.253 units. The statistical significance of this link is indicated by the high t-value and significance level (< 0.001). When the Beta value of 0.264 is converted to a standardized coefficient, it shows that full transparency is a significant determinant.

In general terms, positive and statistically significant independent variables about Sustainable Supply Chain Performance (SSCP) include Digital Collaboration (DC), Intelligent Optimization (IO), and End-to-End Transparency (EE). That suggests that higher performance in sustainable supply chain operations will most likely be achieved through improvement within this domain. On the other hand, although Agility and Responsiveness (AG) has a positive correlation with SSCP, it was not significantly proven. It means more variables or different agility and responsiveness assessments may be needed to fully understand their influence on SSCP.

Table 5

Correlations

		DC	AG	IO	EE	SSCP
DC	Pearson Correlation	1	.559**	.628**	.515**	.718**
	Sig. (2-tailed)		0	0	0	0
AG	Pearson Correlation	.559**	1	.667**	.601**	.602**
	Sig. (2-tailed)	0		0	0	0
IO	Pearson Correlation	.628**	.667**	1	.588**	.702**
	Sig. (2-tailed)	0	0		0	0
EE	Pearson Correlation	.515**	.601**	.588**	1	.651**
	Sig. (2-tailed)	0	0	0		0
SSCP	Pearson Correlation	.718**	.602**	.702**	.651**	1
	Sig. (2-tailed)	0	0	0	0	

**. Correlation is significant at the 0.01 level (2-tailed).

This study's results display how sustainable supply chain performance (SSCP) in the industrial sector of Pakistan is profoundly affected by digitalization. DC, IO, and EE improvements are projected to boost the sustainability of the supply chain as suggested by the regression study findings that indicate that these three domains have significant positive linkages with SSCP. Of these three, Digital Collaboration has a greater influence indicating that enhancing SSCP through digital channels can be boosted through joint efforts. The smartest way of optimizing processes and keeping transparency alive across all levels within any organization is via intelligent optimization and end-to-end transparency respectively, which significantly affect SSCC. Although there is a positive correlation between Agility Responsiveness and SSCP, this relationship is not statistically significant suggesting that whilst agility matters, its direct influence on SSCP might not be as strong or may require additional measurements to be relevant. These results are further supported by correlation analysis showing strong positive connections between each independent variable and SSCP where DC has the highest correlation. These findings highlight the importance of having an all-encompassing plan for digital transformation within manufacturing to enhance sustainable supply chain performance.

5 | CONCLUSION

A study was conducted in the manufacturing sector of Pakistan to examine the relationship between digital transformation and Sustainable Supply Chain Performance (SSCP), showcasing how this study strengthens the hypothesis that "Digital transformation and sustainable supply chain performance have a significant and positive relationship". Digital collaboration (DC), agility and responsiveness (AG), intelligent optimization (IO), and end-to-end transparency (EE) are some of those aspects of digital transformation that positively influence SSCP. An analysis of these statistics showed similar results.

Given the significant regression coefficient together with its strong positive correlation, digital collaboration (DC) should be regarded as a fundamental part of SSCP. This implies that Pakistani manufacturers perform more sustainably when they adopt cutting-edge digital tools in coordinating supply chain partners through improved communication. By allowing collaborative problem-solving and a free flow of information, it has been observed that the use of digital technologies will improve sustainability performance by making the supply chain more responsive and efficient.

Moreover, its high regression coefficient (0.702) and positive correlation imply that it is an important variable in improving SSCPS. Intelligent optimization refers to the application of advanced analytics, AI, machine learning, or other similar techniques in optimizing supply chain processes. Thus, this study concludes that firms can better anticipate demand for their products and services while also reducing waste and enhancing sustainability through these strategies. This way, they ensure that their operations align with emerging needs by making data-driven decisions two fundamental principles of a sustainable supply chain system.

Another important component of SSCP is End-to-End Transparency (EE). The large regression coefficient coupled with a positive correlation indicates that increased supply chain transparency enhances sustainability performance (0.651). It means that when there is increased transparency in supply chain operations, monitoring procedures become easier thus reducing chances of mistakes, inefficiencies, and unethical actions occurring within an organization's policies or practices relating specifically to ethical implications to corporate social responsibility which are very important in today's business environment. According to regression analysis, though there is a positive correlation between Agility and Responsiveness (AG) and SSCP, this link however is not statistically significant. Even though it has less of an effect as was seen in the examined variables, agility remains important given the positive correlation of 0.602. Maintaining a healthy supply chain requires the ability to respond quickly and nimbly in the face of unforeseen disruptions and changes in the market.

As such, this research supports our hypothesis that digital transformation greatly enhances the performance of sustainable supply chains. With an adjusted R-square value at .657 in the regression model, which is high thus indicating that independent variables explain a considerable amount of variance in SSCP suggesting that our model is robust. Additionally, significant F-change value also provided further support for the explanatory power of these models thereby underscoring how crucial digital transformation programs are when it comes to promoting sustainability within the supply chain. Evidence from this research shows that there is a strong relationship between digital transformation and sustainable supply chain performance. By adopting digitization, manufacturers in Pakistan can develop more robust and sustainable industries that bring enormous benefits beyond efficiency gains derived from integrating ICTs into production processes mainly for sustainability as well.

5.1 | Limitation and Future Research Directions

The research has some limitations despite making insightful conclusions on the topic. The study only concentrated on Pakistan's manufacturing industry; thus, the results cannot be generalized to other parts of the economy or regions. In addition, there are particular challenges and trends specific to some sectors and localities that may affect how digital transformation has an impact on sustainable supply chains.

Consequently, future investigations should explore a wider range of geographical areas and sectors to confirm these findings. Additionally, as far as the sample size is concerned, this study was conducted with only 125 respondents; hence, it gives only one point in time without considering any upcoming developments or changes in digital transformation approaches. To understand how digital transformation initiatives have evolved and their long-term effects on the performance of sustainable supply chains, more sample size and longitudinal studies are needed. Lastly, this study identifies key variables that influence sustainable supply chain performance including technological factors such as blockchain, AI, and IOT or processes by which

digital transformation influences sustainability. These results could be better understood through mixed methodological approaches or qualitative research that delves into the strategies and methods used to achieve them.

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