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Impact of Supply Chain Digitalization on Supply Chain Performance: A Mediated Moderation Model

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Abstract
This study investigates the impact of supply chain digitalization (SCD) on performance within Pakistan's sugar industry, adopting a mediated moderation model to analyze the roles of resilience capabilities and risk management. Despite growing global emphasis on digital transformation, a significant research gap exists in understanding how these technologies influence supply chain dynamics in developing economies, particularly in agro-industrial sectors facing infrastructural and institutional challenges. Using a quantitative research design, data were collected from 400 supply chain (SC) professionals across seven sugar mills in Khyber Pakhtunkhwa, Pakistan, through structured questionnaires. The study employed regression analysis and Hayes' PROCESS macro to test the hypothesized relationships. Findings suggested that SCD significantly enhances performance reducing operational costs and improving efficiency. Supply chain resilience (SCR) capabilities partially mediate this relationship confirming that digital tools bolster performance by strengthening risk anticipation and recovery. Supply Chain Risk Management (SCRM) acts as a critical moderator, amplifying digitalization's benefits. Firms with mature risk frameworks derive greater supply chain performance (SCP) gains from digital investments. The study contributes to theory by integrating dynamic capabilities and contingency perspectives, demonstrating that digitalization's impact is context-dependent. Practical implications highlight the need for Pakistani sugar mills to adopt integrated strategies combining technology, workforce up skilling, and risk mitigation. In conclusion, while digital transformation drives competitiveness, its full potential is unlocked only when paired with resilience-building and proactive risk management. Future research should explore longitudinal effects and sector-wide scalability of these findings. This study provides a roadmap for agro-industries in developing economies to navigate digital disruption while addressing systemic vulnerabilities.

Keywords: *Supply chain digitalization, resilience capabilities, risk management, sugar industry, Pakistan, mediated moderation model.*

Introduction
Over the last ten years, the digital economy has altered supply chain management (SCM), incorporating novel technologies, including blockchain, IoT, and AI, which transform the conventional linear SC into vibrant

ecosystems(Rashid et al., 2024). Digitalization helps boost SCP in a significant manner as it helps in tackling such an issue as complexity, uncertainty, and lacks of agility in operations, latency, or demand forecasting accuracy(Zhou et al., 2025). Although it has some advantages, such as quicker recovery and greater resilience in times of disruption, companies have to manage issues such as cybersecurity threats and skills shortages in technology adoption(Siddiqui et al., 2025). The SCRrequirement has taken center stage with new frameworks suggesting the incorporation of SCRM instruments and digital technologies to develop so-called cognitive supply chains which autonomously counteract risks(Harju et al., 2023). Consistent research highlights the moderating effect of resilience capabilities in utilizing digital investments to achieve performance improvement and the need to conduct additional research to build a resilient SCR strategy(Shi et al., 2023).

Ahmadi et al. (2025)research confirms that SC survivability mediates the influence of SCD on the visibility and performance in the Turkish industrial sector. They also focus on the analysis of different skills and resources to increase SCR and flexibility and propose that future studies should use the identical analytical framework on management abilities. The theoretical framework by Jum'a et al. (2025)relies on the dynamic capacity theory, emphasizing the importance of refocusing on more than resilience and adopting the capabilities of the SC, such as sustainability. Harju et al. (2023)discuss the potential to reduce uncertainty and enhance the SCRMwith the help of digitalization in procurement. Taken together, these studies indicate that there exist major gaps in research on agility and survivability in supply chains and that the further development of the interaction between digitalization and supply chain capabilities and the influence of risk factors on sustainable supply chain operations should be further researched.

The impact of Covid-19 increased the acceleration of SCD, shedding light on the possible consequences of SCM and organizational resilience. Technologies such as blockchain and artificial intelligence support digital changes that enhance efficiency and quality of the products(Saddique et al., 2023). The study highlights that empirical research should be conducted to confirm the benefits of digital technologies in improving the resilience of the supply chain, especially in a complicated setting such as the Khyber Pakhtunkhwa sugar mills industry. The paper delves into the mediating role of SCRM and skills in the relationship between digitization and performance in order to give an insight into the enhancement of supply chain efforts in the digital era(Abourokbah et al., 2023). This research paper deals with the digitalization of the sugar industry in Pakistan and the study adds to the research in the sphere of the academic, industry, and policymaking by concentrating on the efficiency of the supply chain of the sector(Kumar et al., 2023). The sugar industry, a sector that sustains 1.5 million livelihoods and 0.6% GDP, is a special case of digitalization in Khyber Pakhtunkhwa(Rehman et al., 2025). The study provides evidence-based policies on incentives and frameworks of digitization and applies them to the context of Pakistan, where such problems as lack of energy or access to the Internet remains. It outlines the significance of the existence of public-private partnerships in reducing logistical and cyber risks. These findings offer an industry practitioner with a roadmap to pursue cost-effective digital tools, focus on such technologies as on IoT and blockchain, and enhance the workforce training and supply chain design. Besides, the paper suggests the notion of frugality digitalization to resource-limited conditions and stresses sustainable growth with the help of digital solutions(Das et al., 2024). It has international applicability to other third world countries that have the same issues of inadequate infrastructure and resources and can be used in updating supply chains in the Global South.

Literature Review

Supply Chain Performance (SCP)

SCP is one of the critical research topics as it is directly correlated with the competitiveness of the organizations in terms of increased customer satisfaction, minimized costs and financial gain(Salamah et al., 2023). The performance measures no longer focus on the conventional cost based measures, but adopt responsiveness and sustainability measures. Balanced scorecard method is taking off in the integration of holistic performance elements(Siddiqui et al., 2025). The initiatives of digital transformation are relatively promising in terms of increasing performance measures, whereas the integration of the supply chain has a positive correlation with performance outcomes, especially in fluctuating environmental uncertainties(Ngo et al., 2024). The long term competitiveness and increased profitability have gained links with sustainability practices. Also, blockchain and AI can be used to enhance traceability and inventory management with the help of digital technologies(Pant et al., 2024). The ability to respond to disruption and improve flexibility depends on the risk management skills and developing human capital. The culture and principles of the organizational environment also have an effect on performance outcomes, and the measurement systems will have to evolve under the influence of the market complexities and the elements of the context that require the application of the new metrics to stay relevant(Tan et al., 2023).

Supply Chain Digitalization (SCD)

Contemporary companies need to have supply chain digitalization to be more resilient and responsive to technologies like blockchain, IoT, and AI(Salamah et al., 2023). Supply chains that are digitally transformed offer half the response time of disruption and a fifth of the operational expenses(Zhou et al., 2025). Blockchain enhances transparency and decreases fraud, which is supported by the fact that pharmaceutical counterfeiting has reduced by 35% and that companies such as Walmart have made major progress in traceability(Perano et al., 2023). IoT has increased the visibility, which is projected to reach 101.3 billion by the year 2027 to minimize spoilage to manage the efficiency of the fleet(Deepu & Ravi, 2023). The use of AI in supply chain is increasing with demand forecasting accuracy increasing 40-60 times, although bias concerns. Supply chain operations are based on the cloud that 89 percent of enterprises use, but the problem of data sovereignty is why hybrid solutions are used(Aamer et al., 2023). The digital transformations have the potential to dramatically enhance the resilience of the supply chain, but 62% of the initiatives fail, which is often because of organizational resistance(Al Tera et al., 2024). The future is marked with the emerging technologies such as digital twins and autonomous delivery, which emphasize the significance of critical technology implementation in the process of success(Wei et al., 2025).

Supply Chain Resilience (SCR) Capabilities

Resilience capabilities in the supply chain have become necessary in the operational continuity in the wake of global disruption(Dubey et al., 2023). This ability to counteract, react and recuperate any disturbance has been defined as the ability to prepare, respond and recuperate and hence the concept has not been focusing on recovery but anticipation and adapting(Shishodia et al., 2023). The main dimensions of resilience are the absorptive capacity, the adaptive capacity, and the restorative capacity, and it has been empirically demonstrated that resilient firms are more effective in managing crises, such as having fewer disruptions and recovering more quickly(Chowdhury et al., 2024). The role of digital technologies such as AI and blockchain is crucial, as they improve the visibility of the situation and the timeliness of reaction, yet organizational capacity is also important(Stadtfeld & Gruchmann, 2024). Also, the resilience capabilities are regarded as useful organizational assets that may result in competitive advantage, although there is controversy over the trade-offs between the resilience investments and competitive cost structures(Han & Um, 2024). New studies are evaluating the connection between sustainability and resilience with noting the intricacies of balancing the two(Faruquee et al., 2024). Moreover, the resilience measurement is evolving, with quantitative measures being used to measure preparedness and recovery, and the field is in its development with new studies in different settings(Kähkönen et al., 2023).

Supply Chain Risk Management (SCRM)

SCRM is a vital strategic competence of resilience and competitive edge in an interdependent globalized economy. In the academic world, SCRM is always discussed as a workflow that involves the risks identification, evaluation, mitigation and monitoring(Rashid et al., 2024). A typology of risks is highlighted in research, and these risks are operational (e.g., failure of suppliers), financial, or disruptive (e.g., natural disasters or geopolitical upheaval)(Qiao & Zhao, 2023b). One of the most common themes of the modern discourse is the change between reactive practices to proactive resilience-building practices which entails acquiring the ability to be agile, redundant and flexible to take and recover unexpected shocks(Ngo et al., 2024). Moreover, researchers emphasize the importance of supply chain visibility and the joint risk management(Zhou et al., 2025). The weaknesses that are described are the lack of information sharing and poor relationships. Therefore, the research suggests more transparency enabled by digital technologies and more reliable and trustworthy collaboration to enable collective risk evaluation and reaction(Shahadat et al., 2023). The dynamic nature of international networks coupled with the emergence of new dilemmas of climate change and cyber-threats, highlights the need to have integrated and end-to-end SCRM solutions that are incorporated into the overall corporate strategy(Ahmadi et al., 2025).

Hypothesis Development

Relationship between Supply Chain Digitalization and Supply Chain Performance

The correlation between the digitalization of supply chains and their performance has become popular in operations management, and it has been demonstrated that digital transformation greatly enhances the efficiency of operations(Perano et al., 2023). Organizations that use AI-based forecasting have reduced unwanted stock by 20-30% and increased inventory availability. The cost of logistics has been reduced by 10-15% using IoT technologies, and up to 40% using blockchain applications(Zhou et al., 2025). Digital maturity leads to 17 percent lower costs of operation than the old systems. Digitalization increases visibility and responsiveness in such a way that real-time sharing of data reduces lead times by 25-35(Wei et al., 2025). Besides, digital twin technology helps reduce the risks, and AI predicts the changes in demand with the accuracy of 85-90(Salamah et al., 2023). It has been shown that digitally mature supply chains bounce back to their regular course 50 times quicker, with blockchain enhancing traceability, especially in the pharmaceutical industry(Jum'a et al., 2025). The concept of sustainability is also considered, and AI optimization of logistics can reduce carbon emission by 10-20 percent, and blockchain can promote the progress of ESG compliance of 30 percent of implementing companies(Al Tera et al., 2024).

Relationship between Supply Chain Resilience Capabilities and Supply Chain Performance

The capabilities of resilience in supply chain are imperative in excellent SCP especially during disruptions such as geopolitical wars and pandemics(Huang et al., 2023). Strong supply chains have quicker and more effective recovery and enjoys improved operational and financial results(Zhou et al., 2025). The major resilience elements are absorptive, adaptive and restorative capabilities that together improve performance by means of successful risk anticipation, response to disruption and prompt recovery(Luqman et al., 2023). It is empirically demonstrated that the ability to absorb a crisis makes someone less vulnerable in a time of crisis, whereas the ability to adapt to current operational changes makes the operation more efficient(Salam & Bajaba, 2023). Restorative capacity has tremendous influence on financial performance through the ability to recover faster after being disrupted(Hamidu et al., 2023). Digital technologies also enhance the performance through optimizing the inventory and increasing transparency. Moderating factors like industry volatility and firm size have an effect in the resilience-performance relationship, through which high-risk industries gain more advantages when making resilience investments(Abourokbah et al., 2023). Even though resilience can have increased costs in the short-term, strategic redundancies can help enhance the stability of performance in the long-term(Kamble et al., 2023).

Relationship between Supply Chain Risk Management and Supply Chain Performance

SCRMand supply chain performance interaction are critical in the operations management, particularly in the context of the growing global disruptions(Waqas et al., 2023). Studies have shown that good practices of SCRM increase operational efficiency, cost management, services delivery and financial performance(Yanginlar et al., 2023). To apply the theoretical frameworks such as resource-based view and contingency theory, the importance of risk management capabilities is highlighted as important resource which brings about competitive advantages(Fernando et al., 2023). Advanced analytics and AI make risk identification and assessment practices to enhance preparedness to disruption(Qiao & Zhao, 2023a). SCRM should have mitigation strategies such as redundancy and flexibility. Moreover, the digital transformation brings in new risk management tools but creates new risks as well. Sustainability is increasingly critical in the context of improving performance in the SCRM(Pham et al., 2023). The COVID-19 crisis highlighted the importance of resilience and dynamic risk management. The SCRM-performance relation depends on different variables, such as the nature of the industry and size of the firm(Ngo et al., 2024). Although improvements have been made there are still lapses in the integration of SCRM with the larger risk management structures and in the human nature of it(Yang et al., 2023).

Mediating role of Supply Chain Resilience Capabilities

SCD improves the resilience potential by boosting absorptive, adaptive, and restorative potentials of organizations(Chatterjee et al., 2023). Absorptive capacity that depends upon digital technologies such as IoT and blockchain enables supply chains to obtain and process new data efficiently(Atieh Ali et al., 2024). The real time data sharing builds adaptive capacity to allow responsive operational adjustments. In addition, the restorative capacity enables recovery after disruption through AI tools and smart contracts to resolve faster(Tortorella et al., 2023). The success of these capabilities depends on industry features and digital infrastructures in place(Stentoft et al., 2025). Recent research is still underway to investigate the overlap between digital resilience and sustainability, as there has been a growing necessity to have holistic frameworks and research on how digitalization is changing the performance of the supply chain(Rashid et al., 2024). The main technologies, such as blockchain, enhance the quality and visibility of data and, accordingly, the quality of decision-making in accordance with market changes(Belhadi et al., 2024).

Moderating role of Supply Chain Risk Management

SCRMis a moderating variable that is critical in supply chain digitalization-performance relationship and shapes the effects of digital tools on improvement capabilities. According to the research, the successfulness of digital transformation depends on the maturity of risk management of an organization, and more sophisticated frameworks make it possible to extract more benefits based on digital technologies. This moderation can be reinforced by particular industry factors, the size of the firm, and geographical factors especially in high-risk industry. Additionally, another category of risks that digitalization imposes is tackled by SCRM that ensures the required protection against such threats as cyber threats. The COVID-19 pandemic has demonstrated empirically that organizations that mature their SCRM practices are more apt to exploit digital investments during crisis. The potentials of the future research are the incorporation of the AI in risk management and the investigation of the cultural influence on the SCRM-digitalization interactions. On the whole, SCRM is necessary to convert digital investments into the performance increase, and organizational capabilities must be taken into consideration. Keywords: SCRM performance, management, risk.

Supply chain risk management in relationship between supply chain resilience and supply chain performance

The concepts of SCRM, SCR, and SCP are interrelated, and they are important to operations management, particularly when global disruptions. SCRM is considered another enabler which enhances the correlation between the resilience and performance results because strong risk management increases the resilience potential and the performance efficiency. Empirical research shows that companies that have integrated SCRM and resilience in their strategies record much improved performances during disruptions especially in high-tech and pharmaceutical industries. Digital transformation brings with it both opportunities, such as greater visibility of risks, and threats, such as new cyber threats, which require integrated efforts to deal with traditional and digital risks. Moreover, sustainability concerns outline the importance of SCRM in ensuring a balance between resilience, environment and social aspects.

Developed Hypotheses:

H1: SCD has significant impact on SCR.

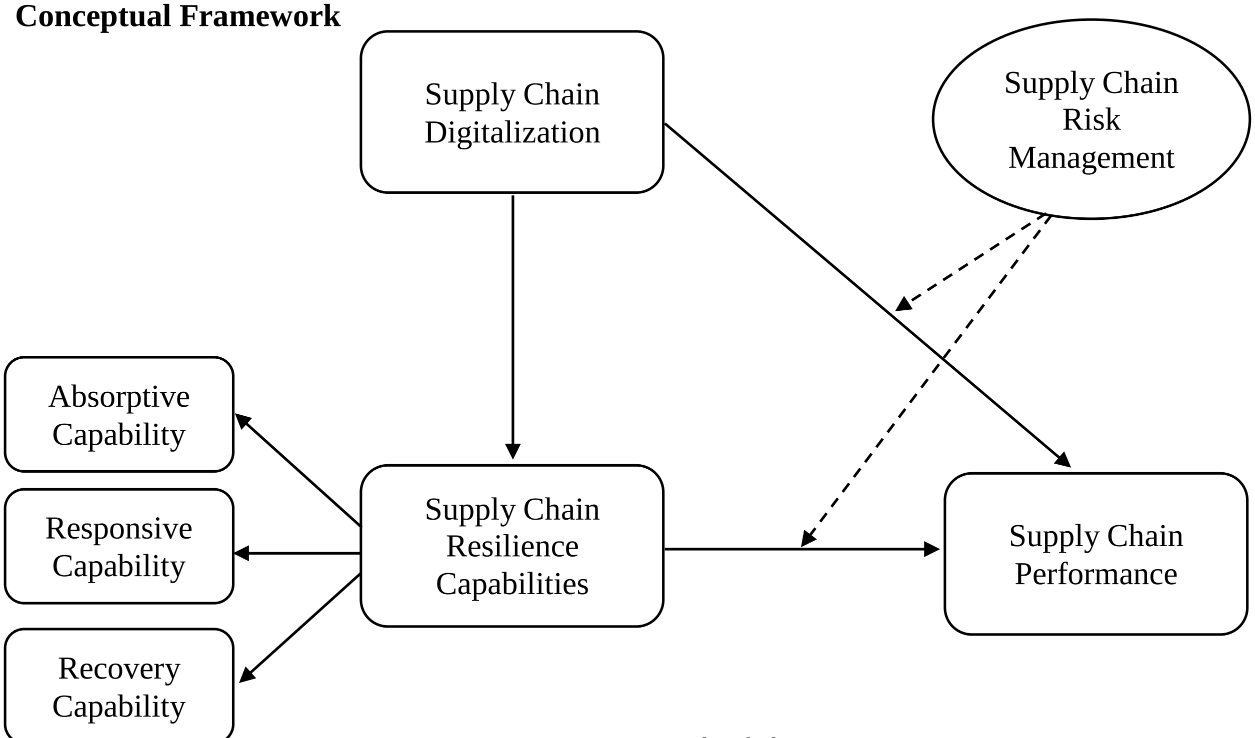
H2: SCR capabilities (Absorptive Capability, Responsive Capability, and Recovery Capability) significantly meditates the relationship between SCD and SCP.
H3: SCRM significantly moderated upon SCD and SCP.
H4: The combined effect of SCD and SCR capabilities (Absorptive Capability, Responsive Capability, and Recovery Capability) on SCP significantly moderated by SCRM.

Theoretical Perspective

Dynamic Capacity Theory (DCT)

The dynamic capacity theory, established by Teece et al. (1997)as part of the resource-based view (RBV), posits that firms with valuable, rare, inimitable resources can achieve a sustained competitive advantage(Farooq, 2023). While conventional resources are evaluated statically, this perspective emphasizes the need for dynamic capacities that allow firms to integrate and effectively utilize internal and external assets in changing markets(Malakar et al., 2025). Dynamic capabilities improve adaptability and are more difficult to copy than operational skills(Lu et al., 2025). They include flexibility, knowledge acquisition, and innovation as key elements, facilitating a firm's response to competitive pressures(Mazar et al., 2024). Effective resource management enhances competitiveness, especially in volatile environments, making dynamic capabilities essential for sustained advantage(Ali & Mahfouz, 2025).

Conceptual Framework



Methodology

Research Design

The survey method has been applied, the structured questionnaires were distributed among a chosen sample of supply chain professionals. The questionnaire was constructed upon the scope of literature review of measurement scales, and it was ensured that it would be relevant to supply chain digitalization(Alzoubi et al., 2024). Such a method made it possible to obtain standardized answers, measure the complex variables, and to develop statistical correlations. The data analysis consisted of descriptive and inferential statistics(Forza & Sandrin, 2023). Descriptive statistics were used to give key summaries of data distributions and sample characteristics and calculate measures of central tendency and dispersion. Data patterns were made visually to detect the anomalies(Roy et al., 2025). The first step of inferential statistics, which was correlation analysis, investigated the relationship between variables, including the performance metrics and digitalization adoption. A deeper analysis of the conceptual framework was conducted with the help of multivariate methods, such as regression analysis and structural equation modeling, to discuss mediating and moderating effects(Gillespie et al., 2023).

Various statistical tests were used in order to make the findings robust and valid. The internal consistency was evaluated with reliability tests based on the use of Cronbach's alpha and the dimensionality and construct validity were measured through the use of factor analysis(Vasilev et al., 2023). Parametric tests were assessed in assumptions and remedies were used on any violation. These methodology controls enhanced the validity and reliability of the statistical conclusions(Becker et al., 2023).

Population, Sample Size and Sampling Technique

The research problem is centered on the residents of the manufacturing sector within the sugar industry in the Pakistani province known as Khyber Pakhtunkhwa (KP Province). The region has seven sugar mills that are in operation and have an aggregate workforce of 4,813 people. There are distinguished companies like Bannu Sugar Mill Ltd. that employs 600, Al-Moiz Industries Ltd. with 700, Chashma Unit I that has 400 employees, Chashma Unit II with the highest number of employees of 1,400 and Khazana Sugar Mill (13 employees), premier sugar mill Ltd. with 900 employees and Tandlianwala Sugar Mill Ltd with 800 employees. This serves to emphasize that the sugar industry is playing an important role in creating job opportunities in the different cities of Khyber Pakhtunkhwa.

A sample in this analysis of the data on a quantitative data analysis is a subdivision of the total data, which can be achieved through surveys or extensive observations. A sample is referred to as this subset. This has produced a more accurate image of the data. This means that quantitative researchers have difficulties when it comes to the selection of respondents within a community.

Becker et al. (2023)extensively discusses the process of selection among the population, pointing out that the selected entities should be a clear representation of the entire population. The sampling technique deployed in this study is also known as convenience sampling that is not based on probability. Various researchsuggest that the size of a sample in multivariate research is ten times the number of variables that they are studying. An appropriate sample size, as per various researches (Khan et al., 2023), is a sample that is above thirty and below five hundred. To attain the objectives of the on-going research, a sample of four hundred employees in the sugar industry were selected to fill questionnaire survey. This was carried out in accordance with the provisions provided by publishes studies which require a sample size of 30 to 500(Khan et al., 2023).

Table 1 Data Collection Instrument

Variable	Measurement Approach	Key References
Supply Chain Digitalization	5-point Likert scale (1=Not implemented to 5=Fully implemented) assessing adoption levels of IoT, AI, blockchain, cloud platforms	Frank et al. (2019), Zhao et al. (2023)
Supply Chain Resilience Capabilities	Multi-dimensional scale measuring: 1) Absorptive capacity (redundancy, visibility) 2) Adaptive capacity (response speed) 3) Restorative capacity (recovery metrics)	Ambulkar et al. (2015), Ponomarov& Holcomb (2009)
Supply Chain Risk Management	1) SCRM maturity score (1-5) 2) Risk audit frequency 3) % suppliers with risk profiles	ISO 31000 (2018), Hallikas&Lintukangas (2016)
Supply Chain Performance	1) Operational metrics (fill rate, inventory turns) 2) Financial metrics (SC costs, cash cycle) 3) Customer metrics (OTD, satisfaction)	Beamon (1999), Gunasekaran et al. (2004)

Data Analysis Tools

Data analysis was done through Statistical package of Social Sciences also known as SPSS version 26. Cronbach's alpha test was used to test the reliability of data in the present study due to its applicability in descriptive research design. Inferential analysis Regression analysis analyzes the dependency of independent variables on dependent and a correlation test is used to test the relationship strength. As per our findings, a significant percentage of the respondents indicated that Hayes micro analysis technique can be used in moderation and mediation analysis. In order to evaluate different moderator or mediator variables, Hayes micro analysis uses regression analyses, that is, - ordinary least square (OLS) or hierarchical linear modelling (HLM). ANOVA and t-tests are going to be used to analyses the demographic factors.

Ethical Considerations

This research had an ethical setup that based its approach on safeguarding the rights of the participants and the integrity of research. Ethical consent was received beforehand, which made it conform to existing guidelines. Vitality was ensured when the participants were told about the purpose of the study and their right to pull out without repercussions, which encouraged them to engage in the study voluntarily. Informed consent was strictly given, and confidentiality was also observed such as anonymity of data and safe storage. Information security was in agreement with applicable laws, and it secured confidential data. The research was academically integrity by proper reference and proper reporting of the research design. There was no disclosure of conflicts of interest and findings were reported without being falsified and with the best interests of the participants. The wider ethical consideration of the study was factored and it was to be circulated among the participants and other interested parties with a view to serving an ethical duty to the community.

Results and Analysis

To establish the validity of the constructs, the researchers used correlation analysis to measure the strength and direction of the relationships between the main variables. They also conducted exploratory factor analysis (EFA) to examine the structure of the data, ensuring it aligned with the theoretical framework and previous research standards.

Frequency Distribution

Table2 Agewise FrequencyDistributionof Respondents

Age					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20-25	44	11.0	11.0	11.0
	25-30	95	23.8	23.8	34.8
	30-35	188	47.0	47.0	81.8
	35-40	48	12.0	12.0	93.8
	Above 40	25	6.3	6.3	100.0
	Total	400	100.0	100.0	

The modal age group was 30-35 years, comprising nearly half the workforce (n = 188, 47.0%). Workers aged 25-30 years formed the second largest segment (n = 95, 23.8%), followed by those aged 35-40 years (n = 48, 12.0%). Younger workers (20-25 years) accounted for 11.0% (n = 44), while the smallest group consisted of workers above 40 years (n = 25, 6.3%). Cumulative percentages highlight the youth-skewed nature of this workforce: 81.8% of workers were aged 35 or younger, with over one-third (34.8%) aged 30 or younger. Only 18.2% exceeded 35 years, with a notably small proportion (6.3%) above age 40.

Table3 Genderwise FrequencyDistributionof Respondents

Gender					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	299	74.8	74.8	74.8
	Female	101	25.3	25.3	100.0
	Total	400	100.0	100.0	

Analysis of gender representation among manufacturing workers in Khyber Pakhtunkhwa sugar industry (N = 400) revealed a pronounced gender disparity. Male workers constituted the overwhelming majority of the workforce (n = 299, 74.8%), while female workers represented approximately one-quarter of the sample (n = 101, 25.3%).

Table4Educationwise FrequencyDistributionof Respondents

Education					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Intermediate	7	1.8	1.8	1.8

Graduation	22	5.5	5.5	7.2
Masters	215	53.8	53.8	61.0
MS/MPhil	142	35.5	35.5	96.5
Others	14	3.5	3.5	100.0
Total	400	100.0	100.0	

89.3% of the 400 manufacturing workers in Khyber Pakhtunkhwa sugar industry had postgraduate degrees, indicating a highly educated workforce. 35.5% had MS/MPhil degrees, and 53.8% had master's degrees. Just 5.5% had a bachelor's degree, 1.8% an intermediate degree, and 3.5% other credentials. Overall, 96.5% of workers had at least a bachelor's degree, suggesting that the region's sugar manufacturing jobs either demand or attract highly educated workers, reflecting a competitive and highly skilled labor market.

Table5 Work Experiencewise FrequencyDistributionof Respondents

Work Experience					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Up to 1 year	18	4.5	4.5	4.5
	1-5 years	107	26.8	26.8	31.3
	5-10 years	183	45.8	45.8	77.0
	10- 15 years	72	18.0	18.0	95.0
	More than 15 Years	20	5.0	5.0	100.0
	Total	400	100.0	100.0	

Analysis of work experience among manufacturing workers in Khyber Pakhtunkhwa's sugar industry (N = 400) revealed a workforce characterized by substantial industry tenure. The majority of workers (77.0%) reported at least 5 years of experience, with the modal group being those with 5-10 years of service (n = 183, 45.8%).

Descriptive Statistics

To determine whether parametric analysis is appropriate, George and Mallery (2024)stress the importance of first checking if the data follows a normal distribution.

Table 6 Data Normality Statistics

Descriptive Statistics							
	N	**Mean**	**Std. Deviation**	**Skewness**		**Kurtosis**	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
SCD	400	2.1517	.92419	.987	.122	.085	.243
SCRCP	400	3.0074	.81331	-.545	.122	-.740	.243
SCRM	400	2.2081	.82240	1.106	.122	.519	.243
SCP	400	2.2325	.84904	1.085	.122	.536	.243

Valid (listwise)	N	400

The descriptive statistics for all variables were calculated based on a valid sample size of N = 400. SCD had a mean score of 2.15 (SD = 0.92). The distribution of SCD scores demonstrated positive skewness (skewness = 0.99, SE = 0.12) and kurtosis close to mesokurtic (kurtosis = 0.09, SE = 0.24). SCRCP exhibited the highest mean score (M = 3.01, SD = 0.81), with negative skewness (skewness = -0.55, SE = 0.12) and platykurtic kurtosis (kurtosis = -0.74, SE = 0.24).

Reliability Analysis

One of the most widely used statistics for assessing reliability is Cronbach's alpha. Freitas et al. (2023) points out that a high Cronbach's alpha indicates internal consistency, meaning the items on the scale are measuring the same underlying concept. Generally, a Cronbach's alpha between 0.6 and 0.7 is considered acceptable, meaning the reliability is satisfactory. Scores above 0.8 indicate excellent reliability.

Table 7 Reliability Statistics of Supply Chain Digitalization

Item-Total Statistics	**Cronbach's Alpha if Item Deleted**	**Cronbach's Alpha**
SCD1	.721	
SCD2	.766	.756
SCD3	.711	

The internal consistency reliability of the SCD scale was assessed using Cronbach's alpha. The analysis was based on the three scale items (SCD1, SCD2, SCD3) with a valid sample size implied by the previous analysis (N = 400). The overall reliability coefficient for the scale was α = .756, indicating acceptable internal consistency.

Table 8 Reliability Statistics of SCRC

Item-Total Statistics	**Cronbach's Alpha if Item Deleted**	**Cronbach's Alpha**
SCRC1	.891	
SCRC2	.893	
SCRC3	.891	
SCRC4	.889	.905
SCRC5	.892	
SCRC6	.901	
SCRC7	.892	
SCRC8	.895	
SCRC9	.902	

The internal consistency reliability of the SCRC scale, measured by Cronbach's alpha, was excellent based on the sample 400. The overall reliability coefficient was α = .905, exceeding the conventional threshold of .70 for good reliability (Nunnally& Bernstein, 1994).

Table 9 Reliability Statistics of Supply Risk Management

Item-Total Statistics	Cronbach's Alpha if Item Deleted	Cronbach's Alpha
SCRM1	.702	
SCRM2	.732	.783
SCRM3	.699	
SCRM4	.803	

The SCRM scale demonstrated acceptable internal consistency with a Cronbach's alpha of α = .783 based on the four-item scale and sample (N = 400 implied), meeting the conventional threshold for reliability.

Table 10 Reliability Statistics of Supply Chain Digitalization

Item-Total Statistics	Cronbach's Alpha if Item Deleted	Cronbach's Alpha
SCP1	.704	
SCP2	.715	.769
SCP3	.732	
SCP4	.705	

The SCP scale demonstrated acceptable internal consistency with a Cronbach's alpha of α = .769 based on its four items and sample (N = 400 implied), meeting the conventional reliability threshold.

Validity Analysis

In this study, EFA was conducted to confirm the reliability of the criteria-related validity. Key tests, such as the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity, were used to check if the data was suitable for factor analysis. Additionally, scatter plots, principal component analyses, and factor loadings were analyzed to further assess the reliability of the criteria.

Table 11 (a) Supply Chain Digitization

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.716
Bartlett's Test of Sphericity	Approx. Chi-Square	591.113
	df	3
	Sig.	.000

Table 11 (b) Supply Chain Digitization

	Loadings
SCD1	.875
SCD2	.881
SCD3	.838

The factorability of the SCD scale was assessed through two preliminary tests. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was .716, exceeding the recommended threshold of .60 (Kaiser, 1974), indicating adequate intercorrelations for factor analysis. Bartlett's test of sphericity was significant, χ^2 (3) = 591.113, $p < .001$, confirming sufficient correlations among items to proceed with factor extraction.

Table 12 (a) Supply Chain Resilience Capabilities

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.905
Bartlett's Test of Sphericity	Approx. Chi-Square	1903.763
	df	36
	Sig.	.000

Table 12 (b) Supply Chain Resilience Capabilities

	Loadings
SCRC1	.789
SCRC2	.761
SCRC3	.794
SCRC4	.815
SCRC5	.783
SCRC6	.768
SCRC7	.773
SCRC8	.743
SCRC9	.749

The factorability of the SCRC scale was examined through established diagnostic measures. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was .905, exceeding the recommended threshold of .80 (Kaiser, 1974) and indicating excellent suitability for factor analysis. Bartlett's test of sphericity was significant, χ^2 (36) = 1903.763, $p < .001$, confirming sufficient inter-item correlations for factor extraction.

Table 13 (a) Supply Chain Risk Management

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.831
Bartlett's Test of Sphericity	Approx. Chi-Square	951.700
	df	6

	Sig.	.000

Table 13 (b) Supply Chain Risk Management

	Loadings
SCRM1	.850
SCRM2	.846
SCRM3	.826
SCRM4	.861

Principal component analysis revealed a unidimensional solution for the four-item scale. All items demonstrated exceptionally strong factor loadings, substantially exceeding the recommended .50 threshold (Field, 2018): SCRM1 (.850), SCRM2 (.846), SCRM3 (.826), and SCRM4 (.861). The consistently high loadings indicate excellent representation of the underlying construct, with SCRM4 showing the strongest association with the factor.

Table 14 (a) Supply Chain Performance

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.796
Bartlett's Test of Sphericity	Approx. Chi-Square	809.551
	df	6
	Sig.	.000

Table 14 (b) Supply Chain Performance

	Loadings
SCP1	.833
SCP2	.822
SCP3	.851
SCP4	.782

Principal component analysis revealed a unidimensional solution for the four-item scale. All items demonstrated strong factor loadings substantially exceeding the recommended .50 threshold (Field, 2018): SCP1 (.833), SCP2 (.822), SCP3 (.851), and SCP4 (.782).

Inferential Analysis

Table 15 Correlation Analysis

Correlations					
		SCD	**SCRCP**	**SCRM**	**SCP**
SCD	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	400			
SCRCP	Pearson Correlation	.452**	1		
	Sig. (2-tailed)	.000			
	N	400	400		
SCRM	Pearson Correlation	.684**	.362**	1	

	Sig. (2-tailed)	.000	.000		
	N	400	400	400	
SCP	Pearson Correlation	.729**	.438**	.838**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	400	400	400	400

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

Significant positive relationships were observed among all key supply chain variables (N = 400). SCD demonstrated strong positive correlations with SCRM (SCRM; r = .68, p < .001) and SCP (SCP; r = .73, p < .001), both exceeding Cohen's (1988) threshold for large effect sizes. SCD also showed a medium-to-large positive correlation with Supply Chain Resilience Capabilities (SCRCP; r = .45, p < .001)

Table 4.6.2 Simple Linear Regression Analysis

Table 16 (a) Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.729[a]	.532	.531	.58146	.532	452.723	1	398	.000

a. Predictors: (Constant), SCD

b. Dependent Variable: SCP

The model was statistically significant, F (1, 398) = 452.72, p < .001. SCD accounted for 53.2% of the variance in SCP (R^2 = .532), with an adjusted R^2 of .531.

Table 16 (b) Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.791	.074		10.720	.000
	SCD	.670	.031	.729	21.277	.000

a. Dependent Variable: SCP

The standardized coefficient (β = .729) exceeds Cohen's (1988) benchmark for large effects (β ≥ .50), confirming SCD's substantial predictive utility. The magnitude of the t-statistic (21.28) demonstrates strong statistical reliability, with the slope coefficient being over 21 times larger than its standard error.

Mediation Analysis

Table 17 (a) Mediation of Supply Chain Resilience Capabilities in relationship between Supply chain Digitalization and Supply Chain Performance

Model Summary

R	R-sq	MSE	F	df1	df2	p
.4521	.2044	.5276	102.2606	1.0000	398.0000	.0000

Model						
coeff	se	t	p	LLCI	ULCI	
constant	2.1513	.0921	23.3536	.0000	1.9702	2.3324
SCD	.3979	.0393	10.1124	.0000	.3205	.4752

The model was statistically significant, $F(1, 398) = 102.26$, $p < .001$, indicating SCD significantly predicts SCRCP. The coefficient of determination revealed SCD accounts for 20.44% of the variance in SCRCP ($R^2 = .204$).

Table 17 (b)

Model Summary						
R	R-sq	MSE	F	df1	df2	p
.7395	.5468	.3283	239.5140	2.0000	397.0000	.0000

Model						
coeff	se	t	p	LLCI	ULCI	
constant	.4857	.1119	4.3411	.0000	.2657	.7057
SCD	.6138	.0348	17.6386	.0000	.5454	.6822
SCRCP	.1417	.0395	3.5831	.0004	.0639	.2194

The overall model was statistically significant, $F(2, 397) = 239.51$, $p < .001$, explaining 54.68% of the variance in SCP ($R^2 = .547$, adjusted $R^2 = .544$). Both predictors demonstrated significant unique effects on the outcome variable.

Table 17 (c)

Total effect of X on Y

Effect	se	t	p	LLCI	ULCI
.6702	.0315	21.2773	.0000	.6083	.7321

Direct effect of X on Y

Effect	se	t	p	LLCI	ULCI
.6138	.0348	17.6386	.0000	.5454	.6822

Indirect effect(s) of X on Y:

	Effect	SE	LLCI	ULCI
SCRCP	.0564	.0134	.0300	.0826

The total effect of SCD on SCP was statistically significant, B = 0.670, SE = 0.032, t = 21.28, $p < .001$, 95% CI [0.608, 0.732], indicating that without considering the mediator, digitalization strongly predicts performance.

Moderation Analysis

Table 18 (a) Moderation of Supply Chain Risk Management upon Supply Chain Digitalization and Supply Chain Performance

Model Summary

R	R-sq	MSE	F	df1	df2	p
.8691	.7553	.1777	407.4172	3.0000	396.0000	.0000

Model

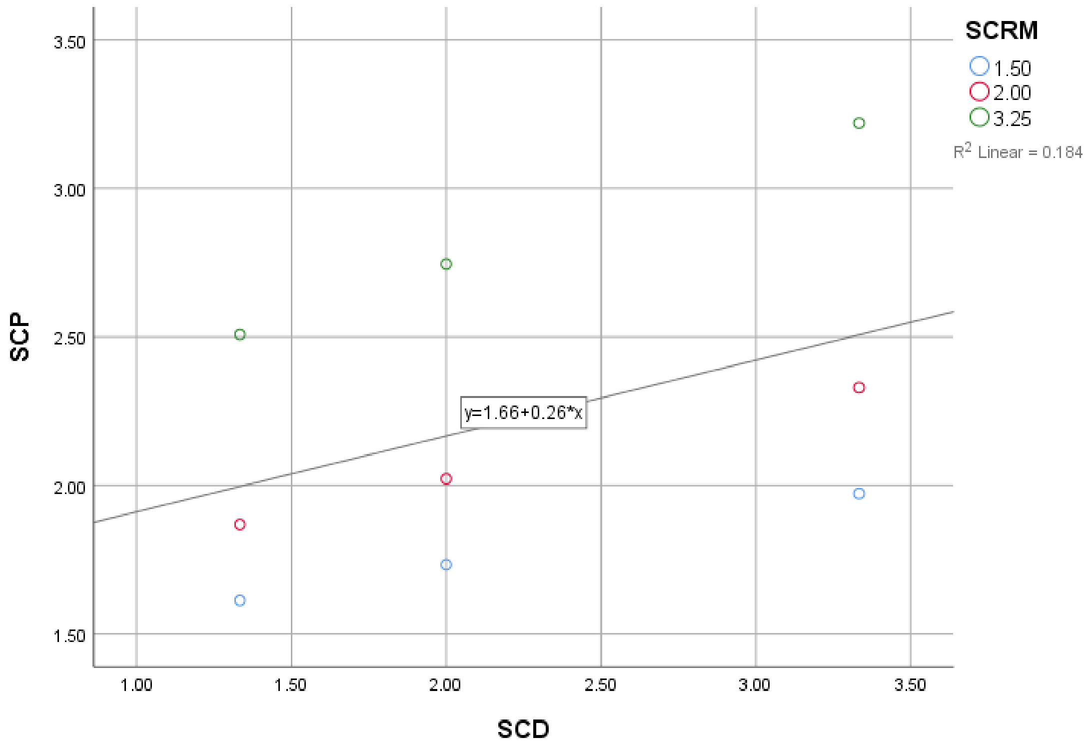
	coeff	se	t	p	LLCI	ULCI
constant	.8054	.1899	4.2410	.0000	.4320	1.1787
SCD	.0292	.0777	.3759	.7072	-.1236	.1820
SCRM	.3778	.0902	4.1881	.0000	.2005	.5552
Int_1	.1006	.0298	3.3756	.0008	.0420	.1591

Table 18 (b)

Test(s) of highest order unconditional interaction(s):

	R2-chng	F	df1	df2	p
X*W	.0070	11.3949	1.0000	396.0000	.0008

The overall model was statistically significant, $F(3, 396) = 407.42$, $p < .001$, explaining 75.53% of the variance in SCP ($R^2 = .755$). The interaction term (SCD × SCRM) was significant, B = 0.101, SE = 0.030, t = 3.38, p = .001, 95% CI [0.042, 0.159], indicating SCRM significantly moderates the SCD-SCP relationship.



(Moderation Graph)

Mediated Moderations

Table 19 (a) Mediated Moderation of SCRM in relationship between SCRC and SCP through SCD

Model Summary

R	R-sq	MSE	F	df1	df2	p
.4521	.2044	.5276	102.2606	1.0000	398.0000	.0000

Model

	coeff	se	t	p	LLCI	ULCI
constant	-.8561	.0921	-9.2934	.0000	-1.0372	-.6750
SCD	.3979	.0393	10.1124	.0000	.3205	.4752

The moderated mediation analysis examined whether the mediating effect of SCRCP between SCD and SCP depends on levels of SCRM. The first stage of the analysis revealed a significant positive relationship between SCD and the proposed mediator SCRCP, B = 0.398, SE = 0.039, t (398) = 10.11, $p < .001$, 95% CI [0.321, 0.475], with SCD explaining 20.44% of the variance in SCRCP ($R^2 = .204$).

Table 19 (b)

Model Summary						
R	R-sq	MSE	F	df1	df2	p
.8792	.7731	.1652	336.4077	4.0000	395.0000	.0000

Model

	coeff	se	t	p	LLCI	ULCI
constant	1.7695	.0716	24.7283	.0000	1.6288	1.9102
SCD	.1928	.0326	5.9130	.0000	.1287	.2569
SCRCP	.1612	.0303	5.3173	.0000	.1016	.2208
SCRM	.5884	.0357	16.4725	.0000	.5182	.6587
Int_1	.1994	.0359	5.5626	.0000	.1290	.2699

The moderated mediation analysis examining the relationship between SCD, SCRCP, and SCP, with SCRM as a moderator, revealed significant effects. The overall model was statistically significant, $F(4, 395) = 336.41$, $p < .001$, explaining 77.31% of the variance in SCP ($R^2 = .773$). All predictor variables demonstrated significant effects on the outcome variable.

Table 19 (c)

Int_1 : SCRCP x SCRM

Test(s) of highest order unconditional interaction(s):

	R2-chng	F	df1	df2	p
M*W	.0178	30.9420	1.0000	395.0000	.0000

The analysis revealed a statistically significant interaction between SCRCP and SCRM in predicting SCP. The interaction term accounted for a significant 1.78% of unique variance in SCP (R^2 change = .018), $F(1, 395) = 30.94$, $p < .001$. This small but meaningful interaction effect indicates that the strength of the relationship between resilience capabilities and performance varies depending on levels of risk management.

Table 19 (d)

Direct effect of X on Y

Effect	se	t	p	LLCI	ULCI
.1928	.0326	5.9130	.0000	.1287	.2569

Conditional indirect effects of X on Y:

INDIRECT EFFECT:

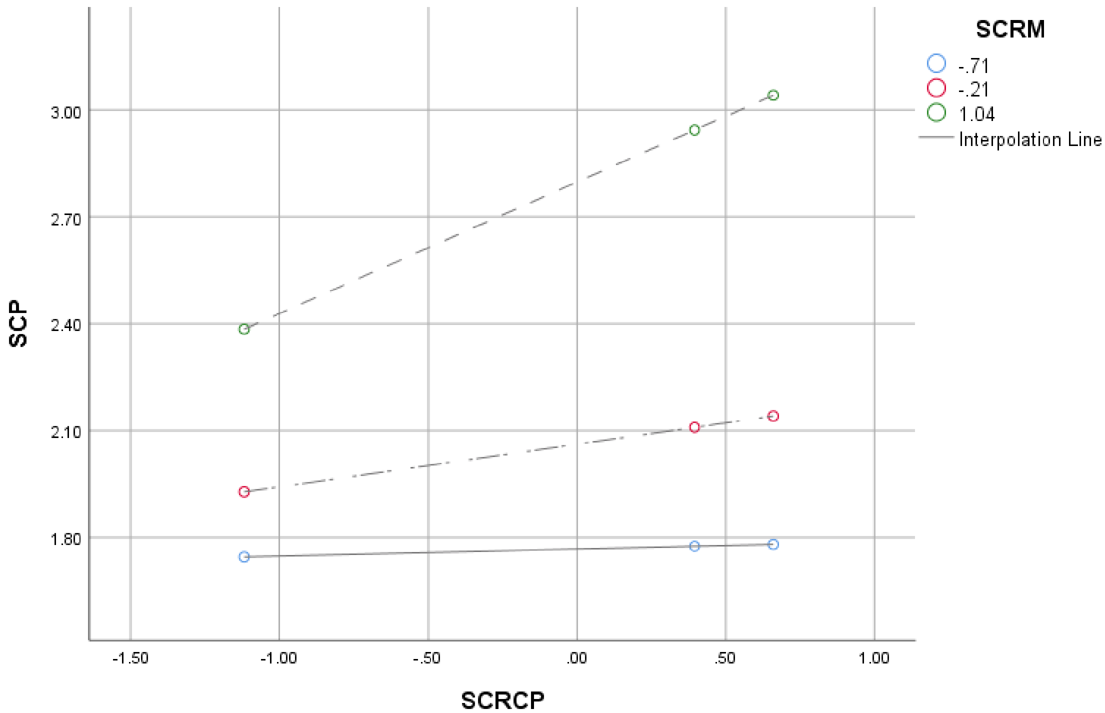
SCD -> SCRCP -> SCP

SCRM	Effect	SE	LLCI	ULCI
-.7081	.0079	.0110	-.0155	.0282
-.2081	.0476	.0106	.0265	.0686
1.0419	.1468	.0249	.0968	.1957

Index of moderated mediation:

	Index	SE	LLCI	ULCI
SCRM	.0794	.0155	.0488	.1102

The analysis revealed a significant direct effect of SCD on SCP after accounting for the mediator and moderator, B = 0.193, SE = 0.033, t = 5.91, p< .001, 95% CI [0.129, 0.257]. This persistent direct effect suggests digitalization enhances performance through mechanisms beyond just building resilience capabilities, even when considering the moderating role of risk management.



Test of Significance

The analysis of differences in the averages of research variables in relation to respondents' demographic characteristics reveals the use of two primary statistical methods: the independent sample t-test and the ANOVA test. These are commonly applied to assess the statistical significance of differences between groups or means.

Table 20 (a) Independent Sample t-test for Gender Differences

Group Statistics

	Gender	N	Mean	Std. Deviation	Std. Error Mean
SCD	Male	299	2.1784	.89083	.05152
	Female	101	2.0726	1.01719	.10121
SCRCP	Male	299	3.0185	.80809	.04673
	Female	101	2.9746	.83177	.08276
SCRM	Male	299	2.1773	.81457	.04711
	Female	101	2.2995	.84263	.08384
SCP	Male	299	2.2375	.83247	.04814
	Female	101	2.2178	.90046	.08960

Table 20 (b)

Independent Samples Test

	Levene's Test for	t-test for Equality of Means

		Equality of Variances								
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
SCD	Equal variances assumed	.872	.351	.994	398	.321	.10577	.10637	-.10334	.31487
	Equal variances not assumed			.931	155.037	.353	.10577	.11357	-.11858	.33011
SCRCP	Equal variances assumed	.285	.594	.468	398	.640	.04384	.09369	-.14035	.22804
	Equal variances not assumed			.461	168.196	.645	.04384	.09505	-.14379	.23148
SCRM	Equal variances assumed	.775	.379	-1.293	398	.197	-.12225	.09457	-.30817	.06367
	Equal variances not			-1.271	167.498	.205	-.12225	.09617	-.31211	.06762

	assumed									
SCP	Equal variances assumed	.929	.336	.201	398	.841	.01964	.09783	-.17270	.21197
	Equal variances not assumed			.193	161.558	.847	.01964	.10171	-.18122	.22050

Independent samples t-tests were conducted to examine potential gender differences across four supply chain variables. For SCD, males (M = 2.18, SD = 0.89) reported slightly higher levels than females (M = 2.07, SD = 1.02), but this difference was not statistically significant, t (398) = 0.99, p = .321, 95% CI [-0.10, 0.31], with equal variances assumed (F = 0.87, p = .351). Similarly, no significant gender differences emerged for SCRCP, with males (M = 3.02, SD = 0.81) and females (M = 2.97, SD = 0.83) showing comparable scores, t(398) = 0.47, p = .640, 95% CI [-0.14, 0.23].

Table 21 (a) ANOVA by Age

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
SCD	Between Groups	18.967	4	4.742	5.820	.000
	Within Groups	321.832	395	.815		
	Total	340.799	399			
SCRCP	Between Groups	4.140	4	1.035	1.574	.180
	Within Groups	259.787	395	.658		
	Total	263.927	399			
SCRM	Between Groups	14.396	4	3.599	5.565	.000
	Within Groups	255.465	395	.647		
	Total	269.861	399			
SCP	Between Groups	14.872	4	3.718	5.384	.000
	Within Groups	272.755	395	.691		
	Total	287.628	399			

A one-way between-groups ANOVA was conducted to examine age differences across four supply chain variables with five age groups. For SCD, there was a statistically significant difference between age groups, F (4, 395) = 5.82, p < .001, with age accounting for approximately 5.6% of the variance in SCD scores (η^2 = .056).

Similarly, significant age differences emerged for SCRM, $F(4, 395) = 5.57, p < .001, \eta^2 = .053$, and SCP, $F(4, 395) = 5.38, p < .001, \eta^2 = .052$.

Table 21 (b) ANOVA by Education

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
SCD	Between Groups	2.465	4	.616	.720	.579
	Within Groups	338.333	395	.857		
	Total	340.799	399			
SCRCP	Between Groups	3.018	4	.755	1.142	.336
	Within Groups	260.909	395	.661		
	Total	263.927	399			
SCRM	Between Groups	.825	4	.206	.303	.876
	Within Groups	269.036	395	.681		
	Total	269.861	399			
SCP	Between Groups	.891	4	.223	.307	.873
	Within Groups	286.737	395	.726		
	Total	287.628	399			

A one-way between-groups ANOVA revealed no statistically significant differences in supply chain variables across education levels for any of the measured constructs. For SCD, the analysis showed non-significant variation between education groups, $F(4, 395) = 0.72, p = .579$, with education accounting for less than 1% of the variance in SCD scores ($\eta^2 = .007$). Similarly, no significant differences were found for SCRCP, $F(4, 395) = 1.14, p = .336, \eta^2 = .011$; SCRM, $F(4, 395) = 0.30, p = .876, \eta^2 = .003$; or SCP, $F(4, 395) = 0.31, p = .873, \eta^2 = .003$.

Table 21 (c) ANOVA by Experience

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
SCD	Between Groups	23.953	4	5.988	7.465	.000
	Within Groups	316.846	395	.802		
	Total	340.799	399			
SCRCP	Between Groups	3.717	4	.929	1.411	.230
	Within Groups	260.210	395	.659		
	Total	263.927	399			
SCRM	Between Groups	14.444	4	3.611	5.585	.000
	Within Groups	255.417	395	.647		
	Total	269.861	399			
SCP	Between Groups	15.755	4	3.939	5.723	.000

Within Groups	271.872	395	.688
Total	287.628	399	

A one-way ANOVA revealed significant differences in supply chain capabilities based on work experience for three of the four measured constructs. For Supply Chain Digitalization (SCD), there was a statistically significant effect of experience level, $F(4, 395) = 7.47$, $p < .001$, with experience accounting for approximately 7.0% of the variance in SCD scores ($\eta^2 = .070$), representing a medium effect size. Similarly, significant experience differences emerged for Supply Chain Risk Management (SCRM), $F(4, 395) = 5.59$, $p< .001$, $\eta^2 = .054$, and Supply Chain Performance (SCP), $F(4, 395) = 5.72$, $p < .001$, $\eta^2 = .055$, both showing medium effect sizes.

Discussion, Implication and Conclusion

Discussion

Hypothesis 1: Digitalization of supply chain has a great influence on performance especially in the sugar industry in Pakistan. The research concludes that IoT, blockchain, and AI technologies have a beneficial effect on the efficiency of operations and minimize costs. Digital technologies deal with inefficiency in the acquisition of cane and tracking of its logistics, and blockchain introduces a sense of transparency and prevents procurement anomalies resulting in financial losses. Nonetheless, challenges such as cost of implementing and skill gaps demand policy interventions that can ensure digital transformation in this industry.

Hypothesis 2: The association between digitalization and performance in the mills of Pakistani sugar is mediated by SCR capabilities, including absorptive, adaptive, and restorative capabilities. The research proves that, despite the beneficial effect of digitalization on performance, it is not the only one; the workforce should be trained, and processes should be agile. Digital technology such as satellite monitoring of crops and IoT tracking make the restoration faster after disturbances but a comprehensive strategy of integrating technology with development of organizational capabilities is key to real resilience in the field.

Hypothesis 3: It is noted in the research that SCRMis an important factor that promotes the digitalization-performance relationship, which served as a key facilitator of digitalization advantages. This supports the fact that digital investments can bring more benefits to firms by having an effective risk management system as theorized by Wieland and Durach. Particularly, combined electronic procurement systems that have supplier risk ratings, and AI-driven price prediction are more effective with robust risk reduction initiatives. As the case of sugar mills in Pakistan, installing a cybersecurity system and alternative sources of power is necessary to protect the digital transformation initiative against such vulnerabilities as power outages and energy interruptions.

Hypothesis 4: The paper demonstrates that resilience capabilities and supply chain digitalization can greatly improve the performance of the supply chain, but when regulated by the successful management of the risk, it can lead to better outcomes. Mills in the sugar industry in Pakistan will enjoy better results of the digital tools and resiliency strategies when there are sound risk management practices. In particular, at the minimal risk management levels, the influence of the digitalization on the performance through resilience is low, but powerful risk systems dramatically enhance it. This implies that Pakistani sugar mills need to combine digital transformation and resilience building and risk management to deliver optimal outcomes instead of the implementation of technologies separately. The results demonstrate that diversified networks of suppliers and cybersecurity measures constitute the part of the overall risk management principles aimed to handle the challenges specific to the sector.

Theoretical Implication

The research provides important theoretical implications concerning the supply chain management within the sugar industry in Pakistan and more so, the dynamic capabilities theory. It unveils the fact that digitalization, resilience, and risk management are inseparable aspects that lead to improved performance of supply chains which do not follow the conventional models of linear adoption of technology. These results highlight the importance of having strong risk management frameworks in the success of digital transformation as a performance driver. The study provides an example of contingency in that the overall benefits of digitalization and resilience can be achieved only through risk management. In this way, it supports a subtle approach to the understanding of the capability development, as it demonstrates that digitalization starts resilience but full performance gains are achieved after the risk management is developed. It also suggests that the presence of proper functioning of these elements can be dependent on the minimum degree of risk management competency after which the stakeholders can be able to optimize their investment in digital and resilience strategies.

PracticalImplication

The research offers practical recommendations to sugar mill owners in Pakistan on the need to digitize the business in stages in order to be resilient amid the risk management process. Among the main suggestions, there is focused digitalization, including transparency tools such as blockchain and predictive maintenance tools such as AI, and data literacy training of the workforce. It is recommended that Mills should mitigate the risks in their strategies by diversifying the suppliers and investing in the cybersecurity measures. There is also the discussion of the role of government and industry associations in scaling technologies and sharing risks programs to support small mills in their digital adoption processes.

Recommendations

The sugar mills of Pakistan need to focus on digitalizing their supply chains using blockchain to increase the supply chain transparency, IoT to manage the inventory, and AI to predict demands better. Resiliency is also important; to have mitigating reserves against climate and political contingencies, mills must diversify their suppliers and create buffer stocks. Vigorous risk management systems, such as frequent supplier evaluations and cybersecurity, are needed. Also, policy interventions and collaboration within the industry are required to facilitate the use of digital technologies and set standards. The adoption of a staged implementation strategy that emphasizes pilot testing, scaled up and completely integrated will help inculcate efficiency and competitiveness in a highly volatile market, which will ensure that the sector grows in the long term.

Limitations and Future Research Directions

This part summarizes the weaknesses and research agenda of the digital transformation in the sugar sector of Pakistan. Among the limitations, it is regional, Khyber Pakhtunkhwa, which restricts generalizability, it is cross-sectional, which prevents monitoring the effects of digital adoption on a long-term basis, and it uses quantitative data, which ignores subtle elements. The paper has analyzed a small number of digital technologies, disregarded others such as digital twins and robotics, and failed to take into account external factors such as sugar prices in the world market. The areas of the future research should be longitudinal studies to adequately monitor digital transformation and compare it in various sectors of agriculture, mixed-method research to gain a better understanding, and investigation of new technologies such as generative AI. Also, exploring the connection between digital transformation and sustainability objectives, evaluating the efficacy of government policy in digital adoption is also mentioned as one of the key directions of research in the future that can contribute to the further knowledge of the field.

Conclusion

This study emphasizes the fact that in the sugar sector in Pakistan, digital transformation and resilience capabilities and risk frameworks works well in enhancing SCP. Digitalization has a direct positive impact on the performance of operations, and resilience capabilities are a mediating factor. The paper stresses that the implementation of technology cannot work effectively without workforce training and effective risk management. It goes beyond the dynamic capabilities perspective by demonstrating how these aspects constitute a competitive advantage. But it adds that it has limitation like being restricted to one type of industry and recommends the need to conduct more research in other areas. The results suggest the implementation of comprehensive transformation programs, which requires the stakeholders to consider digital infrastructure, skill development, and risk management in a united approach towards the sustainable competitiveness.

References

Aamer, A., Sahara, C. R., & Al-Awlaqi, M. A. (2023). Digitalization of the supply chain: transformation factors. *Journal of Science and Technology Policy Management*, *14*(4), 713-733.

Abourokbah, S. H., Mashat, R. M., & Salam, M. A. (2023). Role of absorptive capacity, digital capability, agility, and resilience in supply chain innovation performance. *Sustainability*, *15*(4), 3636.

Ahmadi, T., Hesaraki, A. F., & Morsch, J. P. (2025). Exploring IT-driven supply chain capabilities and resilience: the roles of supply chain risk management and complexity. *Supply Chain Management: An International Journal*, *30*(1), 50-66.

Al Tera, A., Alzubi, A., & Iyiola, K. (2024). Supply chain digitalization and performance: A moderated mediation of supply chain visibility and supply chain survivability. *Heliyon*, *10*(4).

Ali, A., & Mahfouz, A. (2025). Building dynamic resilience capabilities for supply chain disruptions: insights from the Irish food industry. *International Journal of Logistics Research and Applications*, 1-29.

Alzoubi, H. M., Shwedeh, F., Shamout, M. D., Alquqa, E. K., & Bawaneh, B. (2024). Process Control Influence on Mitigating Supply Chain Risk: Exploring the Mediating Effect of Information Security—Evidence from the UAE Construction Industry. International Scientific Conference Management and Engineering,

Atieh Ali, A. A., Sharabati, A.-A. A., Allahham, M., & Nasereddin, A. Y. (2024). The relationship between supply chain resilience and digital supply chain and the impact on sustainability: Supply chain dynamism as a moderator. *Sustainability*, *16*(7), 3082.

Becker, J.-M., Cheah, J.-H., Gholamzade, R., Ringle, C. M., & Sarstedt, M. (2023). PLS-SEM's most wanted guidance. *International Journal of Contemporary Hospitality Management*, *35*(1), 321-346.

Belhadi, A., Mani, V., Kamble, S. S., Khan, S. A. R., & Verma, S. (2024). Artificial intelligence-driven innovation for enhancing supply chain resilience and performance under the effect of supply chain dynamism: an empirical investigation. *Annals of Operations Research*, *333*(2), 627-652.

Chatterjee, S., Mariani, M., & Ferraris, A. (2023). Digitalization of supply chain and its impact on cost, firm performance, and resilience: technology turbulence and top management commitment as moderator. *IEEE transactions on engineering management*, *71*, 10469-10484.

Chowdhury, M. M. H., Chowdhury, P., Quaddus, M., Rahman, K. W., & Shahriar, S. (2024). Flexibility in enhancing supply chain resilience: developing a resilience capability portfolio in the event of severe disruption. *Global Journal of Flexible Systems Management*, *25*(2), 395-417.

Das, D., Roy, A., Chaudhuri, A., Tripathy, S., Singhal, D., & Chandrasekhar, P. (2024). Digitalization of SCM in the Agriculture Industry. In *Advanced Computational Methods for Agri-Business Sustainability* (pp. 168-189). IGI Global.

Deepu, T., & Ravi, V. (2023). A review of literature on implementation and operational dimensions of supply chain digitalization: Framework development and future research directions. *International Journal of Information Management Data Insights*, *3*(1), 100156.

Dubey, R., Bryde, D. J., Dwivedi, Y. K., Graham, G., Foropon, C., & Papadopoulos, T. (2023). Dynamic digital capabilities and supply chain resilience: The role of government effectiveness. *International journal of production economics*, *258*, 108790.

Farooq, R. (2023). Knowledge management and performance: a bibliometric analysis based on Scopus and WOS data (1988–2021). *Journal of Knowledge Management*, *27*(7), 1948-1991.

Faruquee, M., Paulraj, A., & Irawan, C. A. (2024). A typology of supply chain resilience: recognising the multi-capability nature of proactive and reactive contexts. *Production Planning & Control*, *35*(12), 1503-1523.

Fernando, Y., Tseng, M.-L., Wahyuni-Td, I. S., de Sousa Jabbour, A. B. L., Chiappetta Jabbour, C. J., & Foropon, C. (2023). Cyber supply chain risk management and performance in industry 4.0 era: information system security practices in Malaysia. *Journal of Industrial and Production Engineering*, *40*(2), 102-116.

Forza, C., & Sandrin, E. (2023). Surveys. In *Research methods for operations and supply chain management* (pp. 76-158). Routledge.

Freitas, K. A. d., Flynn, B. B., Paiva, E. L., & Awaysheh, A. (2023). Achieving risk resilience in an environment of mistrust: supply chain piracy of physical goods. *International Journal of Operations & Production Management*.

George, D., & Mallery, P. (2024). *IBM SPSS statistics 29 step by step: A simple guide and reference*. Routledge.

Gillespie, J., da Costa, T. P., Cama-Moncunill, X., Cadden, T., Condell, J., Cowderoy, T., Ramsey, E., Murphy, F., Kull, M., & Gallagher, R. (2023). Real-time anomaly detection in cold chain transportation using IoT technology. *Sustainability*, *15*(3), 2255.

Hamidu, Z., Boachie-Mensah, F. O., & Issau, K. (2023). Supply chain resilience and performance of manufacturing firms: role of supply chain disruption. *Journal of Manufacturing Technology Management*, *34*(3), 361-382.

Han, N., & Um, J. (2024). Risk management strategy for supply chain sustainability and resilience capability. *Risk Management*, *26*(2), 6.

Harju, A., Hallikas, J., Immonen, M., & Lintukangas, K. (2023). The impact of procurement digitalization on supply chain resilience: empirical evidence from Finland. *Supply Chain Management: An International Journal*, *28*(7), 62-76.

Huang, Y.-F., Phan, V.-D.-V., & Do, M.-H. (2023). The impacts of supply chain capabilities, visibility, resilience on supply chain performance and firm performance. *Administrative Sciences*, *13*(10), 225.

Jum'a, L., Zighan, S., & Alkalha, Z. (2025). Influence of supply chain digitalization on supply chain agility, resilience and performance: environmental dynamism as a moderator. *Journal of Manufacturing Technology Management*, *36*(4), 798-819.

Kähkönen, A.-K., Evangelista, P., Hallikas, J., Immonen, M., & Lintukangas, K. (2023). COVID-19 as a trigger for dynamic capability development and supply chain resilience improvement. *International Journal of Production Research*, *61*(8), 2696-2715.

Kamble, S. S., Gunasekaran, A., Subramanian, N., Ghadge, A., Belhadi, A., & Venkatesh, M. (2023). Blockchain technology’s impact on supply chain integration and sustainable supply chain performance: Evidence from the automotive industry. *Annals of Operations Research*, *327*(1), 575-600.

Khan, S., Rashid, A., Rasheed, R., & Amirah, N. A. (2023). Designing a knowledge-based system (KBS) to study consumer purchase intention: the impact of digital influencers in Pakistan. *Kybernetes*, *52*(5), 1720-1744.

Kumar, M., Raut, R. D., Gunasekaran, A., Venkateshwarlu, M., & Choubey, V. K. (2023). Developing supply chain capabilities through digitalization and viability for controlling the ripple effect. *IEEE transactions on engineering management*, *71*, 10341-10357.

Lu, Q., Cui, S., Jiang, Y., & Wang, Y. (2025). The effect of SMEs’ digital supply chain capabilities on supply chain financing performance: An information processing theory perspective. *Journal of Enterprise Information Management*, *38*(3), 974-997.

Luqman, N. A., Ahmad, S. Z., & Hussain, M. (2023). Effects of the degree of supply chain resilience capability in supply chain performance in the UAE energy industry. *Supply Chain Management: An International Journal*, *28*(6), 1009-1025.

Malakar, P., Khan, S. A., Gunasekaran, A., & Mubarik, M. S. (2025). Digital technologies for social supply chain sustainability: An empirical analysis through the lens of dynamic capabilities and complexity theory. *IEEE transactions on engineering management*.

Mazar, M., Gossett, K., & Shashi, M. (2024). Sustainable strategies for improving humanitarian supply chain management in the United Nations using dynamic capability theory. *Standards*, *4*(4), 154-175.

Ngo, V. M., Quang, H. T., Hoang, T. G., & Binh, A. D. T. (2024). Sustainability-related supply chain risks and supply chain performances: The moderating effects of dynamic supply chain management practices. *Business Strategy and the Environment*, *33*(2), 839-857.

Pant, P., Dutta, S., & Sarmah, S. (2024). Supply chain relational capital and firm performance: an empirical enquiry from India. *International Journal of Emerging Markets*, *19*(1), 76-105.

Perano, M., Cammarano, A., Varriale, V., Del Regno, C., Michelino, F., & Caputo, M. (2023). Embracing supply chain digitalization and unphysicalization to enhance supply chain performance: a conceptual framework. *International Journal of Physical Distribution & Logistics Management*, *53*(5/6), 628-659.

Pham, T. H., Testorelli, R., & Verbano, C. (2023). Supply chain risk and its impact on performance: A structured literature review. *Journal of Industrial Engineering and Management*, *16*(2), 236-262.

Qiao, R., & Zhao, L. (2023a). Highlight risk management in supply chain finance: effects of supply chain risk management capabilities on financing performance of small-medium enterprises. *Supply Chain Management: An International Journal*, *28*(5), 843-858.

Qiao, R., & Zhao, L. (2023b). Reduce supply chain financing risks through supply chain integration: dual approaches of alleviating information asymmetry and mitigating supply chain risks. *Journal of Enterprise Information Management*, *36*(6), 1533-1555.

Rashid, A., Rasheed, R., Ngah, A. H., Pradeepa Jayaratne, M. D. R., Rahi, S., & Tunio, M. N. (2024). Role of information processing and digital supply chain in supply chain resilience through supply chain risk management. *Journal of Global Operations and Strategic Sourcing*, *17*(2), 429-447.

Rehman, F. U., Imran, M., & Taous, M. (2025). FROM CANE TO CHAIN: THE ROLE OF DIGITALIZATION AND RISK MANAGEMENT IN SUGAR SUPPLY EFFICIENCY. *Journal of Management Science Research Review*, *4*(3), 165-185.

Roy, K. S., Udas, P. B., Alam, B., & Paul, K. (2025). Unveiling Hidden Patterns: A Deep Learning Framework Utilizing PCA for Fraudulent Scheme Detection in Supply Chain Analytics. *International Journal of Intelligent Systems and Applications*, *17*(2), 14-30.

Saddique, F., Patel, K. R., Niaz, M., Chukwu, M. U., & Nwagwu, U. (2023). Impact of supply chain transformation on supply chain performance: the empirical study that bases on mediating role of supply chain resilience on construction organization on Pakistan. *Asian Journal of Engineering, Social and Health*, *2*(9), 1072-1086.

Salam, M. A., & Bajaba, S. (2023). The role of supply chain resilience and absorptive capacity in the relationship between marketing–supply chain management alignment and firm performance: a moderated-mediation analysis. *Journal of business & industrial marketing*, *38*(7), 1545-1561.

Salamah, E., Alzubi, A., & Yinal, A. (2023). Unveiling the impact of digitalization on supply chain performance in the post-COVID-19 era: the mediating role of supply chain integration and efficiency. *Sustainability*, *16*(1), 304.

Shahadat, M. H., Chowdhury, A. H. M. Y., Nathan, R. J., & Fekete-Farkas, M. (2023). Digital technologies for firms' competitive advantage and improved supply chain performance. *Journal of Risk and Financial Management*, *16*(2), 94.

Shi, Y., Zheng, X., Venkatesh, V., Humdan, E. A., & Paul, S. K. (2023). The impact of digitalization on supply chain resilience: an empirical study of the Chinese manufacturing industry. *Journal of business & industrial marketing*, *38*(1), 1-11.

Shishodia, A., Sharma, R., Rajesh, R., & Munim, Z. H. (2023). Supply chain resilience: A review, conceptual framework and future research. *The International Journal of Logistics Management*, *34*(4), 879-908.

Siddiqui, H. M. A., Azher, E., Ali, O., Khan, M. F. U., Salman, S., & Ahmed, O. (2025). Synergizing Resilience and Digitalization: A New Paradigm in Supply Chain Performance. *The Critical Review of Social Sciences Studies*, *3*(1), 3506-3526.

Stadtfeld, G. M., & Gruchmann, T. (2024). Dynamic capabilities for supply chain resilience: a meta-review. *The International Journal of Logistics Management*, *35*(2), 623-648.

Stentoft, J., Wickstrøm, K. A., & Haug, A. (2025). The operational performance effect of digitalized manufacturing processes and the mediation effect of supply chain resilience. *Journal of Manufacturing Technology Management*.

Tan, C. L., Tei, Z., Yeo, S. F., Lai, K.-H., Kumar, A., & Chung, L. (2023). Nexus among blockchain visibility, supply chain integration and supply chain performance in the digital transformation era. *Industrial Management & Data Systems*, *123*(1), 229-252.

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic management journal*, *18*(7), 509-533.

Tortorella, G., Prashar, A., Samson, D., Kurnia, S., Fogliatto, F. S., Capurro, D., & Antony, J. (2023). Resilience development and digitalization of the healthcare supply chain: an exploratory study in emerging economies. *The International Journal of Logistics Management*, *34*(1), 130-163.

Vasilev, V., Stefanova, D., & Popescu, C. (2023). Human capital management and digitalization–From good practices and traditions to sustainable development. In *Digitalization, Sustainable Development, and Industry 5.0* (pp. 41-65). Emerald Publishing Limited.

Waqas, U., Abd Rahman, A., Ismail, N. W., Kamal Basha, N., & Umair, S. (2023). Influence of supply chain risk management and its mediating role on supply chain performance: perspectives from an agri-fresh produce. *Annals of Operations Research*, *324*(1), 1399-1427.

Wei, S., Liu, H., Xu, W., & Chen, X. (2025). The impact of supply chain digitalization on supply chain performance: a moderated mediation model. *Information technology and Management*, *26*(4), 467-481.

Yang, M., Lim, M. K., Qu, Y., Ni, D., & Xiao, Z. (2023). Supply chain risk management with machine learning technology: A literature review and future research directions. *Computers & Industrial Engineering*, *175*, 108859.

Yanginlar, G., Civelek, M. E., & Gülçür, E. (2023). The effect of supply chain risk management on logistics performance and innovation performance. *International Journal of Professional Business Review: Int. J. Prof. Bus. Rev.*, *8*(11), 6.

Zhou, H., Wang, Q., & Yang, Q. (2025). How does digitalisation influence supply chain performance? Evidence from a supply chain risk management perspective. *International Journal of Logistics Research and Applications*, *28*(3), 325-343.