KMANPUB | AI and Tech in Behavioral and Social Sciences Vol. 4 No. 1 (2026): 1-15

Article history:
Received 26 April 2025
Revised 19 June 2025
Accepted 25 June 2025
Published online 01 January 2026

# Developing a Resilient Supply Chain Model Based on Industry 4.0 in the Circular Printing Industry

Manochehr Heidari[1], Mehdi Aliakabarnia Omran[2*], Mahmoud Modiri[3], Mohammad Hossein Darvish Motavali[4]

[1] Department of Industrial Management, Ki. C, Islamic Azad University, Kish, Iran
[2] Department of Management, Amol Institute of Higher Education, Amol, Iran
[3] Department of Industrial Management, ST. C., Islamic Azad University, Tehran, Iran
[4] Department of Industrial Management, WT. C., Islamic Azad University, Tehran, Iran

*** Corresponding author email address**: Mehdiomran@amol.ac.ir

Article Info

**Article type:**
*Original Research*

**How to cite this article:**
Heidari, M., Aliakabarnia Omran, M., Modiri, M., & Darvish Motavali, M. H. (2026). Developing a Resilient Supply Chain Model Based on Industry 4.0 in the Circular Printing Industry. *AI and Tech in Behavioral and Social Sciences, 4*(1), 1-15.
https://doi.org/10.61838/kman.aitech.5033



ABSTRACT

Today, enhancing supply chain resilience has become one of the fundamental responsibilities of management, which can be improved through emerging Industry 4.0 technologies. This study aims to develop a resilient supply chain model based on Industry 4.0 within the circular printing industry. The study was conducted in two qualitative and quantitative phases. In the qualitative phase, the research method was hybrid content analysis (deductive–inductive), and in the quantitative phase, causal and correlational methods were employed. The research population in the qualitative phase included participants such as senior managers, senior experts, consultants from the printing industry, and university faculty members specializing in technology management, supply chain management, and environmental management. These participants were selected using purposive non-probability sampling, totaling 20 individuals. In the quantitative phase, the statistical population consisted of experts working in the printing company, and a complete census method was used to select 107 individuals. The findings of the qualitative phase indicated that the model variables included "transformational capacity," "absorptive capacity," "adaptive capacity," and "continuity capacity." According to the fuzzy DEMATEL results, the variable "transformational capacity" was identified as the most influential factor, which sequentially affects "absorptive capacity," "adaptive capacity," and "continuity capacity." The results of testing the developed model showed that "transformational capacity" has a positive and statistically significant effect on "absorptive capacity," "adaptive capacity," and "continuity capacity." Furthermore, the effect of "absorptive capacity" on "adaptive capacity" and "continuity capacity" was confirmed to be positive and statistically significant. Finally, "adaptive capacity" has a positive and statistically significant relationship with "continuity capacity." The results of the study indicate the critical role of digital strategic transformation in enhancing supply chain resilience capacity within the circular economy.

***Keywords:*** *Digital transformation, resilient supply chain, circular economy, printing industry.*

## 1. Introduction

Supply chains have entered a period characterized by persistent turbulence, cascading disruptions, and tightening sustainability constraints, where competitiveness increasingly depends on the ability to anticipate, absorb, adapt to, and recover from shocks while meeting environmental and circularity imperatives. Contemporary resilience scholarship has consequently moved beyond "bounce-back" recovery toward a capabilities-based view that treats resilience as a set of dynamic, interacting capacities embedded in network structures, information flows, and operational routines. From a network modeling perspective, resilience is shaped by topology, interdependencies, and the propagation of disruption impacts across tiers, making the analytical lens of supply-chain-as-a-network essential for understanding why the same shock produces different outcomes across industries and firms (Borgatti & Li, 2009; Ma et al., 2024). At the same time, sustainability has become inseparable from resilience because supply chains now operate under regulatory, social, and resource pressures that compel firms to redesign processes, products, and sourcing strategies for lower environmental impact and higher continuity. Extending supply chains to address sustainability has highlighted the need for integrated approaches that jointly consider environmental goals and operational robustness rather than treating them as separate agendas (Taghikhah et al., 2019). In this integrated framing, the circular economy (CE) is not merely a sustainability program but an operational architecture that can reduce dependency on virgin inputs, enable recovery loops, and create new buffers against supply scarcity—thereby strengthening resilience when designed and governed appropriately (Fiksel et al., 2021; Kennedy & Linnenluecke, 2022). However, CE configurations also introduce new risk profiles—such as uncertainty in returns, variable quality of recovered materials, and coordination complexity across reverse flows—requiring explicit risk evaluation and mitigation strategies within circular supply chains (De Lima & Seuring, 2023; Lahane & Kant, 2021).

Parallel to the rise of CE and resilience agendas, Industry 4.0 (I4.0) and digital transformation have redefined how supply chains sense, decide, and execute. Digital transformation is increasingly conceptualized as the development of organizational and inter-organizational digital capabilities that enable visibility, coordination, and rapid reconfiguration under disruption. Evidence across sectors suggests that digital transformation can strengthen resilience by enabling real-time monitoring, predictive analytics, and faster cross-functional decision-making (Li et al., 2025; Zhao et al., 2023; Zouari et al., 2021). The mechanisms proposed in the literature emphasize that data connectivity and analytics enhance situational awareness and shorten response cycles, while digital integration across partners reduces information asymmetry and improves synchronization in the face of volatility (Ngo et al., 2023; Yuan et al., 2023). The strategic relevance of these mechanisms became particularly salient during the COVID-19 era, as organizations used digital initiatives to maintain continuity, accelerate remote coordination, and redesign operating models under extreme uncertainty (Elgazzar et al., 2022; Spieske & Birkel, 2021). Yet the digital–resilience link is not automatic; it depends on the alignment of technology investments with process redesign, governance, and human capabilities that convert digital resources into resilient performance (He et al., 2022; Vadigicherla, 2024).

A growing body of research now explicitly examines the intersection of I4.0, CE, and resilience, arguing that resilience in the coming decade will be increasingly "digital-by-design" and "circular-by-architecture." Reviews and roadmaps emphasize that I4.0 technologies—such as cyber–physical systems, IoT-enabled traceability, cloud platforms, and AI—can enable circular supply chains by improving product lifecycle data, reverse logistics coordination, and closed-loop planning, while simultaneously enhancing resilience through better detection and mitigation of disruptions (Cherrafi et al., 2022; Ghobakhloo et al., 2025; Liu et al., 2023). Conceptual and empirical studies further suggest that the joint implementation of CE practices and digital transformation strengthens resilience and sustainability outcomes through complementary effects: CE reduces exposure to input scarcity and waste, while digitalization increases transparency and operational agility within both forward and reverse flows (Bhawna et al., 2024; Duman Altan et al., 2024). In specialized contexts, such as healthcare supply chains, scholars have also emphasized the importance of prioritizing CE transition indicators to ensure that digital and circular initiatives translate into measurable performance improvements, highlighting the managerial need for structured indicator frameworks (Alfina et al., 2025). Moreover, research examining circularity–analytics–resilience pathways shows that CE initiatives can reinforce the role of big data analytics, which in turn supports resilience, suggesting mediated relationships among these constructs in operational settings (Dubey et al., 2019; Islam et al., 2025). These findings collectively underscore that resilient supply chains in the I4.0 era require a systemic approach that


AITBSS
AI and Tech in Behavioral and Social Sciences
E-ISSN: 3041-9433

integrates circular design principles with digitally enabled capabilities.

Despite this progress, three gaps remain prominent in the literature and motivate the present study. First, many studies treat resilience as a unidimensional outcome and report aggregated effects of digital transformation, while fewer explicitly model resilience as a configuration of interrelated capacities. Configuration-oriented research has argued that resilience is achieved through distinct but complementary capacities and strategies that must fit the disruption environment and organizational context, implying that capacity interactions should be modeled rather than assumed (Gaudenzi et al., 2023). Second, while digital transformation research increasingly highlights capabilities, there is still ambiguity about which I4.0-enabled capacities are most influential in driving other resilience capacities, especially in circular settings where reverse flows, product recovery, and resource recirculation add complexity. The concept of a digital supply chain twin has been proposed as a powerful mechanism for disruption risk management and resilience, but its effective use still depends on foundational capabilities and governance that determine how insights are translated into action (Ivanov & Dolgui, 2021; Ivanov et al., 2019). Third, much of the empirical evidence comes from broad manufacturing or service settings, whereas industry-specific contexts with distinct operational logics—such as circular printing—remain underrepresented. Sectoral studies (e.g., shipbuilding and food supply chains) show that digital and resilience dynamics are sensitive to industry characteristics, suggesting the need for domain-grounded model development and testing rather than direct transfer of generic frameworks (Centobelli et al., 2023; Tortorella et al., 2025).

The circular printing industry is a particularly relevant setting for advancing this agenda because it combines resource-intensive processes, quality-sensitive outputs, and increasing pressure to implement circular economy principles (e.g., waste minimization, material recovery, and closed-loop handling of consumables). In circular production contexts, the resilience objective is not limited to maintaining throughput; it also entails maintaining environmental performance and compliance while dealing with variability in returned materials, recycled inputs, and circular logistics operations. Studies on circular economy and resilience in sectoral supply chains have shown both convergences and deviations, indicating that circularity can enhance resilience in some pathways while creating new vulnerabilities in others (Gkountani et al., 2021). Accordingly, firms in such contexts need practical models that specify which digital and circular capacities to build first and how these capacities influence one another to produce resilient performance. Recent research in Iran has pointed to significant implementation challenges for CE and I4.0 in supply chain management, including infrastructural gaps, skill limitations, and coordination barriers—factors that can alter the relative importance of different capabilities and justify context-specific modeling (Sharifian Jazi et al., 2025). Additional evidence from sustainable agriculture circular supply chains emphasizes that I4.0 adoption challenges are not merely technical but also organizational and institutional, further reinforcing the need to conceptualize resilience as a structured set of capacities rather than a single outcome (Karimi Shirazi & Vakil Alroaia, 2024). Complementary applied research in Tehran's online retail sector has also demonstrated the usefulness of designing AI-based resilience models tailored to local operational realities, encouraging methodological approaches that combine qualitative exploration with quantitative validation (Jowkar et al., 2024).

To address these gaps, this study positions digital transformation as a capability-building process that enables circular and resilient supply chain management through distinct but interacting resilience capacities. Recent conceptual work has proposed integrated frameworks for resilience and criticality assessment (particularly in raw material supply chains), emphasizing that resilience must be assessed alongside exposure and criticality dimensions that determine vulnerability to shortages and disruptions (Wietschel et al., 2025). In circular supply chains, these considerations intensify because the availability and quality of secondary materials can be volatile, and resilience depends on the ability to reconfigure sourcing, recovery, and production planning dynamically. Hence, the present study adopts a capacity-based perspective consistent with the view that I4.0 enhances supply chain resilience through technology-enabled sensing, analytics, and reconfiguration, especially in the horizon toward 2035 where disruptions are expected to remain frequent and systemic (Birkel & Müller, 2025). At the operational level, procurement digitalization has been empirically linked to resilience improvements, suggesting that digitizing upstream interfaces and decision processes can materially improve responsiveness and continuity (Harju et al., 2023). At the firm capability level, I4.0 technology capabilities have also been connected to resilience and innovation through mediation pathways, indicating that capabilities may operate indirectly by enabling adaptive behaviors and incremental improvements (Nakandala et al., 2023). Additionally, the North American research agenda on


E-ISSN: 3041-9433

smart supply chain management in I4.0 emphasizes strategic alignment, data governance, and interoperable architectures—elements directly relevant for designing actionable models in complex, multi-actor settings (Zhang et al., 2023).

Methodologically, the intersection of digitalization, CE, and resilience often requires mixed-method designs that can (a) discover context-specific indicators and causal logics and (b) test hypothesized relationships in a rigorous quantitative framework. In supply chain and marketing-related inter-firm technology contexts, integrated DEMATEL and PLS-SEM approaches have been used to identify influence structures among determinants and validate relationships statistically, demonstrating suitability for complex, multi-construct models (Çolak & Kağnıcıoğlu, 2023; Hair et al., 2021). In the context of circular and smart reverse supply chains, recent mixed-method work has similarly shown the value of combining qualitative model development with quantitative testing to produce strategic and implementable frameworks (Sadat Mousavipour et al., 2026). Moreover, as circular models increasingly incorporate reverse logistics and recovery constraints, quantitative modeling of green supply chains that includes recovery capacity and demand uncertainty becomes relevant background for understanding how circular constraints affect performance and resilience, especially under uncertainty (Mehrbakhsh & Ghezavati, 2020). At the same time, the literature also warns that empirical claims must be carefully interpreted when sources are retracted or otherwise problematic; for example, a study on digital transformation era performance within sustainable supply chain strategies has been retracted, underscoring the importance of relying on robust and validated evidence when building theoretical arguments (Nayal et al., 2022).

Building on these foundations, the present study conceptualizes resilient supply chain management in a circular printing context as emerging from four higher-order capacities (transformational, absorptive, adaptive, and continuity), which are theorized to be enabled by I4.0 digital transformation and circular economy strategies. Transformational capacity reflects strategic digital transformation, foresight, and the ability to reorient the supply chain's operating model toward digitally integrated and circular configurations, consistent with organizational resilience building through digital transformation (Ghobakhloo et al., 2025; He et al., 2022). Absorptive capacity reflects the ability to sense, assimilate, and operationalize information and resources (including digital information) to prepare for and withstand disruptions, echoing work linking supply chain digitalization to resilience through visibility and data integration (Zhao et al., 2023; Zouari et al., 2021). Adaptive capacity represents flexibility and reconfiguration capabilities required to adjust sourcing, production, and logistics in response to demand and disruption, aligning with the broader resilience literature and circular risk mitigation perspectives (De Lima & Seuring, 2023; Gaudenzi et al., 2023). Continuity capacity represents the ability to sustain essential operations, recover efficiently, and exploit new opportunities during and after disruptions, consistent with resilience and criticality assessment frameworks and digital transformation–enabled continuity narratives (Elgazzar et al., 2022; Wietschel et al., 2025). Practical guidance further supports integrating CE strategies with digital transformation to achieve sustainable and resilient supply chain practices, providing an applied rationale for examining these capacities in combination (Mamun, 2025; Tathavadekar, 2025). Finally, recent work also highlights that digital transformation can influence resilience through mediated and moderated mechanisms, suggesting that examining direct paths among capacities is useful but should be grounded in a coherent causal structure (Li et al., 2025; Yuan et al., 2023).

This study aims to develop and empirically test a capacity-based model of a resilient supply chain grounded in Industry 4.0 digital transformation and circular economy principles within the circular printing industry.

## 2. Methods and Materials

The present study is an applied research aimed at developing a resilient supply chain model based on Industry 4.0 in the circular printing industry. The study was conducted using a mixed-methods approach, consisting of qualitative and quantitative phases. Based on its nature, the research employed multiple content analysis (deductive and inductive) in the qualitative phase and a descriptive–correlational design in the quantitative phase.

The research population consisted of the printing industry. The statistical sample in the qualitative phase included experts such as senior managers, specialists, consultants from the printing industry, and university faculty members in the fields of technology management and supply chain management. These participants were selected using purposive non-probability sampling with the snowball technique, totaling 20 individuals, based on characteristics such as managerial experience, extensive professional experience, and subject-matter expertise. The statistical sample in the quantitative phase consisted of specialists and


AITBSS E-ISSN: 3041-9433

experts knowledgeable about the research topic within the printing industry. Due to the limited size of the population, a complete census method was used, resulting in the selection of 107 participants.

In this study, the data collection instrument in the qualitative phase was semi-structured interviews, and in the quantitative phase, questionnaires were used. Three questionnaires were employed in this study. The first questionnaire was designed to assess the Content Validity Ratio (CVR), in which experts responded using three options: “essential,” “useful but not essential,” and “not essential.” This questionnaire was used to screen the indicators based on Lawshe’s coefficients. The second questionnaire consisted of pairwise comparisons, in which experts evaluated the degree of influence of each model dimension on others using the following scale: no influence (0), low influence (1), moderate influence (2), high influence (3), and very high influence (4). The third questionnaire was used for model testing, in which responses from the statistical sample were collected using a five-point Likert scale.

The construct validity of the questionnaire was evaluated using the Average Variance Extracted (AVE) method, and discriminant validity was assessed using the Fornell and Larcker (1981) criterion. The reliability assessment criteria included Cronbach’s alpha, composite reliability (CR), and factor loading coefficients, as emphasized by Hair et al. (2021).

Data analysis methods in the qualitative phase involved inductive and deductive multiple content analysis using coding techniques. In the deductive phase, some indicators were identified through a Systematic Literature Review (SLR) using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. In the inductive phase, indicators were discovered through semi-structured interviews with experts. Since this study is exploratory and the relationships between the dimensions were not predetermined, the fuzzy DEMATEL method was used to develop the model. Subsequently, Structural Equation Modeling (SEM) was employed to test the relationships of the developed model, and the analysis was performed using SmartPLS version 3 software. Structural equation modeling provides correlation coefficients to assess the relationships between constructs and the construct quality criteria of the model developed through the fuzzy DEMATEL method, and the effectiveness of this combined methodological approach has been confirmed by previous researchers.

## 3. Findings and Results

To identify and extract the indicators using the multiple content analysis method, a Systematic Literature Review (SLR) was conducted in the deductive phase using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach. In this process, 52 articles were initially identified through searches in the Web of Science and Scopus databases. Most of the identified articles were published from 2021 onward. After screening based on title and abstract, and excluding articles lacking verifiable supporting information, a total of 16 articles were ultimately approved for the deductive phase. In the inductive phase, semi-structured interviews were conducted with experts, and open codes were identified and extracted. Subsequently, using coding techniques, relationships among the extracted codes were identified, and after classification, concepts and categories were formed. To evaluate the extracted codes, the Content Validity Ratio (CVR) was calculated using Lawshe’s coefficient (Lawshe, 1975). In this phase, the total scores obtained from 20 experts for each code were compared against the Lawshe critical value of 0.42. Out of 53 indicators, 5 non-essential indicators were removed, and ultimately, 48 indicators along with 12 components and 4 concepts were confirmed. The qualitative results are presented in Table 1.

**Table 1**

*Concepts and Indicators for Developing a Resilient Supply Chain Model Based on Industry 4.0 in the Circular Printing Industry*

| Concepts | Indicators | Source |
|---|---|---|
| Transformational Capacity | Supply chain foresight and vision; Management commitment to using digital technologies in developing new products/services/solutions; Shared vision and collaboration among supply network members; Investment in supply chain digital technologies and skills | He et al. (2023); Spieske & Birkel (2021); Experts |
| | Knowledge management and organizational learning; Risk management culture (preparedness plans and exercises); Roles and responsibilities; Collaborative culture and crisis management teams | Acquah & Chen (2021); Liu et al. (2023); Experts |

| | | |
|---|---|---|
| | Adoption of advanced and emerging Industry 4.0 technologies; Digital technology integration; IT systems management and quality; Cybersecurity capability | Ivanov & Dolgui (2021); Mourtzis & Panopoulos (2022); Experts |
| Absorptive Capacity | Smart warehousing and inventory storage; Intelligent multimodal transportation and route optimization; Network planning and optimization; Delivery monitoring and improved information flow | Alquraish (2025); Dubey et al. (2019); Experts |
| | Real-time monitoring of supply chain activities; Information and data integration across supply chain systems and platforms; Predictive and early warning systems | Sharma et al. (2024); Ivanov et al. (2019); Ivanov & Dolgui (2021) |
| | Data sharing through collaborative cloud computing relationships; Decision support systems across supply chain systems; Integrated planning to proactively manage disruptions | Zouari et al. (2021); Gaudenzi et al. (2023); Islam et al. (2025) |
| | Increased information flow speed; Virtual models for defect detection and cybersecurity; Supply–demand management systems | Alquraish (2025); Zouari et al. (2021) |
| | Production and quality monitoring and control; Reduction of quality costs; Recycling potential and innovation (remanufacturing and material recovery); Closed-loop recycling of materials, products, and components | Chaouni Benabdellah et al. (2021); Liu et al. (2022); Cherrafi et al. (2022) |
| | Flexibility in multi-sourcing within the circular economy; Smart reverse logistics; Flexible production through cyber–physical systems integration; Diversification, substitution, and customization through intelligent production systems | Zouari et al. (2021); Liu et al. (2022); Cherrafi et al. (2022); Mamun (2025); Experts |
| Continuity Capacity | Recovery capability with minimal costs; Digital optimization for high productivity; Data analytics for operational decision-making; New business models; Identification of new business opportunities; Supply chain and customer integration | Dubey et al. (2019); Ivanov et al. (2019); Ivanov & Dolgui (2021); Experts |
| | Supply chain network reconfiguration; Resource and process reconfiguration; Customer configuration through digital platforms; Redesign of digital integration processes; Infrastructure and equipment reconfiguration | Experts |
| | Customer preference marketing and product/service distribution; Service delivery through digital channels; Integrated systems supporting customer information to improve customer service | Experts |

After extracting the concepts (variables) of the theoretical resilient supply chain model based on Industry 4.0 in the circular printing industry, the fuzzy DEMATEL method was used to determine the relationships and develop the causal model. For this purpose, data related to expert opinions on the intensity of influence among variables were collected and analyzed using the fuzzy DEMATEL approach. In the first step, the direct-relation matrix was constructed, then normalized, and finally, the total-relation matrix was obtained. In the final step, the sums of rows and columns of the total-relation matrix were calculated, and the influence and dependence intensity of variables were determined, as presented in Tables 2 and 3. Figure 1 illustrates the network relationship map and causal relationships among variables.

**Table 2**

*Fuzzy Direct-Relation Matrix of Variables*

| | C1 (L) | C1 (M) | C1 (U) | C2 (L) | C2 (M) | C2 (U) | C3 (L) | C3 (M) | C3 (U) | C4 (L) | C4 (M) | C4 (U) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 0 | 0 | 0 | 0.6 | 0.85 | 1 | 0.6 | 0.85 | 0.95 | 0.45 | 0.7 | 0.9 |
| C2 | 0.1 | 0.35 | 0.6 | 0 | 0 | 0 | 0.45 | 0.7 | 0.95 | 0.55 | 0.8 | 0.95 |
| C3 | 0.05 | 0.3 | 0.55 | 0.1 | 0.35 | 0.6 | 0 | 0 | 0 | 0.7 | 0.95 | 1 |
| C4 | 0.15 | 0.4 | 0.65 | 0.45 | 0.7 | 0.95 | 0.1 | 0.3 | 0.55 | 0 | 0 | 0 |

**Table 3**

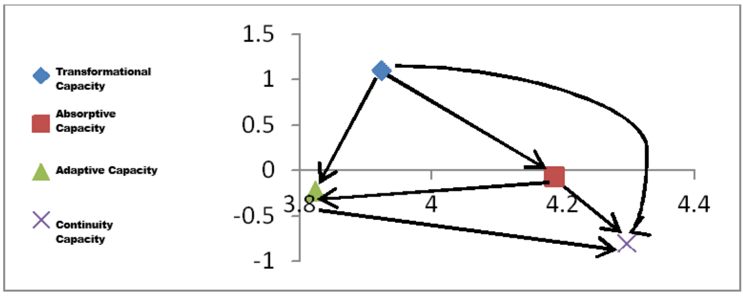
*Importance, Influence, and Dependence of Variables*

| Concepts | $\tilde{D}$ | $\tilde{R}$ | $\tilde{D} + \tilde{R}$ | $\tilde{D} - \tilde{R}$ | Result |
|---|---|---|---|---|---|
| Transformational Capacity | 2.945 | 1.780 | 4.726 | 1.165 | Most influential |
| Absorptive Capacity | 2.484 | 2.566 | 5.050 | -0.081 | Influenced |
| Adaptive Capacity | 2.175 | 2.447 | 4.622 | -0.272 | Influenced |
| Continuity Capacity | 2.162 | 2.974 | 5.135 | -0.812 | Most influenced |


AITBSS
AI and Tech in Behavioral and Social Sciences
E-ISSN: 3041-9433

**Figure 1**

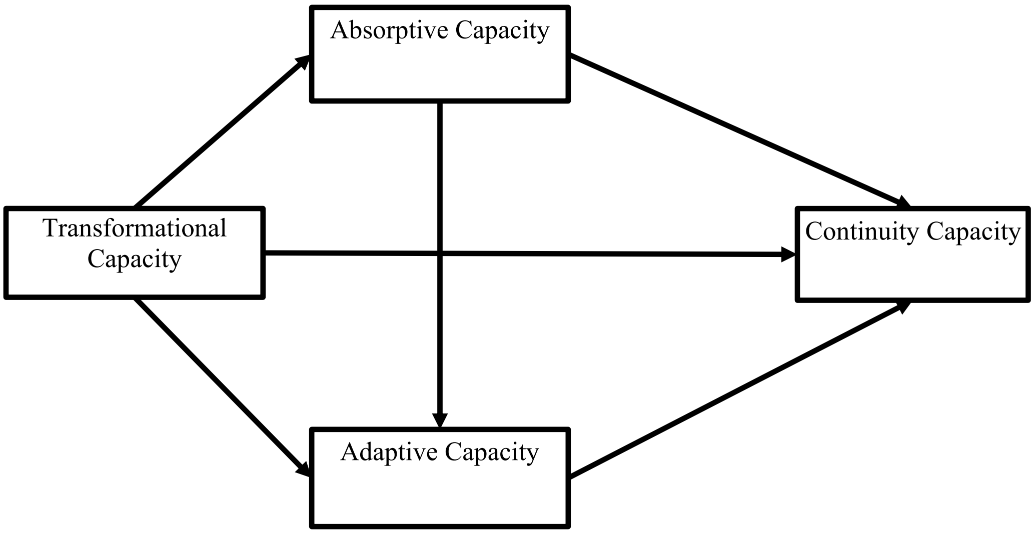
*Network Relationship Map and Causal Relationships Among Variables*




The findings presented in Table 3 and Figure 1 indicate that the variables "transformational capacity," "absorptive capacity," and "adaptive capacity," respectively, influence "continuity capacity" in supply chain resilience. According to these findings, transformational capacity incorporates managerial vision, foresight, and scenario planning for potential disruptions and risks, thereby enhancing absorptive capacity by improving preparedness methods to address disruptions. Furthermore, strengthening absorptive capacity increases supply chain flexibility and agility in responding to demand, ultimately improving continuity capacity. This causal process demonstrates that improving one capacity contributes to strengthening other capacities within a digitally transformed resilient supply chain. Based on these findings, the model developed using the fuzzy DEMATEL approach is presented in this section. According to this model, transformational capacity influences absorptive capacity, adaptive capacity, and continuity capacity. Additionally, absorptive capacity affects adaptive capacity and continuity capacity, and adaptive capacity influences continuity capacity. The model developed using the fuzzy DEMATEL method and the causal relationships are presented in Figure 2.

**Figure 2**

*Digital Transformation Model for Resilient Supply Chain Management in the Circular Economy*




To test the relationships specified in the model presented in Figure 2, Structural Equation Modeling (SEM) was employed using SmartPLS software. The first stage of data analysis concerned the demographic characteristics of the respondents, which are presented in Table 4.



AITBSS
E-ISSN: 3041-9433

**Table 4**

*Demographic Characteristics of Respondents*

| Variable | Frequency (%) | Variable | Frequency (%) |
|---|---|---|---|
| Gender | | Age (Years of Experience) | |
| Male | 78.50% | 11–15 | 7.48% |
| Female | 21.50% | 16–20 | 14.02% |
| Education | | 21–25 | 42.99% |
| Bachelor's degree | 14.02% | More than 25 | 35.51% |
| Master's degree | 50.47% | | |
| PhD and above | 35.51% | | |

The findings in Table 4 indicate that the majority of participants were male. Furthermore, most respondents possessed postgraduate education, indicating a high level of academic expertise among the specialists. Additionally, most respondents had more than 21 years of professional experience, reflecting substantial professional expertise. Based on these characteristics, it can be concluded that the respondents answered the questionnaire items with awareness and careful consideration.

In the structural equation modeling phase, both the measurement model and the structural model were evaluated. The validity of the measurement model was assessed using convergent validity through the Average Variance Extracted (AVE) criterion, and discriminant validity was evaluated using the Fornell and Larcker (1981) criterion. The reliability of the measurement model was assessed using factor loadings, Cronbach's alpha, and composite reliability (CR), as recommended by Hair et al. (2021). The results obtained from SmartPLS indicated that the factor loadings for the indicators "increased information flow speed (Q23)," "identification of new business opportunities (Q36)," "integration of supply chain and customer (Q37)," and "supply chain network reconfiguration (Q38)" were below 0.50. According to Hair et al. (2021), these indicators were removed from the model, and the model was subsequently re-estimated. The results of the revised measurement model indicated that all remaining factor loadings were confirmed, demonstrating strong correlations between the indicators and their respective constructs. Figure 3 illustrates the measurement model along with the factor loadings.

**Figure 3**

*Measurement Model and Factor Loadings of the Revised Model*

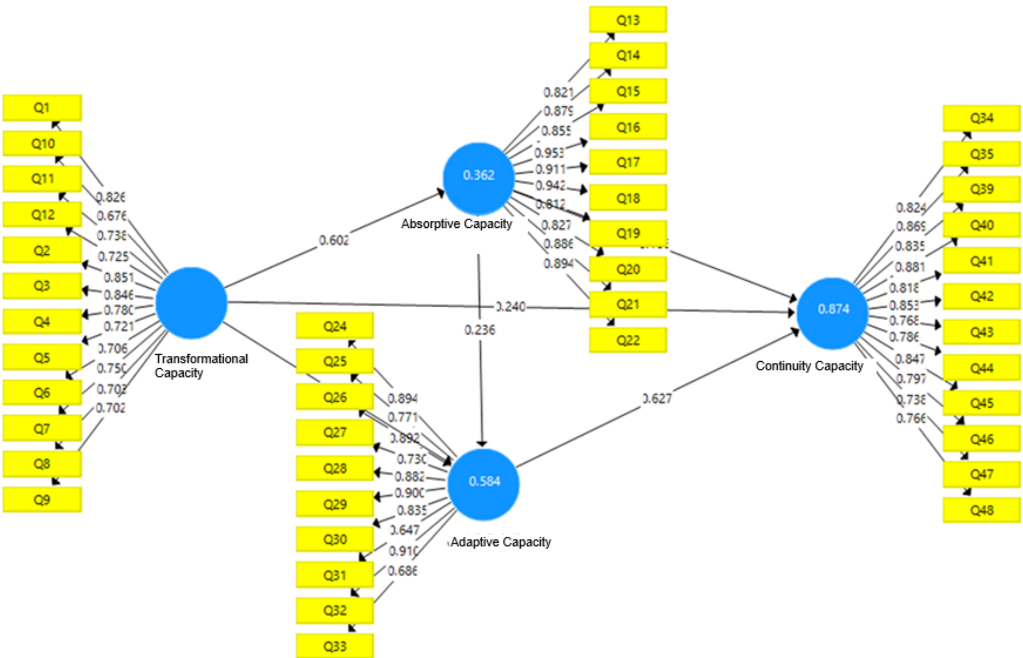


Table 5 presents the calculated values for Average Variance Extracted (AVE), composite reliability, and Cronbach's alpha. The AVE values for all constructs exceeded the threshold of 0.50, confirming convergent validity. These findings indicate strong correlations among the indicators of each construct. Furthermore, the composite reliability values for all constructs exceeded 0.70, confirming adequate internal consistency reliability and demonstrating appropriate correlations between indicators and their respective constructs based on factor loadings. Cronbach's alpha values also exceeded 0.70, confirming the internal consistency reliability of the model. Overall, these findings demonstrate satisfactory construct reliability, indicator reliability, and convergent validity.

**Table 5**

*Measurement Model: Cronbach's Alpha, Composite Reliability, and Convergent Validity*

| Constructs | Cronbach's Alpha | Composite Reliability (CR) | Average Variance Extracted (AVE) |
|---|---|---|---|
| Transformational Capacity | 0.948 | 0.940 | 0.569 |
| Continuity Capacity | 0.954 | 0.960 | 0.666 |
| Adaptive Capacity | 0.944 | 0.953 | 0.673 |
| Absorptive Capacity | 0.967 | 0.971 | 0.773 |

Discriminant validity was also evaluated using the Fornell and Larcker (1981) criterion to assess the correlations among the research variables. The results are presented in Table 6. The findings indicate that the square roots of the AVE values (diagonal elements) are greater than the correlations between constructs, confirming discriminant validity and demonstrating meaningful differentiation among constructs.

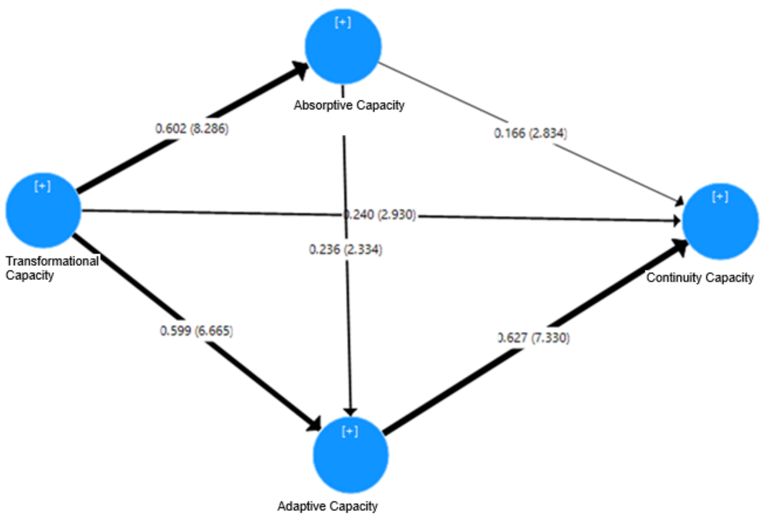
**Table 6**

*Correlation Coefficients and Discriminant Validity Among Research Variables*

| Constructs | Transformational Capacity | Continuity Capacity | Adaptive Capacity | Absorptive Capacity |
|---|---|---|---|---|
| Transformational Capacity | 0.754 | | | |
| Continuity Capacity | 0.705 | 0.816 | | |
| Adaptive Capacity | 0.741 | 0.804 | 0.820 | |
| Absorptive Capacity | 0.602 | 0.684 | 0.596 | 0.879 |

**Figure 4**

*Path Coefficients and Significance Values (T-statistics) of the Structural Model of Industry 4.0-Based Resilient Supply Chain in the Circular Economy*



After confirming the measurement model, the structural model was evaluated. Figure 4 presents the structural model output generated using SmartPLS software.

To evaluate the structural model, the $R^2$ and $Q^2$ criteria were examined. The $R^2$ values, presented at the center of the latent constructs in Figure 4, were 0.874 for continuity capacity, 0.584 for adaptive capacity, and 0.362 for absorptive capacity. According to Hair et al. (2021), these values indicate moderate to high explanatory power, suggesting that the independent variables adequately predict the variance of the dependent variables. Additionally, the predictive relevance ($Q^2$) values were 0.529 for continuity capacity, 0.350 for adaptive capacity, and 0.247 for absorptive capacity, indicating strong predictive relevance of the structural model.

Following confirmation of the structural model, the results of the structural relationships are presented in Table 7.

**Table 7**

*Structural Equation Modeling Results and Direct Relationship Testing*

| Relationship | Beta (β) | T-statistic | P-value | Result | Direction |
|---|---|---|---|---|---|
| Transformational Capacity → Continuity Capacity | 0.240 | 2.930 | 0.004 | Supported | Positive |
| Transformational Capacity → Adaptive Capacity | 0.599 | 6.665 | 0.000 | Supported | Positive |
| Transformational Capacity → Absorptive Capacity | 0.602 | 8.286 | 0.000 | Supported | Positive |
| Adaptive Capacity → Continuity Capacity | 0.627 | 7.330 | 0.000 | Supported | Positive |
| Absorptive Capacity → Continuity Capacity | 0.166 | 2.834 | 0.005 | Supported | Positive |
| Absorptive Capacity → Adaptive Capacity | 0.236 | 2.334 | 0.020 | Supported | Positive |

Note. $|t| > 1.96$ significant at $p < 0.05$; $|t| > 2.58$ significant at $p < 0.01$.

The findings in Table 7 indicate that all relationships between the variables in the Industry 4.0-based resilient supply chain model in the circular economy were statistically significant, as all t-statistics exceeded the threshold of 1.96. The first relationship demonstrates a positive and significant effect of transformational capacity on continuity capacity (β = 0.240, t = 2.930). The second relationship confirms the positive and significant effect of transformational capacity on adaptive capacity (β = 0.599, t = 6.665). The third relationship confirms the positive and significant effect of transformational capacity on absorptive capacity (β = 0.602, t = 8.286). The fourth relationship confirms the significant positive effect of adaptive capacity on continuity capacity (β = 0.627, t = 7.330). The fifth relationship confirms the positive and significant effect of absorptive capacity on continuity capacity (β = 0.166, t = 2.834). The sixth relationship confirms the positive and significant effect of absorptive capacity on adaptive capacity (β = 0.236, t = 2.334). Overall, all six hypothesized relationships were supported.

Finally, the Goodness-of-Fit (GOF) index was calculated using the average AVE and average $R^2$ values to evaluate the overall structural model fit. The GOF value was calculated as $GOF = \sqrt{(0.670 \times 0.607)} = 0.637$. According to Hair et al. (2021), this value exceeds the threshold of 0.36, indicating strong overall model fit.

## 4. Discussion

The present study aimed to develop and empirically validate a resilient supply chain model grounded in Industry 4.0 and circular economy principles within the circular printing industry. The findings demonstrated that transformational capacity exerts a positive and statistically significant influence on absorptive capacity, adaptive capacity, and continuity capacity, while absorptive capacity also positively affects adaptive capacity and continuity capacity, and adaptive capacity significantly enhances continuity capacity. These results confirm that supply chain resilience is not a singular capability but rather an integrated configuration of interdependent capacities that evolve through digitally enabled transformation. The structural relationships identified in this study support the theoretical premise that digital transformation serves as a foundational enabler of resilience, influencing both upstream preparedness and downstream continuity outcomes through layered capability development. The strong explanatory power of the structural model, as indicated by high $R^2$ and predictive relevance ($Q^2$) values, further confirms that transformational capacity plays a central and foundational role in enabling resilient performance in circular supply chains.

The significant and positive effect of transformational capacity on absorptive capacity represents one of the most


AITBSS
AI and Tech in Behavioral and Social Sciences
E-ISSN: 3041-9433

important findings of this study, highlighting the role of digital transformation in enhancing the ability of supply chains to sense, assimilate, and respond to disruption-related information. Transformational capacity reflects strategic foresight, digital integration, and technological readiness, which enable organizations to process and operationalize information effectively. This finding aligns with prior research demonstrating that digital transformation enhances supply chain resilience by improving information visibility, coordination, and predictive decision-making capabilities (Li et al., 2025; Zhao et al., 2023). Similarly, the integration of Industry 4.0 technologies such as IoT, artificial intelligence, and cloud-based systems enhances real-time monitoring and situational awareness, thereby strengthening absorptive capacity and disruption preparedness (Ghobakhloo et al., 2025; Ivanov & Dolgui, 2021). Research has also shown that digital transformation strengthens resilience by enabling organizations to develop sensing and response capabilities, allowing faster identification and mitigation of risks (He et al., 2022). In circular supply chains, absorptive capacity becomes even more critical because organizations must manage uncertainties related to reverse flows, recycling, and material recovery, which require advanced digital coordination and analytics capabilities (Cherrafi et al., 2022; Islam et al., 2025). Therefore, the present study confirms that transformational capacity, enabled by digital transformation, serves as a foundational driver of absorptive capacity in circular supply chain environments.

The results also demonstrated that transformational capacity significantly enhances adaptive capacity, confirming that digital transformation strengthens the flexibility and responsiveness of supply chains. Adaptive capacity reflects the ability of organizations to adjust operational processes, sourcing strategies, and logistics configurations in response to disruptions. This finding supports prior research indicating that Industry 4.0 technologies improve supply chain adaptability by enabling dynamic reconfiguration, predictive analytics, and real-time operational control (Birkel & Müller, 2025; Vadigicherla, 2024). Digital transformation enables supply chains to shift from reactive to proactive operational models, allowing organizations to anticipate disruptions and implement adaptive strategies before performance deterioration occurs (Yuan et al., 2023). Furthermore, the use of digital supply chain twins and cyber–physical systems enhances adaptive capacity by enabling simulation and scenario planning, allowing organizations to test alternative strategies and optimize responses under uncertainty (Ivanov & Dolgui, 2021). This adaptive capability is particularly important in circular supply chains, where operational flexibility is required to manage variable input quality, reverse logistics flows, and material recovery processes (Mamun, 2025). The findings also align with research demonstrating that Industry 4.0 technology capabilities strengthen organizational flexibility and innovation, which serve as mediators of resilience performance (Nakandala et al., 2023). Therefore, transformational capacity enhances adaptive capacity by enabling digital flexibility, operational agility, and strategic responsiveness in circular supply chains.

Another important finding of this study is the significant positive effect of transformational capacity on continuity capacity, indicating that digital transformation directly contributes to supply chain continuity and recovery performance. Continuity capacity reflects the ability of supply chains to maintain operations and recover efficiently following disruptions. This finding is consistent with previous research showing that digital transformation improves supply chain continuity by enabling real-time coordination, rapid decision-making, and operational transparency (Elgazzar et al., 2022; Tortorella et al., 2025). Digital integration across supply chain partners enables faster information sharing, reducing delays in disruption response and improving operational stability (Zouari et al., 2021). Furthermore, predictive analytics and digital monitoring systems enable early detection of disruptions, allowing organizations to implement mitigation strategies before disruptions escalate into operational failures (Dubey et al., 2019). In circular supply chains, digital transformation also improves continuity by enabling more efficient coordination of reverse logistics and recycling operations, reducing dependency on uncertain external inputs (Liu et al., 2023). Therefore, transformational capacity enhances continuity capacity by enabling digitally integrated, resilient, and adaptive operational systems.

The findings also showed that absorptive capacity significantly enhances adaptive capacity, confirming that disruption preparedness and information assimilation play a critical role in enabling operational flexibility. Absorptive capacity enables supply chains to process disruption-related information and implement appropriate adaptive responses. This finding supports prior research demonstrating that information integration and digital visibility enhance supply chain adaptability by enabling faster and more informed decision-making (Gaudenzi et al., 2023; Harju et al., 2023). Supply chains with strong absorptive capacity can anticipate


AITBSS
AI and Tech in Behavioral and Social Sciences
E-ISSN: 3041-9433

disruptions and adjust sourcing, production, and logistics strategies accordingly. In circular supply chains, absorptive capacity is essential for managing reverse flows and recycled materials, which require accurate information processing and coordination (Alfina et al., 2025). Therefore, absorptive capacity serves as a critical intermediate capability that translates digital transformation into adaptive operational performance.

The results further demonstrated that absorptive capacity positively influences continuity capacity, confirming that preparedness and information assimilation directly contribute to operational continuity. This finding aligns with research showing that digital visibility and predictive analytics enhance supply chain continuity by enabling faster disruption response and recovery (Centobelli et al., 2023; Zhao et al., 2023). Absorptive capacity allows organizations to anticipate disruptions and implement preventive measures, reducing operational interruptions. Furthermore, preparedness and risk management practices improve supply chain stability and recovery performance (De Lima & Seuring, 2023). In circular supply chains, absorptive capacity enables organizations to manage uncertainties associated with recycled materials and reverse logistics, ensuring operational continuity despite disruptions (Kennedy & Linnenluecke, 2022). Therefore, absorptive capacity plays a critical role in ensuring resilient supply chain continuity.

Finally, the findings confirmed that adaptive capacity significantly enhances continuity capacity, indicating that operational flexibility directly contributes to supply chain resilience. Adaptive capacity enables supply chains to reconfigure operations, adjust sourcing strategies, and implement alternative logistics arrangements during disruptions. This finding supports prior research demonstrating that supply chain flexibility enhances resilience by enabling rapid operational reconfiguration and disruption recovery (Birkel & Müller, 2025; Ma et al., 2024). Adaptive capacity also enables supply chains to maintain performance stability despite environmental uncertainty and operational disruptions (Fiksel et al., 2021). In circular supply chains, adaptive capacity is particularly important because organizations must continuously adjust recovery processes, recycling operations, and resource utilization strategies (Bhawna et al., 2024). Therefore, adaptive capacity serves as a critical mechanism for ensuring continuity and resilience in circular supply chains.

## 5. Conclusion

Overall, the findings of this study confirm that digital transformation and Industry 4.0 technologies enable resilient supply chain performance by strengthening transformational, absorptive, adaptive, and continuity capacities. These capacities operate as an integrated system, where transformational capacity serves as the foundational driver, enabling absorptive and adaptive capacities, which ultimately enhance continuity capacity. These findings align with prior research demonstrating that digital transformation strengthens supply chain resilience through interconnected capability development and operational integration (Spieske & Birkel, 2021; Zhang et al., 2023). Furthermore, the integration of circular economy principles enhances resilience by reducing resource dependency and improving operational sustainability (Fiksel et al., 2021; Taghikhah et al., 2019). The results also support recent studies emphasizing that digital transformation and circular economy integration serve as key enablers of resilient supply chains in the modern industrial environment (Mamun, 2025; Tathavadekar, 2025). Therefore, this study provides empirical evidence supporting the capability-based view of resilient supply chains in the context of Industry 4.0 and the circular economy.

One of the primary limitations of this study relates to the industry-specific context in which the model was developed and tested. The research focused exclusively on the circular printing industry, which has unique operational characteristics, technological requirements, and circular economy dynamics. While this specificity enhances the relevance and validity of the findings within this sector, it may limit the generalizability of the results to other industries with different operational structures, supply chain configurations, and digital maturity levels. Additionally, the study employed a cross-sectional research design, which captures relationships among variables at a single point in time. However, supply chain resilience and digital transformation are dynamic processes that evolve, and longitudinal data would provide deeper insights into the temporal development of resilience capacities. Another limitation relates to the reliance on self-reported data collected through questionnaires, which may be subject to respondent bias or subjective interpretation. Although validity and reliability tests confirmed the robustness of the measurement model, objective performance data could provide additional validation of the relationships observed in this study.


E-ISSN: 3041-9433

Future research should examine the proposed resilience model across multiple industries, including manufacturing, logistics, healthcare, and service sectors, to evaluate its generalizability and applicability in different operational contexts. Comparative studies could identify industry-specific variations in the relationships among transformational, absorptive, adaptive, and continuity capacities. Longitudinal research designs should also be employed to examine how digital transformation influences resilience capacity development over time and how organizations progress through different stages of digital maturity. Future studies should also explore the role of emerging technologies such as artificial intelligence, blockchain, and digital twins in enhancing resilience capacities. Additionally, future research could examine potential moderating variables such as organizational size, technological readiness, leadership capability, and environmental uncertainty. Finally, future research should consider integrating objective operational performance indicators such as recovery time, disruption frequency, and operational efficiency to provide more comprehensive validation of resilience models.

Managers should prioritize digital transformation initiatives that enhance visibility, data integration, and predictive analytics capabilities, as these serve as foundational drivers of supply chain resilience. Organizations should invest in Industry 4.0 technologies such as IoT, cloud computing, and artificial intelligence to improve operational monitoring, disruption detection, and decision-making capabilities. Managers should also develop organizational capabilities such as digital skills, knowledge management, and risk management culture to strengthen absorptive and adaptive capacities. Supply chain managers should implement circular economy practices such as recycling, reverse logistics, and material recovery to reduce resource dependency and improve resilience. Additionally, organizations should develop flexible operational structures that enable rapid reconfiguration of supply chain processes during disruptions. Finally, collaboration among supply chain partners should be strengthened through digital platforms to enhance coordination, transparency, and operational continuity.

## Authors' Contributions

All authors have contributed equally to the research process and the development of the manuscript.

## Declaration

To correct and improve the academic writing in our paper, we used the language model ChatGPT.

## Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.


## Acknowledgments

We want to express our gratitude to all individuals who helped us with the project.


## Declaration of Interest

The authors report no conflict of interest.


## Funding

According to the authors, this article has no financial support.


## Ethics Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

## References


Alfina, K. N., Ratnayake, R. C., Wibisono, D., Basri, M. H., & Mulyono, N. B. (2025). Prioritizing Performance Indicators for the Circular Economy Transition in Healthcare Supply Chains. *Circular Economy and Sustainability*, *5*(1), 231-276. https://doi.org/10.1007/s43615-024-00436-9

Bhawna, Kang, P. S., & Sharma, S. K. (2024). Bridging the gap: a systematic analysis of circular economy, supply chain management, and digitization for sustainability and resilience. *Operations Management Research*, *17*(3), 1039-1057. https://doi.org/10.1007/s12063-024-00490-4

Birkel, H., & Müller, J. M. (2025). Resilient by nature or technology? How Industry 4.0 enhances Supply Chain Resilience until 2035. *Supply Chain Management: An International Journal*, *30*(3), 304-322. https://doi.org/10.1108/SCM-07-2023-0340

Borgatti, S. P., & Li, X. (2009). On social network analysis in a supply chain context. *Journal of Supply Chain Management*, *45*(2), 5-22. https://doi.org/10.1111/j.1745-493X.2009.03166.x

Centobelli, P., Cerchione, R., Maglietta, A., & Oropallo, E. (2023). Sailing through a digital and resilient shipbuilding supply chain: An empirical investigation. *Journal of Business Research*, *158*, 113686-113686. https://doi.org/10.1016/j.jbusres.2023.113686

Cherrafi, A., Chiarini, A., Belhadi, A., El Baz, J., & Benabdellah, A. C. (2022). Digital technologies and circular economy practices: vital enablers to support sustainable and resilient supply chain management in the post-COVID-19 era. *The*

*TQM Journal*, *34*(7), 179-202. https://doi.org/10.1108/TQM-12-2021-0374
Çolak, H., & Kağnıcıoğlu, C. H. (2023). Predicting the Blockchain Technology Acceptance in Supply Chains with Inter-Firm Perspective: An Integrated DEMATEL and PLS-SEM Approach. *Journal of Business-to-Business Marketing*, 1-24. https://doi.org/10.1080/1051712X.2023.2214543
De Lima, F. A., & Seuring, S. (2023). A Delphi study examining risk and uncertainty management in circular supply chains. *International Journal of Production Economics*, *258*, 108810-108810. https://doi.org/10.1016/j.ijpe.2023.108810
Dubey, R., Gunasekaran, A., Childe, S. J., Blome, C., & Papadopoulos, T. (2019). Big data and predictive analytics and manufacturing performance: integrating institutional theory, resource-based view and big data culture. *British Journal of Management*, *30*(2), 341-361. https://doi.org/10.1111/1467-8551.12355
Duman Altan, A., Beyca, Ö. F., & Zaim, S. (2024). Link between Digital Technologies Adoption and Sustainability Performance: Supply Chain Traceability/Resilience or Circular Economy Practices. *Sustainability*, *16*(19), 8694-8694. https://doi.org/10.3390/su16198694
Elgazzar, Y., El-Shahawy, R., & Senousy, Y. (2022, 2022). The role of digital transformation in enhancing business resilience with pandemic of COVID-19. Digital transformation technology: Proceedings of ITAF 2020,
Fiksel, J., Sanjay, P., & Raman, K. (2021). Steps toward a resilient circular economy in India. *Clean Technologies and Environmental Policy*, *23*, 203-218. https://doi.org/10.1007/s10098-020-01982-0
Gaudenzi, B., Pellegrino, R., & Confente, I. (2023). Achieving supply chain resilience in an era of disruptions: a configuration approach of capacities and strategies. *Supply Chain Management: An International Journal*, *28*(7), 97-111. https://doi.org/10.1108/SCM-09-2022-0383
Ghobakhloo, M., Iranmanesh, M., Foroughi, B., Tseng, M. L., Nikbin, D., & Khanfar, A. A. (2025). Industry 4.0 digital transformation and opportunities for supply chain resilience: a comprehensive review and a strategic roadmap. *Production Planning & Control*, *36*(1), 61-91. https://doi.org/10.1080/09537287.2023.2252376
Gkountani, V. A., Tsoulfas, G. T., & Rachaniotis, N. P. (2021, 2021). Circular economy and resilience: convergences and deviations in the case of agri-food supply chains. IOP Conference Series: Earth and Environmental Science,
Hair, J. F., Astrachan, C. B., Moisescu, O. I., Radomir, L., Sarstedt, M., Vaithilingam, S., & Ringle, C. M. (2021). Executing and interpreting applications of PLS-SEM: Updates for family business researchers. *Journal of Family Business Strategy*, *12*(3), 100392-100392. https://doi.org/10.1016/j.jfbs.2020.100392
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. https://doi.org/10.1108/SCM-08-2022-0312
He, Z., Huang, H., Choi, H., & Bilgihan, A. (2022). Building organizational resilience with digital transformation. *Journal of Services Management*. https://doi.org/10.1108/JOSM-06-2021-0216
Islam, S., Hassan, S., Hossain, S., Ahmed, T., Karmaker, C. L., & Bari, A. M. (2025). Exploring the influence of circular economy on big data analytics and supply chain resilience nexus: A structural equation modeling approach. *Green Technologies and Sustainability*, 100219-100219. https://doi.org/10.1016/j.grets.2025.100219
Ivanov, D., & Dolgui, A. (2021). A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0. *Production Planning & Control*, *32*(9), 775-788. https://doi.org/10.1080/09537287.2020.1768450
Ivanov, D., Dolgui, A., & Sokolov, B. (2019). The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. *International Journal of Production Research*, *57*(3), 829-846. https://doi.org/10.1080/00207543.2018.1488086
Jowkar, A. A., Mahmoudi Meymand, M., Parhizgar, M. M., & Mohebali, M. M. (2024). Designing an Artificial Intelligence-Based Supply Chain Resilience Model in the Online Retail Sector (Case Study: Tehran City). *Scientific-Research Quarterly of Economics and Urban Management*, *12*(45), 107-129. https://en.civilica.com/doc/2093804/
Karimi Shirazi, H., & Vakil Alroaia, Y. (2024). Identification of the challenges of using the technology of 4.0 industry in the circular supply chain of sustainable agriculture. *Journal of Public Service Marketing*, *2*(1). https://en.civilica.com/doc/1994245/
Kennedy, S., & Linnenluecke, M. K. (2022). Circular economy and resilience: A research agenda. *Business Strategy and the Environment*, *31*(6), 2754-2765. https://doi.org/10.1002/bse.3004
Lahane, S., & Kant, R. (2021). Evaluation and ranking of solutions to mitigate circular supply chain risks. *Sustainable Production and Consumption*, *27*, 753-773. https://doi.org/10.1016/j.spc.2021.01.034
Li, P., Chen, Y., & Guo, X. (2025). Digital transformation and supply chain resilience. *International Review of Economics & Finance*, *99*, 104033-104033. https://doi.org/10.1016/j.iref.2025.104628
Liu, L., Song, W., & Liu, Y. (2023). Leveraging digital capabilities toward a circular economy: Reinforcing sustainable supply chain management with Industry 4.0 technologies. *Computers & Industrial Engineering*, *178*, 109113-109113. https://doi.org/10.1016/j.cie.2023.109113
Ma, C., Zhang, L., You, L., & Tian, W. (2024). A review of supply chain resilience: A network modeling perspective. *Applied Sciences*, *15*(1), 265-265. https://doi.org/10.3390/app15010265
Mamun, M. (2025). Circular Economy and Digital Supply Chain: The role of emerging technologies for facilitating sustainability. https://osuva.uwasa.fi/items/59acbf49-8c3b-4826-ab9f-e973b2c73e76
Mehrbakhsh, S., & Ghezavati, V. (2020). Mathematical modeling for green supply chain considering product recovery capacity and uncertainty for demand. *Environmental Science and Pollution Research*, *27*, 44378-44395. https://doi.org/10.1007/s11356-020-10331-z
Nakandala, D., Yang, R., Lau, H., & Weerabahu, S. (2023). Industry 4.0 technology capabilities, resilience and incremental innovation in Australian manufacturing firms: a serial mediation model. *Supply Chain Management: An International Journal*, *28*(4), 760-772. https://doi.org/10.1108/SCM-08-2022-0325
Nayal, K., Raut, R. D., Yadav, V. S., Priyadarshinee, P., & Narkhede, B. E. (2022). RETRACTED: The impact of sustainable development strategy on sustainable supply chain firm performance in the digital transformation era. *Business Strategy and the Environment*, *31*(3), 845-859. https://doi.org/10.1002/bse.2921
Ngo, V. M., Pham, H. C., & Nguyen, H. H. (2023). Drivers of digital supply chain transformation in SMEs and large enterprises-a case of COVID-19 disruption risk. *International*



AITBSS AI and Tech in Behavioral and Social Sciences
E-ISSN: 3041-9433

*Journal of Emerging Markets*, *18*(6), 1355-1377. https://doi.org/10.1108/IJOEM-10-2021-1561

Sadat Mousavipour, S., Modiri, M., Fathi Hafshjani, K., & Hashemzadeh Khorasgani, G. (2026). Designing a Strategic Smart Reverse Supply Chain Model in the Tire Manufacturing Industry with a Mixed-Methods Approach. *Modern Management Engineering*, *11*(2). https://www.magiran.com/paper/2866824/designing-a-model-of-a-smart-reverse-supply-chain-strategic-in-the-rubber-industry-with-a-mixed-approach?lang=en

Sharifian Jazi, S., Mohammadi, A., Abbasi, A., & Alimohammadlou, M. (2025). Identifying Challenges Affecting the Implementation of Circular Economy and Industry 4.0 in Supply Chain Management. *Management Research in Iran*, *28*(2), 146-183. https://mri.modares.ac.ir/article_661_en.html?lang=fa

Spieske, A., & Birkel, H. (2021). Improving supply chain resilience through Industry 4.0: A systematic literature review under the impressions of the COVID-19 pandemic. *Computers & Industrial Engineering*, *158*, 107452-107452. https://doi.org/10.1016/j.cie.2021.107452

Taghikhah, F., Voinov, A., & Shukla, N. (2019). Extending the supply chain to address sustainability. *Journal of Cleaner Production*, *229*, 652-666. https://doi.org/10.1016/j.jclepro.2019.05.051

Tathavadekar, V. P. (2025). Sustainable and Resilient Supply Chain Practices through Digital Transformation and Circular Economy Strategies. https://zenodo.org/records/15605978/files/V13i601.pdf?download=1

Tortorella, G., Gloet, M., Samson, D., Kurnia, S., Fogliatto, F. S., & Anzanello, M. J. (2025). Food supply chain resilience through digital transformation: a mixed-method approach. *The International Journal of Logistics Management*, *36*(2), 381-412. https://doi.org/10.1108/IJLM-01-2024-0030

Vadigicherla, M. S. (2024). Enhancing Supply Chain Resilience through Emerging Technologies: A Holistic Approach to Digital Transformation. https://www.researchgate.net/publication/384483999

Wietschel, L., Helbig, C., Hillenbrand, M., & Thorenz, A. (2025). Integrated conceptual framework for resilience and criticality assessments for raw material supply chains. *Resources, Conservation and Recycling*, *218*, 108249-108249. https://doi.org/10.1016/j.resconrec.2025.108249

Yuan, Y., Tan, H., & Liu, L. (2023). The effects of digital transformation on supply chain resilience: a moderated and mediated model. *Journal of Enterprise Information Management*. https://doi.org/10.1108/JEIM-09-2022-0333

Zhang, G., Yang, Y., & Yang, G. (2023). Smart supply chain management in Industry 4.0: the review, research agenda and strategies in North America. *Annals of Operations Research*, *322*(2), 1075-1117. https://doi.org/10.1007/s10479-022-04689-1

Zhao, N., Hong, J., & Lau, K. H. (2023). Impact of supply chain digitalization on supply chain resilience and performance: A multi-mediation model. *International Journal of Production Economics*, *259*, 108817-108817. https://doi.org/10.1016/j.ijpe.2023.108817

Zouari, D., Ruel, S., & Viale, L. (2021). Does digitalising the supply chain contribute to its resilience? *International Journal of Physical Distribution & Logistics Management*, *51*(2), 149-180. https://doi.org/10.1108/IJPDLM-01-2020-0038


E-ISSN: 3041-9433