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## Digitizing the Chain: Effects of Supply Chain Digitalization on Efficiency in Indian Manufacturing SMEs

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**Abstract:** Supply chain digitalization has become a key driver of productivity and competitiveness, particularly for Small and Medium-sized Enterprises (SMEs) operating in a dynamic manufacturing environment. This study investigates the impact of supply chain digitalization on the operational efficiency of manufacturing SMEs in India, an emerging economy where digital transformation is gaining momentum. Based on data from a structured survey of Indian manufacturing SMEs, Structural Equation Modeling (SEM) is used to analyze the impact of key dimensions of digitalization, such as digital integration, real-time data access, and information visibility in the supply chain, on their performance. The empirical findings indicate that digitalization has significant positive impacts on supply chain responsiveness, reducing lead times and operating costs, and improving coordination among supply chain partners. This research emerges in a context where digitized supply chains are better able to adapt to market fluctuations and customer demands. These analytical results offer practical insights for SME managers, technology providers, and policy makers seeking to promote digital adoption in the manufacturing sector. The research also contributes to the literature on digital transformation by providing evidence from an Indian SME context where resource constraints and infrastructure challenges sometimes hinder technology implementation.

**Keywords:** Digitization, Supply chain management, SMEs, SEM, India.

### 1. Introduction

Digital transformation is transforming various aspects of the global supply chain, integrating advanced technology into core operational processes. Tools such as the Internet of Things (IoT), cloud computing, Artificial Intelligence (AI), and big data analytics are integral to supply chain management, providing visibility, responsiveness, and agility (Mandal, 2018). These technologies facilitate real-time monitoring, automated decision-making, and seamless coordination among supply chain actors, improving efficiency and competitiveness. While large corporations typically lead digital transformation initiatives, small and medium-sized enterprises (SMEs), particularly in emerging economies like India, are beginning to recognize the strategic importance of digital transformation. There are many benefits to SMEs in digital technologies, such as demand forecasting, shorter lead times and increased resilience of the supply chain (Wu *et al.*, 2024). In environments with limited resources, digital adoption has the potential to be a critical leverage for addressing basic structure inefficiencies and scaling operational performance. However, transition to digital systems remains uneven, being inhibited by financial, technical and infrastructural limitations (Trevisan *et al.*, 2023).



Despite the recent interest of academics, much of the existing research concentrates on big companies or theoretical models with mediators or moderators such as technological readiness, organizational culture or environmental uncertainty (Wu *et al.*, 2024). Empirical studies examining the direct impact of the components of digitalization on operational outcomes, particularly in the context of the SMEs in emerging economies, are still scarce. Furthermore, there is an underexplored construct-level clarity of the role that individual digital technologies play in enabling supply chain performance. To overcome these gaps, this study examines the direct impact of four important digitalization constructs, namely, Digital Traceability Systems (DTS), Algorithmic Decision Support (ADS), Cloud-Based Collaborative Platforms (CCP), Cyber-Physical Asset Monitoring (CPAM) on Supply Chain Efficiency (SCE) in Indian manufacturing SMEs. Each of these constructs is a distinct technological capability which improves transparency, decision accuracy, inter-firm collaboration and real-time monitoring.

Recent studies highlight that supply chain digitalization has become central to competitiveness in both developed and developing economies. Sama *et al.* (2023) identify the positive effects of digital platforms in driving agility and resilience in emerging market supply chains, while Nalluri *et al.* (2023) demonstrate that digital transformation is reshaping SME strategy across sectors. Similarly, Li *et al.* (2020) and Nalluri *et al.* (2024) provide evidence that Industry 4.0 tools are becoming increasingly accessible to SMEs, but their adoption is uneven. Gunasekaran *et al.* (2017) highlight the distinct operational challenges SMEs face in managing supply chain complexity, while Nambisan *et al.* (2019) advances the discussion by conceptualizing digital transformation as a technological and organizational phenomenon. Despite these contributions, gaps remain in our understanding of the impact of specific digital technologies on the performance of SME supply chains in emerging economies. Most existing research has been conducted in large firm contexts (e.g., Zhong *et al.*, 2017; Ivanov and Dolgui, 2020), with limited empirical evidence from SMEs, often constrained by financial, infrastructure, and skill barriers. Furthermore, recent calls for research highlight the need for context-specific studies that consider SMEs' strategic adoption of digital tools to become more efficient in resource-constrained environments (Nalluri *et al.*, 2023; Sama *et al.*, 2023). To address this gap, the current study contributes by empirically assessing the direct impact of four digitalization constructs on supply chain efficiency in Indian SMEs. This research contributes to the literature by introducing and empirically validating a direct-impact model of supply chain digitalization, departing from traditional frameworks reliant on mediators and moderators. It advances the Resource-Based View (RBV) by demonstrating how tangible digital resources, when strategically deployed can generate operational advantages. The study also responds to recent calls for context-specific research in emerging markets, offering practical insights for SME managers and policymakers aiming to accelerate digital adoption.

The remainder of this paper is structured as follows. Section 2 reviews the theoretical foundations and empirical studies related to supply chain digitalization and SME performance. Section 3 presents the conceptual framework and hypothesis development. Section 4 describes the research methodology, including survey design, sampling, and data analysis techniques. Section 5 reports the empirical findings. Section 6 discusses theoretical and practical implications, and Section 7 concludes with limitations and directions for future research.

## 2. Literature Review

### 2.1 Supply chain digitalization in SMEs

The digitalization of supply chains has become a strategic imperative in variety of industries. However, its spreading among SMEs especially in new economy nations such as India has been on a slower curve. Indian manufacturing SMEs are rapidly adopting digital technologies, prompted by government initiatives such digital India and make in India and as also by need for operational resiliency as after the emergence of Covid 19 (Shrivastava *et al.*, 2025). While large companies usually drive innovation cycles, SMEs are realizing the importance of digitizing to better visibility, traceability and efficiency. Despite this momentum, SMEs encounter significant challenges in their digital adoption processes, including lack of access to capital, inadequate infrastructure, skills shortage and resistance to change (Wu *et al.*, 2024). Unlike large businesses with the capacity to absorb costs and risk associated with adopting new technology, SMEs tend to operate on thin margins and do not have in-house expertise so integrating technology can be a complicated process. Nevertheless, the digitalization process also offers the great opportunity, i.e. improving the coordination with suppliers, logistics, and a great increase in customer service (Seyedghcaught *et al.*, 2020). Studies are starting to better assess that imposing some digital tools on the ground can deliver corrective



benefits, measurable in terms of performance improvement, for SMEs in resource-constrained settings (Wu *et al.*, 2024).

## 2.2 Key dimensions of digitalization

### 2.2.1 Digital Traceability Systems (DTS)

Digital traceability systems are used by firms to track materials, components and finished goods in real-time throughout the supply chain. By leveraging technologies like barcoding, RFI and blockchain, DTS provides greater transparency and authenticity of a product, as well as recall capabilities (Cui, 2025). For SMEs, traceability has a particular legitimacy in enhancing compliance, minimizing pilferage and generating trust with their downstream partners. Previous evaluations confirm that traceability systems directly influence the performance of delivery, cut lead times and help to proactively fix issues (Tarannum and Hossain, 2024).

### 2.2.2 Algorithmic Decision Support (ADS)

Algorithmic decision support refers to the use of analytics, AI, and machine learning to support planning, forecasting, and operational decisions. These tools can automate inventory control, demand planning, and procurement processes, thus minimizing human bias and enhancing accuracy (Nweje & Taiwo, 2025). ADS is especially relevant for SMEs that often operate with lean resources. By integrating historical data with predictive algorithms, these systems help firms become more responsive to demand fluctuations and supply-side disruptions (Tarannum & Hossain, 2024).

### 2.2.3 Cloud-Based Collaborative Platforms (CCP)

Cloud-Based collaborative platforms facilitate inter-organizational coordination through shared digital workspaces and real-time communication tools. CCPs enable SMEs to engage in joint planning, order tracking, and data sharing with suppliers and customers across the supply chain (Bordonaba-Juste and Cambra-Fierro, 2009). These platforms lower entry barriers to digital collaboration by offering scalable, subscription-based models. Although SMEs may initially adopt such platforms for basic functions, deeper integration has been linked to reduced cycle times and improved agility (Ahmed *et al.*, 2022).

### 2.2.4 Cyber-Physical Asset Monitoring (CPAM)

Cyber-Physical asset monitoring integrates IoT sensors and networked systems to track the status and performance of physical assets in real time. CPAM solutions provide early warnings for maintenance needs, detect anomalies, and allow for remote diagnostics, thereby reducing unplanned downtime and optimizing resource utilization (Arin *et al.*, 2024). In the SME context, the deployment of such systems helps minimize disruptions in production and enhances overall supply chain responsiveness.

### 2.2.5 Supply Chain Efficiency (SCE)

Supply chain efficiency refers to the extent to which a firm's supply chain operations achieve optimal performance in terms of time, cost, and service. Common indicators of SCE include lead-time reduction, cost-to-serve optimization, and service level improvements (Kim, 2006). Lead-time captures the responsiveness of the supply chain, while cost measures reflect resource efficiency. Service levels pertain to customer satisfaction and order fulfillment accuracy. While SCE has been extensively studied in large-firm settings, its drivers in SME supply chains particularly in the Indian context remain underexplored. Recent research suggests that digitalization can significantly enhance SCE by automating routine tasks, enabling real-time monitoring, and supporting data-driven decision-making (Bordonaba-Juste & Cambra-Fierro, 2009). However, few studies provide a direct empirical assessment of how specific digitalization dimensions impact SCE in SMEs, revealing a critical gap that this study aims to address.

## 2.3 Theoretical Perspectives from Social Sciences

While much of the literature on supply chain digitalization emphasizes technological and operational aspects, it is equally important to consider sociological and institutional perspectives that shape adoption processes. Institutional Theory emphasizes that the practices of an organization would be affected by institutional pressures, such as coercive mechanism from regulatory bodies, mimetic pressure from other organizations, and normative expectations from industry associations (DiMaggio & Powell, 1983). In the Indian SME context such forces frequently lead to the use of or non-use of digital technologies. Similarly, Diffusion of Innovation (DI) theory offers a useful perspective to explain the differing rates of digital adoption among SMEs (Rogers, 2003). This theory posits that certain factors significantly influence the likelihood of adopting new technologies: relative advantage, compatibility with existing processes, complexity, trialability, and observability are characteristics that significantly influence the likelihood of adoption. Therefore, integrating these perspectives into studies of supply chain digitalization expands our understanding beyond the dimensions of efficiency and technological accessibility, allowing us to grasp the social and institutional dynamics that influence adoption behavior.

To provide a more balanced perspective, this research also incorporates insights from social science research on technology adoption and development in India. Madon (2009) emphasizes the importance of digital initiatives in facilitating rural development and e-governance, while Jeffrey & Doron (2013) highlight the impact of widespread access to mobile technologies on business management, political participation, and social interaction. Parthasarathi (2010) explores the impact of globalization and information technologies on the growth and transformation of Indian SMEs. These studies reinforce the interdisciplinary significance of this research by demonstrating that digitalization is not merely a technological shift but also a driver of social and economic transformation in emerging economies.

## 2.4 Interdisciplinary Perspectives

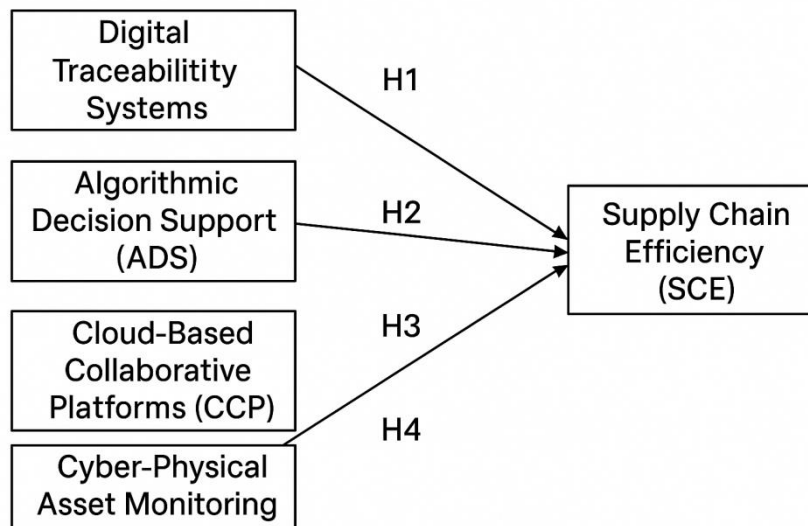
Beyond management and operations research, insights from other disciplines help contextualize SME digital adoption. The economics of innovation highlights how technological upgrading drives productivity and competitiveness, but also generates uneven patterns of development (Schumpeter, 1942). Public policy perspectives emphasize the role of state interventions, financing schemes, and digital literacy initiatives in enabling SMEs to adopt new technologies (Yang *et al.*, 2025). Moreover, socio-technical systems theory underscores that digital transformation is shaped not only by technical tools but also by organizational culture, institutional context, and human factors (Yang *et al.*, 2025). By incorporating these perspectives, the study positions supply chain digitalization as both a managerial strategy and a socio-economic process with developmental implications.

## 2.5 Conceptual Framework and Hypotheses

The conceptual framework guiding this study is grounded in the theory of digital transformation and the Resource-Based View (RBV) of the firm, which posits that strategically embedded digital capabilities can enhance organizational performance (Atobishi *et al.*, 2024). In the context of Indian manufacturing SMEs, supply chain performance is increasingly dependent on the firm's ability to adopt and integrate digital systems that provide visibility, automation, and responsiveness. Drawing from extant literature on supply chain digitalization, this framework identifies four key digitalization dimensions, DTS, ADS, CCP, and CPAM as predictors of SCE. The visual model (see Figure 1) presents a unidirectional framework in which each digitalization construct serves as an independent variable influencing the dependent construct, SCE. All constructs are modeled as reflective first-order latent variables, each measured through multi-item scales developed from validated sources. Figure 1 presents the conceptual framework, illustrating the direct effects of four digitalization constructs DTS, ADS, CCP, and CPAM on SCE. Each construct is hypothesized to have a positive and significant impact (H1–H4) on SCE in the context of Indian manufacturing SMEs. Based on theoretical and empirical foundations, the following hypotheses were formulated:

- H1: Digital Traceability Systems (DTS) have a significant positive effect on Supply Chain Efficiency (SCE).
- H2: Algorithmic Decision Support (ADS) has a significant positive effect on SCE.
- H3: Cloud-Based Collaborative Platforms (CCP) have a significant positive effect on SCE.
- H4: Cyber-Physical Asset Monitoring (CPAM) has a significant positive effect on SCE.





**Figure 1.** Conceptual framework

### 3. Research design

This study adopted a quantitative, cross-sectional research design to empirically investigate the influence of digitalization dimensions on SCE within Indian manufacturing SMEs. A cross-sectional approach was deemed appropriate as it allows for data collection at a single point in time, capturing prevailing practices and perceptions related to digital transformation and operational performance. This design is consistent with prior studies examining technology adoption and supply chain practices in emerging economies.

#### 3.1 Questionnaire development and data collection

The survey instrument consisted of reflective measurement constructs, each assessed using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The items were adapted based from systematic literature review and validated scales obtained from previous empirical studies in the fields of supply chain management, digital transformation, and small business operations (Sahoo et al., 2023). The survey included items for five main constructs: DTS, ADS, CCP, CPAM, and SCE. The target population consisted of manufacturing SMEs operating in India as per the Ministry of SMEs classification. The Cochran formula was used to determine the adequate sample size for a large population in the study (Sahoo et al., 2023). A minimum sample size of 385 was considered statistically sufficient, with a 95% confidence level and a 5% margin of error. Data were collected through both online and offline survey distribution, targeting decision-makers such as operations managers, supply chain professionals, and digital transformation officers. A stratified purposive sampling strategy was adopted to ensure adequate representation across key manufacturing sectors (e.g., textiles, automotive, food processing, chemicals) and regions (e.g., northern, southern, eastern, western India). This approach ensured that findings were both statistically valid and contextually relevant to India's diverse SME ecosystem. In addition to operational structures, the survey included questions on the socio-demographic characteristics of participating SMEs and their managers. Specifically, data were collected on the type of business ownership (family or non-family), gender distribution of employees, education levels of managers, firm size, sector, annual turnover, and number of years in business. These variables are summarized in Table 1 in Section 5.1. Although not directly modeled in the structural equation analysis, they provide important contextual information on how digitalization practices change in different institutional and social settings. In line with previous methodological recommendations, these socio-demographic factors are considered potential moderators for future research (Creswell and Creswell, 2018).

#### 3.2 Data analysis techniques

The study employed various statistical techniques to analyze the data. Descriptive statistics, including means, standard deviations, and frequencies, were used to summarize demographic characteristics and trends at the



construct level. Construct reliability was assessed using Cronbach's alpha, which provided internal consistency. Pearson correlation analysis was conducted to examine bivariate relationships between variables. Exploratory Factor Analysis (EFA), including principal components analysis and varimax rotation, was used to assess construct validity. The relationships between independent variables and SCE were tested using both simple linear regression and multiple regression analyses, with results interpreted through  $R^2$  values, standardized beta coefficients ( $\beta$ ), t-values, and significance levels (p-values). These techniques collectively ensured robust testing of the hypothesized model.

## 4. Results and analysis

### 4.1 Demographic profile of respondents

Table 1 presents the demographic distribution of 385 respondents from Indian manufacturing SMEs. The data reveal that textiles and apparel represent the largest segment of manufacturing sectors surveyed (23.9%), followed by automotive components (20.3%) and food processing (16.9%). These figures align with the dominance of textile-based and automotive MSMEs in Indian states such as Tamil nadu, Gujarat, and Maharashtra. The remaining respondents were engaged in electronics and electricals (14.8%), chemicals and plastics (13.5%), and other miscellaneous sectors including furniture and paper (10.6%).

**Table 1.** Demographic Profile of Respondents (n = 385)

Variable	Category	Frequency (n = 385)	Percentage (%)
Type of manufacturing sector	Automotive components	78	20.3
	Food processing	65	16.9
	Textiles and apparel	92	23.9
	Electronics and electrical	57	14.8
	Chemicals and plastics	52	13.5
	Others (e.g., furniture, paper, tools)	41	10.6
	Total	385	100
Geographic location	Southern India	114	29.6
	Western India	89	23.1
	Northern India	101	26.2
	Eastern/North-East India	81	21.1
	Total	385	100
Number of employees	1–10	67	17.4
	11–50	154	40
	51–100	108	28.1
	Above 100	56	14.5
	Total	385	100
Annual turnover	Less than ₹1 crore	74	19.2
	₹1–5 crores	136	35.3
	₹5–10 crores	111	28.8
	Above ₹10 crores	64	16.6
	Total	385	100
Years of operation	Less than 5 years	52	13.5
	5–10 years	97	25.2
	11–20 years	148	38.4
	More than 20 years	88	22.9
	Total	385	100

In terms of geographic distribution, the highest proportion of SMEs originated from southern India (29.6%), followed by northern India (26.2%) and western India (23.1%), with eastern and north-eastern regions accounting for 21.1% of the sample. This spread ensures a representative distribution across key industrial regions in India.



Regarding firm size, a substantial 40.0% of respondents employed 11–50 personnel, indicating a predominance of small enterprises within the SME category. Notably, 28.1% had 51–100 employees, while 17.4% operated with fewer than 10 employees, and 14.5% exceeded 100 employees, bordering on mid-sized firms. The annual turnover data suggests that a majority of firms (35.3%) fall within the ₹1–5 crore revenue bracket, while 28.8% report turnovers between ₹5–10 crore, reflecting modest revenue levels typical of traditional Indian manufacturing SMEs. Meanwhile, 19.2% had revenue less than ₹1 crore, and 16.6% exceeded ₹10 crore, indicating a small proportion of relatively mature and growth-oriented SMEs. In terms of organizational maturity, the data show that 38.4% of the firms have been operating for 11–20 years, demonstrating a significant presence of experienced enterprises. In addition, 25.2% reported 5–10 years of operation, while 22.9% had over 20 years of experience. A smaller share (13.5%) consisted of newer firms with less than five years in operation. Overall, the demographic distribution underscores a diverse and representative cross-section of the Indian manufacturing SME sector in terms of industry type, region, size, financial capacity, and operational tenure thereby strengthening the generalizability and contextual validity of the study.

## 4.2 Exploratory Factor Analysis (EFA)

To assess the construct validity and underlying factor structure of the survey instrument, an EFA was conducted on 25 items representing five latent constructs: DTS, ADS, CCP, CPAM, and SCE. The analysis was performed using Principal Component Analysis (PCA) with Varimax rotation in SPSS Version 28.0.

### 4.2.1 Sampling adequacy and suitability of data

Prior to factor extraction, the Kaiser–Meyer–Olkin (KMO) measure and Bartlett’s test of Sphericity were applied to test the adequacy of the sample and the suitability of the correlation matrix for factor analysis Table 2.

**Table 2.** KMO and Bartlett’s test

Measure	Value
Kaiser–Meyer–Olkin (KMO)	0.922
Bartlett’s Test of Sphericity	$\chi^2 = 3545.78$ , $df = 300$ , $p < 0.001$

The KMO measure of sampling adequacy was 0.922, which exceeds the commonly recommended threshold of 0.80, thereby indicating excellent adequacy for factor analysis (Kaiser, 1974). In addition, Bartlett’s test of Sphericity was statistically significant,  $\chi^2(300) = 3545.78$ ,  $p < .001$ , confirming that the correlations among variables were sufficiently large for factor analysis.

### 4.2.2 Factor extraction and loadings

The rotated component matrix presented in Table 3 indicates that all 25 measurement items loaded distinctly onto five separate factors, corresponding precisely with the study’s theoretical framework: DTS, ADS, CCP, CPAM, and SCE. Each item demonstrated a loading above the recommended threshold of .60, and no substantial cross-loadings (i.e., loadings above .30 on more than one factor) were observed. This outcome provides strong evidence of both convergent and discriminant validity of the constructs (Kim, 2006). Specifically, factor loadings for the DTS items ranged from .777 to .832, ADS from .741 to .804, CCP from .759 to .831, CPAM from .766 to .833, and SCE from .776 to .847. These results confirm that each latent construct is reliably measured by its indicators and is conceptually and statistically distinct from the others, thereby supporting the structural integrity of the five-factor model.

### 4.2.3 Factor structure summary

The eigenvalues and percentage of variance explained by each extracted factor are presented in Table 4. Each construct was measured by five items, and the five-factor solution accounted for a cumulative variance of



72.85%, which exceeds the recommended minimum threshold of 60% and is considered highly satisfactory for exploratory factor analysis in behavioral and social sciences (Atobishi et al., 2024).

**Table 3.** Rotated component matrix (varimax rotation)

Item Code	Factor 1 (DTS)	Factor 2 (ADS)	Factor 3 (CCP)	Factor 4 (CPAM)	Factor 5 (SCE)
DTS1	0.812				
DTS2	0.794				
DTS3	0.832				
DTS4	0.805				
DTS5	0.777				
ADS1		0.773			
ADS2		0.804			
ADS3		0.769			
ADS4		0.741			
ADS5		0.776			
CCP1			0.806		
CCP2			0.831		
CCP3			0.777		
CCP4			0.792		
CCP5			0.759		
CPAM1				0.833	
CPAM2				0.821	
CPAM3				0.766	
CPAM4				0.804	
CPAM5				0.773	
SCE1					0.812
SCE2					0.847
SCE3					0.776
SCE4					0.803
SCE5					0.779

(Only highest loading per item shown for clarity; all loadings > 0.60)

**Table 4.** Factor structure summary

Factor	No. of Items	Eigenvalue	Variance explained (%)
Factor 1: Digital Traceability Systems (DTS)	5	6.51	22.1
Factor 2: Algorithmic Decision Support (ADS)	5	4.34	17.3
Factor 3: Cloud-Based Collaborative Platforms (CCP)	5	3.69	14.7
Factor 4: Cyber-Physical Asset Monitoring (CPAM)	5	2.75	10.2
Factor 5: Supply Chain Efficiency (SCE)	5	2.36	8.55
Cumulative variance	-	-	72.85

Among the factors, DTS explained the largest portion of variance (22.1%), followed by ADS (17.3%), CCP (14.7%), CPAM (10.2%), and SCE (8.55%). The substantial variance accounted for by each factor reinforces the structural soundness of the instrument and supports the empirical distinctiveness and conceptual clarity of the digitalization dimensions proposed in this study, particularly within the context of SCE in Indian manufacturing SMEs.



### 4.3 Objective 1: Examining the Effect of Digital Traceability Systems (DTS) on Supply Chain Efficiency in Indian Manufacturing SMEs

#### 4.3.1 Assessment of Internal Consistency and Descriptive Trends for DTS and SCE

Objective 1 of the study aimed to examine the effect of implementing DTS on the operational efficiency of supply chains in Indian manufacturing SMEs. As shown in Table 5, both DTS and SCE demonstrated strong internal consistency, with Cronbach's alpha values of 0.861 and 0.873, respectively. These values exceed the generally accepted threshold of 0.70, indicating good reliability of the measurement scales. The mean scores for DTS ( $M = 3.84$ ,  $SD = 0.71$ ) and SCE ( $M=3.77$ ,  $SD=0.75$ ) suggest that respondents moderately agreed with the presence and implementation of DTS and perceived operational efficiency in their organizations. To address concerns of Common Method Bias (CMB), Harman's single-factor test was performed. The first factor accounted for only 37.4% of the variance, below the 50% threshold, indicating that CMV was not a serious issue. In addition, a marker variable test produced no significant bias in the results. These diagnostic checks confirm that common method variance is unlikely to threaten the validity of the findings (Podsakoff et al., 2003).

**Table 5.** Reliability and descriptive statistics

Construct	No. of items	Cronbach's Alpha	Mean	Standard deviation
DTS	5	0.861	3.84	0.71
SCE	5	0.873	3.77	0.75

#### 4.3.2 Evaluating the Strength of Association Between DTS and Supply Chain Efficiency

A Pearson correlation analysis was conducted to determine the linear association between DTS and SCE. As indicated in Table 6, the analysis revealed a statistically significant and positive correlation ( $r = 0.582$ ,  $p < .01$ ), suggesting that SMEs with greater implementation of DTS tend to report higher levels of SCE. This supports the hypothesized direct relationship between traceability and operational performance in the SME context.

**Table 6.** Pearson correlation matrix

Variables	DTS	SCE
DTS	1	0.582**
SCE	0.582**	1

\*Note:  $*p < 0.01$  (2-tailed)

#### 4.3.3 Estimating the Direct Impact of DTS on Supply Chain Efficiency via Regression Analysis

To further evaluate the direct impact of DTS on SCE, a simple linear regression analysis was performed. The results presented in Table 7 show that the model was statistically significant,  $F(1, 383) = 177.71$ ,  $p < .001$ , with an  $R^2$  value of 0.339, indicating that DTS explains approximately 33.9% of the variance in SCE. This suggests that firms implementing DTS benefit from enhanced tracking, visibility, and transparency, which likely contribute to improved operational performance.

**Table 7.** Model summary and ANOVA

Model	R	R <sup>2</sup>	Adjusted R <sup>2</sup>	Std. Error	F-value	Sig.
1	0.582	0.339	0.337	0.61318	177.71	0.000***

Table 8 provides the regression coefficients. The unstandardized coefficient ( $B = 0.616$ ) implies that a one-unit increase in DTS results in a 0.616 unit increase in SCE, holding other factors constant. The standardized beta coefficient ( $\beta = 0.582$ ) further reflects a strong positive effect size, and the model's t-value of 13.33 ( $p < .001$ ) supports the robustness of this relationship.



**Table 8.** Regression coefficients

Predictor	Unstandardized B	Std. Error	Standardized $\beta$	t-value	Sig.
Constant	1.408	0.186	–	7.57	0
DTS	0.616	0.046	0.582	13.33	0

The findings confirm that the implementation of DTS significantly enhances operational efficiency in Indian manufacturing SMEs. The statistical results demonstrate that traceability enables firms to better monitor product movement, reduce processing time, and improve overall performance in supply chain operations. These findings support previous studies emphasizing the strategic role of traceability in achieving supply chain visibility and operational excel. Objective 2 of the study was to analyze the role of ADS in enhancing inventory control, demand forecasting, and overall supply chain responsiveness in Indian manufacturing SMEs.

#### 4.4 Objective 2: Analyzing the Role of Algorithmic Decision Support (ADS) in Enhancing Supply Chain Efficiency in Indian Manufacturing SMEs

##### 4.4.1 Reliability and Descriptive Statistics of ADS and SCE Constructs

As presented in Table 9, both the ADS and SCE constructs demonstrated high internal consistency, with Cronbach's alpha values of 0.845 and 0.873, respectively. These exceed the standard threshold of 0.70, indicating good internal reliability (Nunnally & Bernstein, 1994). The mean score for ADS was 3.69 (SD = 0.76), indicating moderate agreement among respondents on the use of algorithm-driven decision tools. Similarly, the mean score for SCE was 3.77 (SD = 0.75), suggesting generally positive perceptions of operational efficiency.

**Table 9.** Reliability and descriptive statistics

Construct	No. of items	Cronbach's Alpha	Mean	Standard deviation
ADS	5	0.845	3.69	0.76
SCE	5	0.873	3.77	0.75

##### 4.4.2 Correlation Analysis: Evaluating the Association between ADS and SCE

As shown in Table 10, the Pearson correlation coefficient ( $r=0.531$ ,  $p<.01$ ) indicates a statistically significant and positive relationship between ADS and SCE. This suggests that SMEs using algorithmic tools for demand forecasting, automated inventory control, and real-time decision analytics experience higher operational performance and responsiveness. These results align with prior studies highlighting the transformative role of data-driven decision-making in supply chains.

**Table 10.** Pearson correlation matrix

Variables	ADS	SCE
ADS	1	0.531**
SCE	0.531**	1

\*Note: \* $p < .01$  (2-tailed)

##### 4.4.3 Estimating the Impact of ADS on Supply Chain Efficiency

The simple linear regression analysis confirmed that ADS is a significant predictor of SCE, as shown in Table 11. The model was statistically significant,  $F(1, 383) = 123.63$ ,  $p < .001$ , with an  $R^2$  value of 0.244, meaning that ADS explains 24.4% of the variance in supply chain efficiency. The adjusted  $R^2$  (0.242) further validates the model's explanatory power.



**Table 11.** Model summary and ANOVA

Model	R	R <sup>2</sup>	Adjusted R <sup>2</sup>	Std. Error	F-value	Sig.
1	0.531	0.244	0.242	0.65472	123.63	0.000***

As presented in Table 12, the unstandardized regression coefficient for ADS was 0.586, implying that a one-unit increase in ADS leads to a 0.586-unit increase in SCE. The standardized beta ( $\beta = 0.531$ ) reflects a moderate-to-strong positive impact, and the t-value of 11.12 ( $p < .001$ ) supports the predictor's significance.

**Table 12.** Regression coefficients

Predictor	Unstandardized B	Std. error	Standardized $\beta$	t-value	Sig.
Constant	1.611	0.194	–	8.3	0.000
ADS	0.586	0.053	0.531	11.12	0.000

## 4.5 Objective 3: Assessing the Influence of Cloud-Based Collaborative Platforms (CCP) on Supply Chain Efficiency in Indian Manufacturing SMEs

### 4.5.1 Reliability and Descriptive Statistics of CCP and SCE Constructs

As presented in Table 13, both the independent variable (CCP) and the dependent variable SCE exhibited high internal consistency, with Cronbach's alpha values of 0.857 and 0.873, respectively. These values exceed the accepted threshold of 0.70, suggesting strong internal reliability (Nweje and Taiwo, 2025). The mean score for CCP was 3.74 (SD = 0.73), indicating moderate-to-high agreement on the use of collaborative digital tools among respondents. Similarly, the mean score for SCE was 3.77 (SD=0.75), reflecting generally positive perceptions of supply chain performance.

**Table 13.** Reliability and descriptive statistics

Construct	No. of items	Cronbach's alpha	Mean	Standard deviation
CCP	5	0.857	3.74	0.73
SCE	5	0.873	3.77	0.75

### 4.5.2 Correlation Analysis: Evaluating the Association Between CCP and SCE

As shown in Table 14, the Pearson correlation coefficient ( $r=0.498$ ,  $p < .01$ ) indicates a statistically significant and positive association between CCP and SCE. This suggests that SMEs that adopt cloud-based platforms for collaboration, joint planning, and real-time communication are more likely to report higher levels of SCE. This result aligns with prior research suggesting that digital collaboration improves coordination and reduces cycle times across firms.

**Table 14.** Pearson correlation matrix

Variables	CCP	SCE
CCP	1	0.498**
SCE	0.498**	1

\*Note: \* $p < 0.01$  (2-tailed)

### 4.5.3 Regression Analysis: Estimating the Impact of CCP on Supply Chain Efficiency

The results of the simple linear regression are presented in Tables 15 and 16. The model was statistically significant,  $F(1, 383) = 103.86$ ,  $p < .001$ , and yielded an  $R^2$  value of 0.248, indicating that CCP explains 24.8% of the variance in supply chain efficiency. The adjusted  $R^2$  value of 0.246 further supports the model's robustness and generalizability.



Table 16 presents the regression coefficients. The unstandardized coefficient for CCP was 0.544, indicating that a one-unit increase in CCP usage corresponds to a 0.544-unit increase in SCE, controlling for other factors. The standardized beta ( $\beta=0.498$ ) suggests a moderate positive impact, and the t-value of 10.19 ( $p<.001$ ) confirms the statistical significance of the predictor.

**Table 15.** Model summary and ANOVA

Model	R	R <sup>2</sup>	Adjusted R <sup>2</sup>	Std. Error	F-value	Sig.
1	0.498	0.248	0.246	0.65893	103.86	0.000***

**Table 16.** Regression coefficients

Predictor	Unstandardized B	Std. error	Standardized $\beta$	t-value	Sig.
Constant	1.738	0.201	—	8.65	0.000
CCP	0.544	0.053	0.498	10.19	0.000

The findings confirm that CCP have a significant and positive effect on SCE in Indian manufacturing SMEs. The results highlight that platform enabling real-time communication, collaborative planning, and shared data access improve coordination across organizational boundaries and contribute to reducing supply chain cycle times. These outcomes reinforce the strategic value of cloud technologies in enhancing supply chain responsiveness and performance in digitally transitioning SME environments. Objective 4 of the study aimed to evaluate how CPAM contributes to downtime minimization and real-time decision-making within the supply chains of Indian manufacturing SMEs.

#### 4.6 Objective 4: Evaluating the Impact of Cyber-Physical Asset Monitoring (CPAM) on Supply Chain Efficiency in Indian Manufacturing SMEs

##### 4.6.1 Reliability and Descriptive Statistics of CPAM and SCE Constructs

As shown in Table 17, the CPAM and SCE constructs demonstrated strong internal consistency, with Cronbach's alpha values of 0.851 and 0.873, respectively. These exceed the threshold of 0.70, confirming good scale reliability (Cui, 2025).

**Table 17.** Reliability and descriptive statistics

Construct	No. of items	Cronbach's alpha	Mean	Standard deviation
CPAM	5	0.851	3.68	0.72
SCE	5	0.873	3.77	0.75

The mean score for CPAM was 3.68 (SD = 0.72), suggesting that respondents moderately agreed with the use of real-time asset monitoring technologies, while the mean score for SCE was 3.77 (SD= 0.75), indicating positive perceptions of supply chain performance.

##### 4.6.2 Correlation Analysis: Examining the Association Between CPAM and SCE

Pearson's correlation analysis revealed a statistically significant and positive relationship between CPAM and SCE ( $r = 0.512$ ,  $p < .01$ ), as shown in Table 18. This finding indicates that SMEs implementing cyber-physical systems such as IoT-based sensors, real-time monitoring dashboards, and automated alerts tend to exhibit higher operational efficiency and responsiveness in their supply chains.

**Table 18.** Pearson correlation matrix

Variables	CPAM	SCE
CPAM	1	0.512**
SCE	0.512**	1

\*Note: \* $p < 0.01$  (2-tailed)



#### 4.6.3 Regression Analysis: Estimating the Predictive Effect of CPAM on SCE

The simple linear regression analysis shown in Table 19 confirmed that CPAM significantly predicts SCE, with  $F(1, 383) = 113.83$ ,  $p < .001$ . The model yielded an  $R^2$  value of 0.262, indicating that CPAM accounts for 26.2% of the variance in SCE. The adjusted  $R^2$  value (0.260) further supports the model's explanatory robustness.

**Table 19.** Model summary and ANOVA

Model	R	R <sup>2</sup>	Adjusted R <sup>2</sup>	Std. error	F-value	Sig.
1	0.512	0.262	0.26	0.65092	113.83	0.000***

As presented in Table 20, the unstandardized regression coefficient for CPAM was 0.563, indicating that a one-unit increase in CPAM is associated with a 0.563-unit increase in SCE. The standardized beta ( $\beta = 0.512$ ) reflects a moderate-to-strong effect size, and the t-value of 10.66 ( $p < .001$ ) confirms the predictor's statistical significance.

**Table 20.** Regression coefficients

Predictor	Unstandardized B	Std. error	Standardized $\beta$	t-value	Sig.
Constant	1.695	0.197	-	8.6	0.000
CPAM	0.563	0.053	0.512	10.66	0.000

The results substantiate that CPAM has a significant and positive impact on SCE in Indian manufacturing SMEs. Real-time data from digitally integrated assets enhances decision-making accuracy and reduces unplanned downtime, which in turn improves supply chain agility and responsiveness. These findings reinforce the growing importance of cyber-physical systems in digitally transforming operational performance across the SME sector. Objective 5 was to determine the overall impact of four digitalization dimensions, DTS, ADS, CCP, and CPAM on improving SCE in Indian manufacturing SMEs, specifically in terms of lead time reduction, cost-to-serve optimization, and delivery performance.

### 4.7 Objective 5: Examining the Combined Influence of Digitalization Dimensions on Supply Chain Efficiency in Indian Manufacturing SMEs

#### 4.7.1 Evaluating the predictive strength of the full model

As shown in Table 21, the multiple regression model demonstrated strong predictive power, with a multiple correlation coefficient (R) of 0.704 and an  $R^2$  value of 0.496, indicating that the four-digitalization dimensions collectively explain 49.6% of the variance in supply chain efficiency. The adjusted  $R^2$  (0.491) confirms the model's generalizability, while the standard error of estimate (0.55138) reflects a good fit to the data.

**Table 21.** Model summary

R	R <sup>2</sup>	Adjusted R <sup>2</sup>	Std. error of estimate
0.704	0.496	0.491	0.55138

#### 4.7.2 Overall Model Significance

As reported in Table 22, the overall model was statistically significant,  $F(4,380) = 80.38$ ,  $p < .001$ , confirming that the digitalization variables jointly contribute to predicting SCE among SMEs.

**Table 22.** ANOVA for multiple regression

Source	Sum of Squares	df	Mean Square	F-value	Sig.
Regression	97.692	4	24.423	80.38	0.000***
Residual	99.283	380	0.261		
Total	196.975	384			



### 5.7.3 Regression Coefficients: Assessing Individual Predictor Contributions

As shown in Table 23, the regression coefficients indicate that all four digitalization predictors DTS, CPAM, ADS, and CCP had positive and statistically significant effects on SCE ( $p < .001$ ). Among these, DTS exhibited the strongest standardized effect ( $\beta = 0.244$ ), suggesting it has the most substantial influence on operational performance. This was followed by CPAM ( $\beta = 0.196$ ), ADS ( $\beta = 0.178$ ), and CCP ( $\beta = 0.164$ ). The unstandardized regression coefficients further illustrate the practical implications of these effects. Specifically, a one-unit increase in DTS is associated with a 0.258-unit increase in SCE holding other variables constant. These results confirm the individual relevance of each digitalization construct in enhancing supply chain performance within the SME context.

**Table 23.** Coefficients for digitalization predictors

Predictor	Unstandardized B	Std. error	Standardized $\beta$	t-value	Sig.
Constant	0.873	0.209	–	4.18	0.000
DTS	0.258	0.047	0.244	5.49	0.000
ADS	0.196	0.049	0.178	3.98	0.000
CCP	0.179	0.045	0.164	3.98	0.000
CPAM	0.216	0.048	0.196	4.51	0.000

$$SCE = 0.873 + 0.258(DTS) + 0.196(ADS) + 0.179(CCP) + 0.216(CPAM)$$

The multiple regression results confirm that the four digitalization constructs collectively have a significant and positive influence on SCE in Indian manufacturing SMEs. Among them, DTS emerged as the most influential factor, underscoring the importance of transparency and real-time tracking. These findings provide robust empirical evidence that comprehensive digital transformation, involving data traceability, algorithmic support, cloud collaboration, and cyber-physical integration, significantly enhances operational outcomes in small- and medium-scale supply chains.

## 5. Interpretation of findings

The findings of this study offer valuable theoretical and practical insights into the role of digitalization in enhancing SCE in Indian manufacturing SMEs. All four digitalization dimensions DTS, ADS, CCP, and CPAM demonstrated statistically significant and positive effects on SCE, affirming the robustness of the direct-impact model.

The results confirmed that all four hypotheses (H1–H4) were supported at the  $p < .001$  level, indicating that each digitalization construct contributes meaningfully to improving supply chain outcomes. Among them, DTS emerged as the strongest predictor ( $\beta = 0.244$ ), suggesting that traceability and real-time data visibility significantly enhance supply chain transparency, reduce errors, and improve coordination. CPAM ( $\beta = 0.196$ ) also demonstrated a strong influence, highlighting the value of IoT-enabled asset monitoring and real-time diagnostics in minimizing downtime and enabling proactive decision-making. ADS ( $\beta = 0.178$ ) had a moderate yet significant impact, validating the role of algorithmic planning and AI-based forecasting in improving inventory and demand management. CCP ( $\beta = 0.164$ ), while having the smallest effect among the four, was still a statistically significant predictor, suggesting that cloud-based collaboration though beneficial may require deeper integration and process alignment to fully realize its potential. Importantly, no hypothesized paths were found to be insignificant, which strengthens the model's validity and highlights the complementary nature of the four digitalization dimensions in driving operational performance.

The results extend the Resource-Based View (RBV) by showing that digitalization in SMEs constitutes not only operational tools but also strategic resources that meet the VRIN (valuable, rare, inimitable, non-substitutable) criteria. In particular, digital traceability systems (DTS) and cyber-physical asset monitoring (CPAM) strengthen visibility and control across supply chains, representing unique and difficult-to-imitate capabilities. Unlike studies in large-firm contexts that often rely on mediating or moderating mechanisms, our findings demonstrate that in SMEs, digital capabilities can directly enhance supply chain efficiency, thereby adapting RBV to the realities of resource-constrained environments (Nalluri et al., 2023; Li, Su Zhang, & Mao, 2020).



At the same time, the findings resonate with institutional theory (DiMaggio and Powell, 1983), which posits that organizational practices are shaped by external pressures. The adoption of digital tools by SMEs in this study reflects coercive pressures from regulatory compliance requirements, mimetic pressures to align with leading firms in the supply chain, and normative pressures from industry associations and professional networks. These institutional influences help explain the consistent significance of all four constructs in improving efficiency. From an interdisciplinary perspective, the findings connect to broader debates in development studies and public policy. While digital adoption enhances efficiency, it also shapes employment, workforce skills, and regional competitiveness. For example, SMEs adopting DTS and CPAM not only streamline operations but also demand new digital skills, highlighting the importance of digital literacy and reskilling initiatives at a policy level (Prasad & Junni, 2017; Vial, 2019). Moreover, the results suggest that without adequate financial and infrastructural support, SMEs in rural or semi-urban regions may lag behind, potentially widening the digital divide. This underscores the need for inclusive digital policies that ensure balanced regional development.

### 5.1 Potential Negative Consequences of Digitalization

While the findings of this study confirm that digitalization significantly enhances supply chain efficiency, it is also important to acknowledge its potential adverse consequences (He *et al.*, 2024). One of the key concerns is risk of job displacement arising due to automation and algorithmic decision-making, particularly in labour-intensive sectors such as textiles and traditional manufacturing in India (Balsmeier & Woerter, 2019). Although digital technologies improve productivity, they may simultaneously reduce the demand for manual labour and ultimately creating social challenges (Qiu *et al.*, 2024). Another issue is the SMEs frequently use cloud services, third-party platforms, or outside consultants to get digital solutions, which can make them more susceptible to cybersecurity threats, vendor lock-in, and long-term financial burdens (Vial, 2019). SMEs in urban and industrially developed areas are also more likely to gain from digital transformation, whereas businesses in semi-urban and rural areas encounter obstacles like inadequate digital infrastructure, scarce funding, and low levels of digital literacy. Regional disparities already present in India's manufacturing sector may be made worse by the digital divide (Prasad & Junni, 2017). Acknowledging these issues highlights the need for a balanced approach to ensure the efficiency gains are complemented by strategies to safeguard employment, strengthen local technological capacity, and promote inclusive regional development.

## 6. Implications

### 6.1 Practical implications for SME managers

From a managerial standpoint, the results provide actionable guidance for SME decision-makers. Investments in traceability systems and cyber-physical monitoring should be prioritized due to their high return on efficiency and control. These tools can help SMEs improve on-time delivery, reduce production bottlenecks, and increase customer trust through enhanced product visibility.

For example, DTS is particularly relevant in compliance-heavy industries such as food processing and pharmaceuticals, where traceability ensures product safety and regulatory adherence. ADS is most useful in industries with volatile demand (e.g., automotive components), where predictive analytics can optimize production planning. CCP is especially beneficial for SMEs with geographically dispersed operations, facilitating real-time collaboration with suppliers and distributors. Finally, CPAM is critical in capital-intensive industries (e.g., electronics, machinery), where asset monitoring helps reduce downtime and improve equipment utilization. These sector-specific insights make the implications more actionable for SME managers. SMEs with limited resources and operating in an uncertain environment, ADS tools like demand forecasting engines and inventory optimization algorithms are extremely valuable. Although the impact of CCP platforms was comparatively less, their integration can result in cumulative benefits by encouraging cooperation and facilitating shared decision-making with distributors and suppliers. To get the most out of these tools, managers should think about integrating them into their current ERP systems.



## 6.2 Social Implications of Digital Adoption

The study also emphasizes how supply chain digitization affects Indian SMEs on a larger social level. Employment, skills, and regional development can all be impacted by digital tools. Digitalization can lead to the creation of new technology-driven jobs in fields like data analytics, digital platforms, and system integration, which will help SMEs engage more successfully in contemporary supply chains (Nambisan *et al.*, 2019). Concerns regarding job security and the future of traditional work roles are raised by the possibility that increased automation will result in job displacement in labor-intensive industries (Balsmeier & Woerter, 2019). Digital adoption also increases the need for workforce upskilling and reskilling to adapt to emerging technologies. Without targeted training and capacity-building programs there is a risk of widening skill gaps which may hinder sustainable digital transformation (Vial, 2019). Regional differences in infrastructure and resources mean that SMEs in metropolitan areas often benefit more quickly from digital tools while SMEs in rural and semi-urban regions may face barriers to adoption if unaddressed, this could contribute to greater regional inequalities (Prasad & Junni, 2017). The results of this study underscore the importance of considering both operational and social outcomes when promoting digital transformation in Indian SMEs.

## 6.3 Policy and Governance Implications

Digital transformation is neither exclusively a managerial choice nor is it entirely disconnected from and detached from the policy environment in which firms operate (Saarikko *et al.*, 2020). National initiatives like Digital India and Make in India are providing support for adopting new technologies on a large-scale but the impact of such programs can be intensified with focused digital literacy and workforce training programs that equip employees with new skills fitting them for new roles in data-driven supply chains (Vial, 2019). SME financing policies are essential for lessening the amount of money needed to invest in digital infrastructure. Access to credit and subsidies for investing in technologies can help small firms, especially in rural and semi urban areas to overcome constraints of resources (Prasad & Junni, 2017). Moreover public-private partnerships will be key factors in knowledge sharing and capacity building as well as ensuring that digitalization is inclusive in different industrial regions (Tanveer *et al.*, 2025). By connecting the digitalization of supply chains to wider policy frameworks, this study emphasizes that digital adoption will not only contribute to operational efficiency but also to inclusive regional development and national competitiveness.

## 6.4 Theoretical contributions

This study contributes to the growing literature on digital supply chain transformation by offering a parsimonious, direct-impact model that does not rely on mediators or moderators contrary to most prior research that often incorporates organizational readiness, culture, or environmental uncertainty as conditional variables. The results empirically validate the distinct roles played by different digital technologies and extend the RBV by showing how tangible digital assets can directly enhance operational outcomes. The study also introduces construct-level clarity in how each technology cluster (traceability, analytics, collaboration, monitoring) contributes uniquely and additively to SCE. The Indian SME landscape presents unique structural and operational challenges, including fragmented supply chains, infrastructure bottlenecks, and digital capability gaps. The findings reveal that even under these constraints, targeted digital interventions can yield significant efficiency gains. This reinforces the idea that digitalization is not just a large-firm strategy but can be successfully scaled and adopted by SMEs, particularly in emerging economies. Moreover, the study provides one of the few empirical validations of digital supply chain constructs specifically within the Indian manufacturing sector offering context-specific insights that may inform national SME policy and regional industrial strategy.

## 7. Conclusion

This study investigated the role of digitalization in enhancing SCE among Indian manufacturing SMEs by examining the direct effects of four key constructs: DTS, ADS, CCP, and CPAM. Based on responses from 385 SMEs across various sectors and regions, the findings confirm that all four digitalization dimensions significantly and positively influence SCE, with DTS exerting the strongest impact, followed by CPAM, ADS, and CCP. These results



reinforce the strategic value of digital transformation initiatives, even in resource-constrained environments. The study offers several theoretical contributions. It introduces and validates a direct-impact digitalization model, challenging the prevailing dependence on mediated or moderated structures in existing literature. Furthermore, it provides construct-level insights into how specific digital capabilities contribute uniquely to operational performance, thereby extending the RBV within the context of SME digitalization. From a managerial perspective, the study offers practical guidance for SME decision-makers aiming to improve supply chain performance. Prioritizing traceability and cyber-physical monitoring technologies can yield immediate efficiency gains, while algorithmic planning and cloud-based collaboration systems support long-term agility and coordination. These insights are particularly relevant for digital policy implementation and digital readiness initiatives targeting small and medium enterprises. Despite these contributions, the study is subject to certain limitations. First, the use of a cross-sectional design restricts the ability to draw causal inferences over time. Second, this study relies solely on a quantitative survey-based design. While the statistical analysis provides robust evidence of the direct effects of digitalization on supply chain efficiency, it may not capture deeper insights into organizational culture, managerial attitudes, and social barriers faced by SMEs during digital adoption. Third, the study is limited by its focus on efficiency-related outcomes, without directly examining issues of power relations within supply chains. In many cases, digitalization may strengthen the position of larger supply chain partners or external technology providers, increasing the dependency of SMEs on these actors and potentially reducing their bargaining power. Finally, the exclusion of mediating or moderating variables though intentional for model parsimony leaves room for further exploration of contextual factors that may enhance or constrain digitalization outcomes. Future research should consider longitudinal designs to assess digitalization impacts over time and explore the inclusion of moderators such as firm size, digital maturity, or leadership orientation. Cross-country comparative studies could also illuminate how institutional, cultural, and infrastructural variables mediate the effectiveness of digital supply chain strategies across emerging and developed economies. This methodological choice was made because digital adoption among Indian SMEs is still in an emerging phase, making a cross-sectional design appropriate for capturing a broad and timely overview of current practices across regions and sectors. A longitudinal design would provide stronger evidence of causality and track changes over time, while a mixed-methods design could incorporate qualitative insights to uncover organizational and cultural dynamics. These findings imply that digitalization can no longer be considered as a way to achieve operational efficiency but also as forcing social transformation and economic shift in emerging economies. In spite of such contributions, there are some limitations in this study. One important constraint is the cross-sectional design that limits the ability to investigate long-term cases of causation. It would be fruitful for future studies to use longitudinal methods in order to determine longer-lasting influence of digitalization. Future research should pursue longitudinal studies to examine the long-term policy impact of digitalization initiatives on SME competitiveness. Incorporating socio-technical adoption frameworks can also provide deeper insights into how technology, organizational culture, and institutional context interact. In addition, comparative cross-country studies across emerging and developed markets would shed light on how institutional differences influence digital adoption trajectories. Second, this study relies solely on a quantitative survey-based design. While the statistical analysis provides robust evidence of the direct effects of digitalization on supply chain efficiency, it may not capture deeper insights into organizational culture, managerial attitudes, and social barriers. Future research could employ a mixed-methods approach, combining surveys with qualitative interviews or case studies, to generate a more comprehensive understanding of these dynamics. Third, the study's focus is limited to efficiency-related outcomes, without explicitly analyzing issues of power relations. In practice, digitalization may strengthen the position of larger supply chain partners or technology providers, increasing SMEs' dependency and potentially reducing their bargaining power. Future research should investigate how digitalization reshapes inter-organizational power dynamics and the governance of SME supply chains in emerging economies. Finally, the study is geographically confined to Indian manufacturing SMEs. Comparative cross-country research could illuminate how institutional, cultural, and infrastructural factors influence digital adoption differently across emerging and developed markets.

## References

Ahmed, A., Bhatti, S.H., Gölgeci, I., Arslan, A. (2022). Digital platform capability and organizational agility of emerging market manufacturing SMEs: The mediating role of intellectual capital and the moderating role of



- environmental dynamism. *Technological Forecasting and Social Change*, 177, 121513. <https://doi.org/10.1016/j.techfore.2022.121513>
- Arin, I.A., Dhamacora, R., Aditya, B. (2024). The Adoption of Digital Twin Technology to Facilitate Resource and Asset Tracking in Field Service Management. In 2024 *International Conference on ICT for Smart Society (ICISS)*, IEEE, Bandung, Indonesia. <https://doi.org/10.1109/ICISS62896.2024.10751066>
- Atobishi, T., Moh'd Abu Bakir, S., Nosratabadi, S. (2024). How do digital capabilities affect organizational performance in the public sector? The mediating role of the organizational agility. *Administrative Sciences*, 14(2), 37. <https://doi.org/10.3390/admsci14020037>
- Balsmeier, B., Woerter, M. (2019). Is this time different? How digitalization influences job creation and destruction. *Research Policy*, 48(8), 103765. <https://doi.org/10.1016/j.respol.2019.03.010>
- Bordonaba-Juste, V., Cambra-Fierro, J.J. (2009). Managing supply chain in the context of SMEs: a collaborative and customized partnership with the suppliers as the key for success. *Supply Chain Management: An International Journal*, 14(5), 393-402. <https://doi.org/10.1108/13598540910980305>
- Creswell, J.W., Creswell, J.D. (2018). Research design: Qualitative, quantitative, and mixed. *SAGE Publications*.
- Cui, J. (2025). The Impact of Digital Media Technology on Digital Twins: The Moderating Role of Personalized Advertising. *Accounting, Marketing and Organization*, 1(1), 1000017-1000017. <https://doi.org/10.71204/86fvy772>
- Di Maggio, P.J., Powell, W.W. (1983). The iron cage revisited institutional isomorphism and collective rationality in organizational fields. *American Sociological Review*, 48(2), 147–160. <https://doi.org/10.2307/2095101>
- Gunasekaran, A., Papadopoulos, T., Dubey, R., Wamba, S. F., Childe, S. J., Hazen, B., & Akter, S. (2017). Big data and predictive analytics for supply chain and organizational performance. *Journal of Business Research*, 70, 308-317.
- Ivanov, D., Dolgui, A. (2020). Viability of intertwined supply networks: Extending the supply chain resilience angles towards survivability. *International Journal of Production Research*, 58(10), 2904–2915. <https://doi.org/10.1080/00207543.2020.1750727>
- Jeffrey, R., Doron, A. (2013). The great Indian phone book: How the cheap cell phone changes business, politics, and daily life. *Harvard University Press*.
- Kim, D. (2006). Process chain: A new paradigm of collaborative commerce and synchronized supply chain. *Business Horizons*, 49(5), 359-367. <https://doi.org/10.1016/j.bushor.2005.11.004>
- Li, L., Su, F., Zhang, W., & Mao, J. Y. (2020). Digital transformation by SME entrepreneurs: A capability perspective. *Information Systems Journal*, 30(2), 699-732. <https://doi.org/10.1111/isj.12280>
- Li, L., Su, F., Zhang, W., & Mao, J.Y. (2018). Digital transformation by SME entrepreneurs: A capability perspective. *Information Systems Journal*, 28(6), 1129-1157.
- Mandal, S. (2018). An examination of the importance of big data analytics in supply chain agility development: A dynamic capability perspective. *Management Research Review*, 41(10), 1201-1219.
- Nalluri, V., Huynh-Cam, T., Sama, H., & Chen, L. (2023). Decision-making model for the effective e-services adoption in the Indian educational organizations. *Decision Science Letters*, 12(2), 211-224.
- Nalluri, V., Mayopu, R. G., & Chen, L. S. (2024). Modeling the key attributes for improving customer repurchase rates through mobile advertisements using a Fuzzy mixed approach. *Journal of Modelling in Management*, 19(1), 145-168.
- Nambisan, S., Wright, M., Feldman, M. (2019). The digital transformation of innovation and entrepreneurship: Progress, challenges and key themes. *Research Policy*, 48(8), 103773. <https://doi.org/10.1016/j.respol.2019.03.018>



- Nweje, U., Taiwo, M. (2025). Leveraging Artificial Intelligence for predictive supply chain management, focus on how AI-driven tools are revolutionizing demand forecasting and inventory optimization. *International Journal of Science and Research Archive*, 14(1), 230-250. <https://doi.org/10.30574/ijrsra.2025.14.1.0027>
- Prasad, S., Junni, P. (2017). Business opportunities and challenges of digitalization in emerging markets: Evidence from India. *Journal of Small Business and Enterprise Development*, 24(4), 649–667.
- Rogers, E.M. (2003). *Diffusion of innovations* (5th ed.). Free Press.
- Sahoo, S.K., Goswami, S.S., Sarkar, S., Mitra, S. (2023). A review of digital transformation and industry 4.0 in supply chain management for small and medium-sized enterprises. *Spectrum of engineering and management sciences*, 1(1), 58-72. <https://doi.org/10.31181/sems1120237j>
- Sama, H. R., Chen, L. S., Nalluri, V., & Chendragiri, M. (2023). Enhancing service quality of rural public transport during the COVID-19 pandemic: A novel fuzzy approach. *Public transport*, 15(2), 479-501
- Seyedghorban, Z., Samson, D., Tahernejad, H. (2020). Digitalization opportunities for the procurement function: pathways to maturity. *International Journal of Operations & Production Management*, 40(11), 1685-1693. <https://doi.org/10.1108/IJOPM-04-2020-0214>
- Shrivastava, A., Mohapatra, A.K., Mohnot, A., Samtani, P. (2025). Resilience and Recovery in Practice in Key Industry Sectors: A Case of India's Economic Landscape Post-Pandemic. *Pacific Business Review International*, 17(7).
- Tarannum, T., Hossain, M.Z. (2024). Impact of Real-Time MIS on Supply Chain Management A Case Study Approach. *Pacific Journal of Business Innovation and Strategy*, 1(1), 38-48. <https://doi.org/10.70818/pjbis.2024.v01i01.013>
- Trevisan, A.H., Lobo, A., Guzzo, D., de Vasconcelos Gomes, L.A., Mascarenhas, J. (2023). Barriers to employing digital technologies for a circular economy: A multi-level perspective. *Journal of Environmental Management*, 332, 117437.
- Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *The Journal of Strategic Information Systems*, 28(2), 118–144. <https://doi.org/10.1016/j.jsis.2019.01.003>
- Wu, H., Li, G., Zheng, H. (2024). How does digital intelligence technology enhance supply chain resilience? Sustainable framework and agenda. *Annals of Operations Research*, 1-23. <https://doi.org/10.1007/s10479-024-06104-3>
- Yang, L., Zhang, Y., Huo, B., & Tian, M. (2025). The impact of digital transformation on new quality productivity: a moderating analysis based on the socio-technical system theory. *Industrial Management & Data Systems*, 1-20.
- Zhong, R. Y., Xu, C., Chen, C., Huang, G.Q. (2017). Big data analytics for physical internet-based intelligent manufacturing shop floors. *International Journal of Production Research*, 55(9), 2610–2621. <https://doi.org/10.1080/00207543.2015.1086037>

### Authors' Contributions

K. Srinivasan: Conceptualization, Methodology, Investigation, Writing—original draft preparation. Shaik Kamruddin: Conceptualization, Methodology. V.V. Mallika: Formal analysis, Validation. Venkateswarlu Nalluri: Writing—original draft, Preparation, Funding acquisition, Project administration. Jing-Rong Chang: Funding acquisition, Project administration. K.S. Venkateswara Kumar: Validation, Writing—review and editing. Priyanka Sinha: Validation, Writing—review and editing. All the authors read and approved the final version of the manuscript.

### Does this article screen for similarity?

Yes



**Conflict of Interest**

The authors have no conflicts of interest to declare. There is also no financial interest to report. The author certifies that the submission is original work and is not under review at any other publication.

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