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Technological Factors and Supply Chain Transparency: Role of Decision Support System

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ABSTRACT

The study objective was to formulate the impact of digital technologies, namely RFID, IOT, blockchain technology, artificial intelligence, and cybersecurity on the supply chain transparency of manufacturing SMEs. The study also tested the moderating effect of decision support system. For this purpose, quantitative cross-sectional data were collected from 305 manufacturing SMEs using a convenient sampling technique. SPSS was used for both of demographic and regression analysis. Multiple regression analysis results show that all digital technologies positively and significantly affect supply chain transparency. The moderating effect also shows that the decision support system positively strengthens the relationship between digital technologies and supply chain transparency. The study with findings contributes to the literature by confirming that digital technologies significantly enhance supply chain transparency in manufacturing SMEs. It further contributes by highlighting the moderating role of decision support systems, which strengthens the impact of these technologies. These contributions guide SME managers and policymakers to invest in integrated digital solutions for improving supply chain visibility and performance. Limitations and future directions were also discussed at the end.

1. Introduction

In today's globalized complex environment, supply chain transparency (SCT) has become a foundation for achieving resilient supply chains [92]. Transparency enables organizations to trace goods from the raw material to the end consumers to raise accountability, trust, and compliance with regulatory and environmental standards [67]. The increasing demand from consumers and stakeholders for sustainable and ethically sourced products has further accelerated the need for visibility across supply chain tiers [36]. Specifically, transparent supply chains not only enhance stakeholder confidence but also improve operational decision-making and facilitate faster recovery from disruptions [42]. Research has also emphasized that SCT positively impacts firm performance, customer loyalty, and brand image by aligning organizational practices with stakeholder expectations [17]. As the companies struggle to respond a global challenges, that is only possible

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when the companies have good SCT. Literature highlighted that digital transformation has become a key enabler for attaining a SCT [79]. Seeking the significance of SCT, its significance could not for the current study through digital technologies.

Various digital technological factors effects to improve the SCT. Among those, Radio Frequency Identification (RFID) has revolutionized the way organizations track, monitor, and manage their supply chains [76]. RFID technology facilitates seamless product identification, real-time inventory visibility, and reduced manual handling errors, which are essential for improving accuracy and responsiveness [89]. In the same vein, internet of things (IoT) sensors and smart devices enable constant monitoring of conditions such as temperature, humidity, and location, which is particularly useful in goods supply chains [90]. These technologies create rich data streams that enhance traceability, increase transparency [24]. On the other hand, Cybersecurity (CS) has also become critical factor because supply chain is increasingly targeted by hackers who exploit the interconnected nature of modern operations [71]. Without adequate security protocols, the benefits of IoT and RFID can be undermined by data breaches or operational disruptions, necessitating the integration of robust cybersecurity frameworks into supply chain strategies [81]. Therefore, seeking these factors for the SCT, study tested the impact of Iot, RFID, and CS on SCT.

With the significance of the above three factors, blockchain technology (BLT) also offers a decentralized system that strengthens trust among supply chain stakeholders [73]. Its ability to record immutable transactions facilitates verification of product origin, authenticity, and compliance, significantly increasing SCT [4]. This is particularly important for manufacturing companies where traceability and ethical sourcing are paramount [26]. Other researchers also found that BLT is a significant predictor of improving the SCT [85]. In the same vein, artificial intelligence (AI) contributes to intelligent SCT through advanced analytics and predictive modeling [48]. AI systems can forecast demand, detect anomalies, and provide real-time insights to preempt disruptions and inefficiencies [62]. The synergy between AI and BLT, where AI analyzes data and blockchain ensures its credibility, which creates a powerful digital infrastructure for end consumers' supply and increases their transparency [65]. Therefore, this study paying attention on influence of BLT and AI on SCT.

To improve digital technologies, decision support systems (DSS) serve as a central platform that integrates diverse digital technologies to empower supply chain managers in enhancing transparency [34]. These systems synthesize structured and unstructured data from multiple sources, which enables dynamic visualization and optimization of supply chain processes [55]. DSS can analyze digital technology to detect bottlenecks to confirm authenticity for proactive strategies [53]. Furthermore, DSS enhances digital technologies by providing automated alerts and diagnostics in response to abnormal system behavior, thereby mitigating potential threats in real-time [86]. Recent studies have shown that the integration of DSS with digital technologies not only boosts real-time visibility and responsiveness but also raises cross-functional coordination and informed decision-making across the supply chain [9]. By organizing the functionalities of individual technologies, DSS acts as a strategic enabler of digital transformation and plays a crucial role in achieving the ultimate goal of SCT [15]. Therefore, this study used DSS as a moderating variable between digital technologies and SCT.

With the significance of the above digital technologies for the SCT, various gaps exist in the extant literature. Firstly, previous studies mainly concentrated on the direct effect of digital technologies, namely RFID, IoT, BLT, AI, and CS on SCT with a limited attention to the moderating effect [54; 78; 92; 97]. DSS serves as a central platform that integrates diverse digital technologies to empower supply chain managers with timely, data-driven insights for enhanced transparency [84]. These systems synthesize structured and unstructured data from multiple sources, which enables dynamic visualization and optimization of supply chain processes [51]. DSS can analyze digital technology to identify bottlenecks and confirm authenticity, enabling proactive strategies [68]. Therefore, this study added DSS as a moderating variable among digital technologies and SCT. Furthermore, prior studies have also segregated the impact of digital technologies and DSS on SCT, while having limited attention on the combined effect of these factors on SCT [77; 98]. In this regard, this study contributed literature on the impact of all factors on SCT in one model. Furthermore, prior studies have also limited attention on manufacturing SMEs with a majorly focus on other sectors [40; 74; 88]. In this regard, this study contributed literature on manufacturing SMEs. After seeking prior gaps, the study objective was to formulate the impact of digital technologies, namely RFID, IOT, BLT, AI, and CS, on the SCT of manufacturing SMEs. The study also tested the moderating effect of the DSS.

Above identified gap carries important practical significance for the manufacturing SMEs that could also help to other sectors. At first, understanding the combined impact of digital technologies and DSS enables SMEs to make integrated and strategic investments, rather than relying on isolated technological upgrades. Second, recognizing the moderating role of DSS helps SMEs leverage these systems to enhance the effectiveness of technologies like RFID, IoT, BLT, AI, and CS in achieving real-time transparency. Lastly, focusing on the manufacturing sector addresses sector-specific challenges, offering tailored insights that could improve operational efficiency and competitive positioning in dynamic supply chain environments. Four chapters were further discussed namely the literature review, which covered the main hypothesis development. The research methodology covered the research design, and sampling techniques etc. Data analysis and results are interpreted in chapter 4 below. The last chapter was the discussion of the study findings and implications of study.

2. Literature Review and Hypothesis Development

2.1 RFID and Supply Chain Transparency

Radio Frequency Identification (RFID) is a wireless technology using embedded microchips and antennas to enable automatic, contactless identification and tracking of items via radio waves [95]. RFID allows batch scanning of hundreds of tagged goods simultaneously, facilitating efficient data capture across production, warehousing, logistics, and retail stages [2]. This high-frequency item-level visibility reduces manual errors and provides real-time inventory snapshots [37]. RFID enhances supply chain transparency by reducing information asymmetry and improving accountability among stakeholders [56]. Such transparency is critical for compliance, ethical sourcing, and maintaining consumer trust, especially in regulated sectors [95]. Zhang et al. [100] reported an RFID-driven improvement in inventory visibility through increasing the supply chain transparency (SCT). Pajic et al. [69] documented RFID-based monitoring of temperature and location in cold chain logistics, eliminating spoilage which increases the SCT. Further studies indicate that RFID promotes environmental and ethical transparency by enabling traceability of origin and handling conditions [37]. They suggested to conduct research in other region. These findings show RFID contributes not only to efficient operations but also to robust end-to-end transparency, authenticity verification, and trust, and has hypotheses below,

H1: RFID significantly influence to supply chain transparency.

2.2 Internet of Things and Supply Chain Transparency

The Internet of Things (IoT) encompasses networks of interconnected sensors and embedded devices that continuously collect and transmit data such as temperature, humidity, vibration, and

GPS location [6]. IoT enhances traceability in real time which offers rich contextual information beyond simple location and also allows monitoring of the environment and handling conditions to ensure product integrity [21]. It also supports Industry 4.0 goals by integrating production and logistics data streams which is strengthening stakeholder collaboration [90]. Dolgui and Ivanov [32] found that IoT adoption significantly improves physical flow visibility and end-to-end transparency. A systematic review Nikolaev [61], also identifies the significant influence of IOT on SCT. Other research also found the same positive impact of IoT on SCT [3]. Furthermore, hybrid IoT demonstrated tamper-proof traceability chains that reduce fraud and increase consumer trust [43]. Collectively, these studies confirm that IoT plays an instrumental role in generating detailed, trust-enhancing supply chain visibility, and the study has following hypothesis below,
H2: Internet of things significantly influence to supply chain transparency.

2.3 Blockchain and Supply Chain Transparency

Blockchain technology (BLT) is a decentralized system where encrypted transactions are recorded in chained blocks, distributed across network nodes [5]. Its immutability, cryptographic verification, and consensus mechanisms eliminate the possibility of unilateral alteration to increase SLT [57]. This facilitates operational transparency because stakeholders can audit every transaction from procurement to delivery using secure, time-stamped records, without relying on central authorities [47]. They further highlighted that BLT addresses data silos, enhances collaboration, and raises trust in claims about product origin, handling history, and compliance. Cerić [23] study demonstrated that BLT reduces information asymmetry and increases partner trust via decentralized shared data. Xu et al. [97] used data from firms to show that blockchain's transparency and security attributes significantly enhance SCT. Studies also report that BLT reduces costs, improves process coordination, and supports sustainability goals which leads to increase SLT [57; 72]. Additionally, BLT integration has yielded immutable traceability pilots, improving fraud prevention and compliance which increases the SCT [48]. This evidence confirms blockchain's critical role in trust-building and performance improvement through SCT and accordingly following hypothesis is.
H3: Blockchain technology significantly influence to supply chain transparency.

2.4 Artificial Intelligence (AI) and Supply Chain Transparency

Artificial Intelligence (AI) consisted of performance the tasks through using technology where is a need of human intelligence for solving of the problem and making [22]. They also explained that within the context of supply chain, AI consisted of various technologies like machine learning, and natural language processing that analyze vast amounts of data from various sources. Such kind of technology allows to the companies for creating a better decision making through the irregularities detection across the supply chain which helps to increase the SCT [33]. In other words, AI also improves visibility by forecasting demand, optimizing routing, and providing early warnings about disruptions or risks which increase the SCT [95]. It enables a data-driven culture where decisions are not just reactive but predictive which is significantly improve the trust and traceability in supply chains [22]. Other research also emphasized that AI plays a vital role in making supply chains more accountable, visible, and responsive to real-time events [59]. Jones [46] also conducted a study and found that AI-driven analytics significantly enhanced transparency by improving demand forecasting accuracy and shipment traceability. John et al. [45] study also found that AI technologies allowed firms to detect variances in supplier behavior and logistics operations which is leading to more provide a smoother SCT. Other studies also found that AI-enhanced chatbots and intelligent dashboards were also found to enhance communication transparency between suppliers and buyers [80]. These empirical results collectively show that AI not only supports strategic decision-

making but also raises real-time visibility, which increases the SCT through reducing delays in providing goods on time and hence is hypothesis below.
H4: Artificial intelligence significantly influences to supply chain transparency.

2.5 Cybersecurity and Supply Chain Transparency

Cybersecurity technology (CS) in the supply chain refers to the protection of digital systems, data, and communication networks from unauthorized access, cyberattacks, and data breaches [64]. As supply chains become increasingly digitalized and integrated, they also become more vulnerable to cyber threats, which can compromise the transparency, integrity, and reliability of data flows [39]. Transparency relies heavily on accurate and secure data exchange among all participants AllahRakha [13], and for this purpose, CS plays a foundational role in ensuring the reliability of shared information. As global supply chains face growing risks from surveillance and to handle this cybersecurity becomes indispensable for sustaining trust and visibility. Aarland [1] found that firms with mature CS infrastructures reported higher levels of SCT, particularly in digital procurement processes. Furthermore, Solfa [83] conducted a study where results showing that CS investments directly contribute to lower data manipulation risks and greater auditability. Additionally, the integration of CS has been shown to enhance traceability, as shared data is both immutable and protected against external breaches, which increases the SCT [96]. These findings emphasize that CS is not just an IT issue because it is central to maintaining the transparency and integrity of digitally enabled supply chains and following hypothesis is below,
H5: Cybersecurity significantly influences to supply chain transparency.

2.6 Decision Support System Moderating Role

The association between digital technologies and SCT is not clear, which is enforcing to conduct study in other context and could use a variable that could increase the effectiveness of digital technologies to improve SCT. RFID and IoT are foundational technologies in enhancing SCT through real-time visibility and traceability of materials and goods [21]. RFID provides automatic identification and tracking capabilities that reduce errors and increase inventory accuracy. Literature cited that the impact of digital technologies improved when the companies have a stronger decision support system (DSS) [27]. However, the raw data generated by these technologies can become overwhelming and underutilized and a proper DSS can make it easier for supply chain professionals to convert vast volumes of RFID and IoT data into actionable insights [52]. This is supported by the study of Udeh et al. [92] where they found that firms using IoT integrated with DSS experienced a better improvement in lead time transparency, while Unhelkar et al. [93] demonstrated that RFID systems supported by DSS significantly reduced information lags and enhanced compliance tracking, which increases the SCT. Literature also supported the view that emerging technologies such as BLT and AI also contribute significantly to SCT by ensuring data integrity, traceability, and predictive visibility. Literature cited that DSS help interpret on-chain data, generate exception reports, and visualize supply chain flows, which increases the SCT [41]. Similarly, AI contributes to transparency by forecasting disruptions, detecting anomalies, and generating intelligent insights from complex datasets [75]. Yet, AI systems can become "black boxes" without DSS tools to explain model outputs and support real-time decision-making. Further study also show that BLT integrated with DSS improves traceability that could improve the SCT [70].

Equally, CS also plays a fundamental role in enabling trustworthy SCT [44]. Secure systems ensure the legitimacy of shared data across partners, which is a prerequisite for transparent operations [82]. However, CS frameworks alone do not translate to visibility unless paired with systems that monitor, interpret, and communicate the state of security across the chain [70]. For this purpose, DSS fulfills this role by offering audit trails, real-time risk alerts, and compliance dashboards that translate technical security data into operational insights [7]. Studies show that supply chains employing DSS are an important factor in improving the CS, which improves the SCT [31]. Thus, across all five technologies, DSS acts as an indispensable enabler and moderator. It ensures that data generated by these tools is not only secure and voluminous but also structured, interpretable, and decision-ready, which is essential for achieving holistic supply chain transparency in the digital era. Previous studies also emphasized that DSS can be used a moderating variable [14]. They also supported the view that further research could be conducted with other technological factors, and hence the study has following research hypothesis,

H6: RFID significant influence to supply chain transparency with a moderating effect of decision support system.

H7: Internet of things significant influence to supply chain transparency with a moderating effect of decision support system.

H8: Blockchain significant influence to supply chain transparency with a moderating effect of the decision support system.

H9: Artificial intelligence significant influence to supply chain transparency with moderating effect of decision support system.

H10: Cybersecurity significant influence to supply chain transparency with a moderating effect of the decision support system.

3. Research approach and Design

From the study specific objective perspectives, researchers employed the quantitative deductive approach. Creswell and Creswell [29] emphasized that quantitative method is appropriate when the hypotheses are tested based on the existing theories. In other sense, quantitative method also helps to researchers in collecting structured data, which could increase the results generalizability [28]. In this regards, study employed the quantitative deductive approach. Moreover, for one time data collection cross sectional design used, aligning with the study objective to examine the relationship among variables. As per Aljazzazen and Schmuck [12], cross sectional research design is well suited for hypothesis testing when having time and cost constraints. Therefore, cross sectional data collection procedure was selected for the present study.

3.1 Research Instrument Development

The research instrument was taken from prior studies. RFID was comprises from 9 items of [99]. IoT technology comprises 5 items of [99]. Blockchain technology comprises from 7 items of [99]. Supply chain transparency comprised from 5 items of [99]. Artificial intelligence comprises from 15 items were comprises from [35].

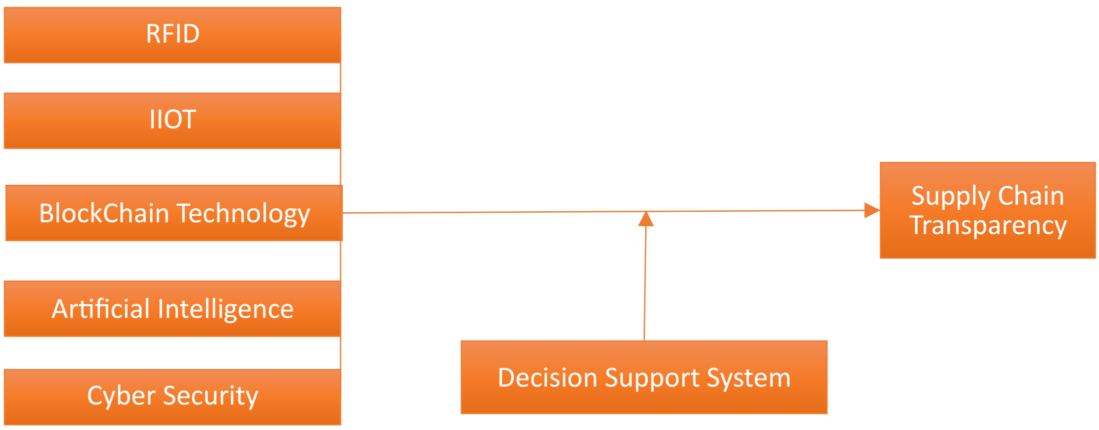

Fig.1: Conceptual Framework

Cybersecurity measured from three dimensions namely confidentiality, integrity, and availability. Each dimension was measured by three items of [10]. Lastly, decision support system comprised from two dimension, key performance indicators and critical success factors and each dimension have 5 question which were taken from [16]. Each item ranked on five point Likert Scale. The above variables are depicted in Figure 1 below,

3.2 Sampling Technique

Manufacturing SMEs employees is research population. From the defined population, sample selected employing non probability convenient sampling technique. This sampling technique seems to be more efficient than random sampling because the population of the study is not defined [91]. Convenient sampling also enables scholars to point out eligible respondents having deep knowledge of the research problem [20; 30; 63]. Questionnaires were distributed among 380 employees of SMEs using convenient sampling technique, and among those 315 questionnaires were returned back. Among these 305 were valid for analysis. This response rate is enough because response rates above 60% seem to be desirable for finding credibility and reliability. The collected data was coded in the excel sheet and analyzed using the SPSS software.

4. Data Analysis and Results

4.1 Demographic Characteristics

This section shows the employee's demographic employee's characteristics. In the respondents, there were majority of respondents were male (63.9%), with females representing a significant portion (36.1%), which reflects a growing gender inclusion in the SME sector. Most respondents were in the age brackets of 26–35 years (39.3%) and 36–45 years (31.1%) which is suggesting that SMEs are predominantly staffed by mid-career professionals who are likely to possess both energy and experience. In terms of education, nearly half of the respondents (49.2%) held a bachelor's degree, and a substantial portion (31.1%) had a master's degree or higher, indicating a well-educated workforce capable of understanding and leveraging advanced technologies in supply chain functions. Furthermore, most employees reported considerable experience in the field, with 36.1% having 4–6 years and 29.5% having more than 6 years of work experience. Demographic results are shown in Table 1.

Table 1
Demographic Profile

Demographic Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	195	63.9%
	Female	110	36.1%
Age	18–25	40	13.1%
	26–35	120	39.3%
	36–45	95	31.1%
	46 and above	50	16.5%
Education	Diploma	60	19.7%
	Bachelor's degree	150	49.2%
	Master's degree and above	95	31.1%
Experience	Below 1 year	20	6.6%
	1 to 3 years	85	27.9%
	4 to 6 years	110	36.1%
	Greater than 6 years	90	29.5%

4.2 Common Method Bias

Harman's single-factor analysis was conducted to check common method bias. The common method biases results (Table 2), showing that there is only 31.5% change of the total variance that is less than 50%. This indicates that no single factor dominated the variance among the measured items.

Table 2:
Common Method Biased Results

Factor	Total Variance Explained (%)
Single factor (unrotated)	31.5%

4.3 Factor Loadings and Cronbach's Alpha

Before testing the study hypothesis, it is essential to check the reliability of the construct that could be analyzed from factor loadings and reliability, which shows the internal consistency [25]. The recommended factor loading value is greater than 0.50, which shows that every item is contributing significantly to the underlying factor [38]. In other words, for internal consistency cronbachalph alpha used, where value above 0.70 is considered good, and values above 0.90 indicate excellent reliability [50], while values above 0.95 show that there is correlation or redundancy in the items. Each alpha value is less than 0.90, which shows that the construct fulfills the requirements of discriminant validity [50], and it could be identified from Table 3 below.

Table 3
Loadings and Alpha

Construct	Item	Factor Loading	Cronbach's Alpha
RFID	RFID1	0.812	0.879
	RFID2	0.824	
	RFID3	0.835	
	RFID4	0.808	
	RFID5	0.790	
	RFID6	0.783	
	RFID7	0.893	
	RFID8	0.842	
	RFID9	0.829	
IoT	IOT1	0.832	0.881
	IOT2	0.844	
	IOT3	0.819	
	IOT4	0.805	
	IOT5	0.829	
Blockchain	BLT1	0.871	0.889
	BLT2	0.886	
	BLT3	0.867	
	BLT4	0.838	
	BLT5	0.812	
	BLT6	0.783	
	BLT7	0.803	
Artificial Intelligence	AI1	0.808	0.851
	AI2	0.816	
	AI3	0.822	
	AI4	0.794	
	AI5	0.809	
	AI6	0.893	
	AI7	0.783	
	AI8	0.843	
	AI9	0.563	
	AI10	0.780	
	AI11	0.645	
	AI12	0.543	
	AI13	0.782	
	AI14	0.749	
Confidentiality	CON1	0.827	0.881
	CON2	0.839	

Table 3 (Continued…)
Loadings and Alpha

	CON3	0.848	
Integrity	INT1	0.826	
	INT2	0.832	
	INT3	0.758	
Availability	AVAI1	0.731	
	AVAI2	0.795	
	AVAI3	0.529	
Critical success factors	CSF1	0.843	0.871
	CSF2	0.851	
	CSF3	0.828	
	CSF4	0.812	
	CSF5	0.817	
Key performance indicators	KPI1	0.753	0.894
	KPI2	0.943	
	KPI3	0.902	
	KPI4	0.673	
	KPI5	0.632	
Supply Chain Transparency	SCT1	0.864	0.90
	SCT2	0.872	
	SCT3	0.861	
	SCT4	0.879	
	SCT5	0.854	

4.4 R Square

R Square values in the regression have been depicted in the current and this shows the proportion of variance in the endogenous variable due to exogenous variables [25]. Before moderation R square values were 0.46, which shows the 46% of the variance in the outcome variable which was explained by the predictor(s) alone. After introducing the moderating variable, the R^2 increased to 0.62, meaning 62% of the variance is now explained. This improvement indicates that the moderating variable has a significant effect by enhancing the explanatory power of the model. The increase of 0.16 in R^2 demonstrates a strengthening effect of the moderating variable, which suggests that it significantly increases the relationship of the independent and dependent variables [8]. Moderating and without moderating effect R-squared values are presented in the Table.4 below,

Table 4:
Table: R-squared Values Before and After Moderation

Model	R-squared (R^2)
Before Moderation	0.46
After Moderation (with Moderator)	0.62
Change in R^2 (ΔR^2)	0.16

4.5 Regression Results (Direct Effects)

This section shows the multiple regression results. The results indicate that all five digital technologies namely RFID (β = 0.294), IoT (β = 0.318), Blockchain (BLT) (β = 0.351), Artificial Intelligence (AI) (β = 0.289), and Cybersecurity (SC) (β = 0.305) have significant and positive effects on supply chain transparency (SCT) in the manufacturing SME sector. Among them, BLT has the strongest influence which highlights its critical role in providing immutable and traceable records. These findings confirm that adopting advanced digital technologies significantly improves visibility, traceability, and trust across supply chain operations, and direct results are depicted in Table.5 below and Figure 2,

Table.5:
Direct Effect results

Hypothesis	Independent Variable	β	t-value	p-value	Supported
H1	RFID->SCT	0.294	5.21	0.000	Yes
H2	IoT->SCT	0.318	5.67	0.000	Yes
H3	BLT->SCT	0.351	6.02	0.000	Yes
H4	AI->SCT	0.289	4.93	0.000	Yes
H5	SC->SCT	0.305	5.48	0.000	Yes

Note: SCT-supply chain transparency, IoT-internet of things, BIC-blockchain, AI-artificial intelligence, SC-cyber security

4.6 Moderation Results

Furthermore, moderation results reveal that the decision support system (DSS) significantly strengthens the relationship between each digital technology and Supply Chain Transparency (SCT) in manufacturing SMEs. Specifically, the interaction effects of RFID × DSS (β = 0.198), IoT × DSS (β = 0.221), BLT × DSS (β = 0.234), AI × DSS (β = 0.185), and CS × DSS (β = 0.209) are all positive and statistically significant ($p < 0.01$). Notably, BLT × DSS shows the highest interaction effect which is suggesting that DSS plays a critical role in enhancing BLT impact on SCT. Moderating results are depicted in Table.6 and Figure.2.

Table 6
Moderating Effect

Hypothesis	Interaction Term	β	t-value	p-value	Supported
H6	RFID × DSS->SCT	0.198	3.42	0.001	Yes
H7	IoT × DSS->SCT	0.221	3.79	0.000	Yes
H8	BLT × DSS->SCT	0.234	4.01	0.000	Yes
H9	AI× DSS->SCT	0.185	3.11	0.002	Yes
H10	CS × DSS->SCT	0.209	3.56	0.000	Yes

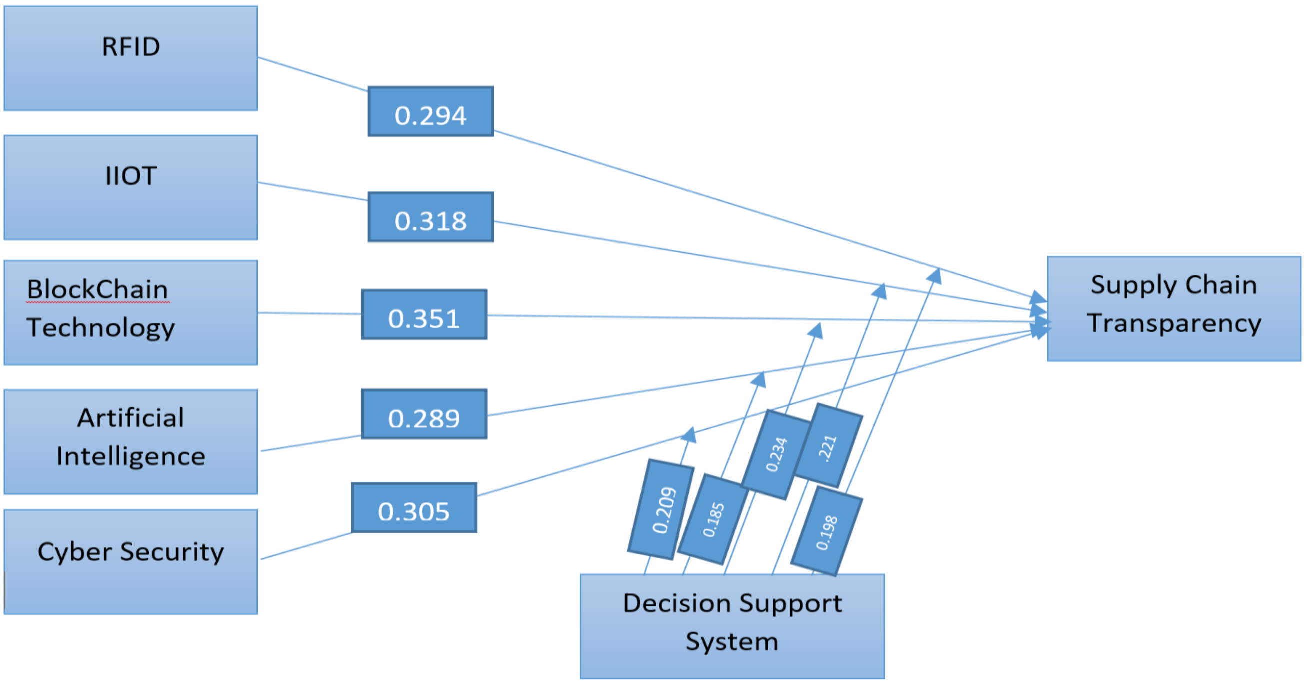

Fig.2: Coefficient Values

5. Discussion

Research focused to formulate the impact of RFID, IOT, blockchain technology (BLT), artificial intelligence (AI), and cybersecurity (SC) on the supply chain transparency (SCT) of manufacturing

SMEs. The study also tested the moderating effect of the decision support system (DSS). The study results highlighted that RFID has a significant and positive impact on SCT in the manufacturing SME sector. This finding emphasizes that RFID serves as an important enabler of real-time visibility by tracking inventory movements, reducing errors, and automating data capture throughout the supply chain. The study results is supported with study of Udeh et al. [92] where they found that RFID empowers companies to accurately trace goods from origin to destination, which enhances transparency, responsiveness, and customer trust. In other study also suggested that RFID facilitates efficient warehouse management, product recall accuracy, and compliance with regulatory requirements [2]. Study results are particularly important for the SMEs where resources are limited, RFID allows managers to make data-driven decisions quickly, improving communication among supply chain partners. As a result, manufacturing SMEs are recommended to invest in cost-effective RFID solutions and integrate them with inventory and logistics systems to build traceability and transparency, thereby achieving operational excellence and a competitive edge in local and global markets.

Further results found that IOT has a significant positive impact on SCT in manufacturing SMEs. The findings indicate that IoT technologies enhance transparency by capturing, transmitting, and analyzing real-time data related to inventory levels, product condition, and delivery status. This empirical evidence is supported by the study of Van Hoang [94], where they found that IoT's capability to integrate physical assets with digital infrastructure results in improve situational awareness, minimized human error, and timely decision-making. The same findings are also supported by the study of Baah et al. [17], which highlighted that IoT applications in supply chains contribute to reducing information asymmetry and improving collaboration among partners. This empirical evidence emphasized that SMEs should focus on IoT that could help to achieve better control over logistics, improve responsiveness to customer demands, and proactively detect disruptions. Thus, SMEs manufacturers should consider implementing IoT technologies not just as a digital tool, but as a strategic mechanism to achieve SCT, and enhance their market competitiveness.

Further results highlighted that BLT technology also significantly increases the SCT in manufacturing SMEs. These findings emphasized that the BLT decentralized ledger system ensures that every transaction is securely recorded and visible to authorized stakeholders, leading to immutable and transparent supply chain data. The strength of this relationship supports existing literature, which identifies BLT as a revolutionary tool that enhances traceability, combats counterfeiting, and increases trust among partners [66]. The results also further supported prior studies that emphasized that BLT allows for the tracking of materials and financial transactions across multiple tiers without requiring a central authority [11]. They also emphasized that enhanced visibility raises compliance, promotes sustainability, and improves buyer confidence. Based on findings, SMEs are encouraged to adopt BLT-based platforms, especially in high-value or sensitive product sectors to build stakeholder trust and attain SCT for driving competitive positioning.

Further results demonstrated that AI also positively and significantly improves the SCT, which suggests that AI technologies, such as machine learning, predictive analytics, and natural language processing play a transformative role in increasing supply chain visibility. The finding is also aligned with a previous study, which highlighted that AI improves SCT by forecasting demand, identifying patterns, and automating decision-making processes that reduce ambiguity and delay [43]. Further empirical study also supported the view that AI applications help organizations detect anomalies, prevent fraud, and improve planning, which directly contributes to transparent operations [18]. These empirical findings emphasized to focus on AI in SMEs because AI presents a powerful tool to compensate for manpower constraints and limited analytical capacity. Integrating AI into procurement, logistics, and production systems allows these firms to improve data accuracy, minimize human bias, and enhance responsiveness. Accordingly, SMEs should leverage AI-driven platforms, preferably cloud-based and modular solutions to boost SCT and differentiate themselves in highly competitive markets.

Other findings show that CS also positively and significantly contributes to SCR. These results indicate that protecting data integrity and ensuring secure information flow are critical for transparent supply chain operations. As manufacturing supply chains become increasingly digital, the role of cybersecurity intensifies, especially in SMEs that are more vulnerable to breaches due to weaker IT infrastructure [19]. The result is supported by the study of Tahmasebi [87] which they emphasized that CS can disrupt operations, compromise sensitive partner data, and damage organizational credibility. These findings are important for the SMES because a strong cybersecurity framework enhances SCT by ensuring that digital records, transactions, and communications are authentic, confidential, and traceable. Therefore, firms should treat cybersecurity as an enabler of SCT, not merely a defense mechanism, to foster trust, ensure compliance, and safeguard operational continuity.

In addition to direct effects, the moderating effect results highlighted the critical moderating role of DSS in enhancing the impact of digital technologies on SCT in manufacturing SMEs. Individually, the positive and significant interaction between RFID and DSS indicates that DSS significantly strengthens RFID's contribution to SCT. RFID alone enhances visibility through item-level tracking, but when integrated with DSS, it provides structured insights for real-time decision-making, inventory control, and anomaly detection [89]. This combination is particularly beneficial in SMEs where resources are limited, as it allows managers to extract timely insights from RFID data. Likewise, IoT also positively and significantly impact SCT through DSS, which is demonstrating that DSS provides a critical analytic layer that converts massive IoT data streams into actionable intelligence. Lee and Mangalaraj [55] emphasized that DSS applications enable SMEs to integrate IoT sensors into decision workflows, thereby increasing visibility, accuracy, and responsiveness in supply operations. These findings emphasized that SMEs should focus on strong DSS to increase the IOT, which could lead to improving the SCR.

Furthermore, results show that BLT significantly contributes to SCT, which becomes even more powerful when paired with DSS. As the BLT only inherently provides immutable and decentralized transaction records, DSS enhances this by facilitating traceability analytics, regulatory compliance tracking, and anomaly detection [60]. For SMEs that rely on lean operations, this synergy supports risk mitigation and ensures trust and integrity throughout the supply chain. In the same vein, further study results highlight that AI's impact on SCT is significantly moderated by DSS. AI can predict disruptions and optimize logistics, but DSS ensures that these AI outputs are aligned with strategic decisions and are deployed effectively across supply chain processes [49]. Final findings highlight that the impact of SC on SCR also positively and significantly strengthens with the moderating effect of DSS. While CS protects data and system integrity, DSS provides dashboards and threat detection models to translate technical signals into managerial decisions [58]. This layered approach supports a proactive and resilient supply chain environment. Overall, these findings emphasize that DSS not only complements each digital technology but also acts as a strategic tool that helps SMEs to convert technological investments into transparent, data-driven, and competitive supply chains.

6. Theoretical Implications

The study has theoretical implications. First, this study contributes significantly to the theoretical understanding of digital changes in supply chains to assess their direct impact on SCT in a single decision sciences framework to RFID, IoT, BLT, AI, and CS. While previous studies have investigated these techniques in isolation, this study leads to the principle of evaluating their individual and interactive impact collectively, and offers a more integrated approach to digitalization in SME's supply chain environment. Second, the study makes a new theoretical contribution by testing the DSS moderating role on each digital technology and the relationship with SCR. This moderating role is rarely addressed in current literature and has been tested for the first time in the context of manufacturing SMEs. The findings contributed that DSS enhances the effectiveness of each technology in improving SCR. Thirdly, the study extends the resource-based view (RBV) by demonstrating that intangible assets like DSS not only directly contribute to transparency but also amplify the value of other digital assets. It highlighted that digital complementarity could generate synergistic effects in resource-constrained environments like SMEs which extends the RBV theory in the digital transformation literature. Lastly, research findings contribute to SCR through empirically showing how different digital enablers, when properly supported with decision-making infrastructure then they can improve not only visibility and traceability but also organizational responsiveness and stakeholder trust. This opens avenues for further research on digital strategy alignment and governance mechanisms in supply chain systems.

7. Practical Implications

There are various practical implications. At first, the study results emphasized the significance for the SMEs manufacturing sector to strategically invest in foundational digital technologies like RFID, IoT, BLT, AI, and CS, to improve their SCT. These technologies help improve visibility, tracking, predictive analysis, and data integrity, which is an essential features for SME competitiveness in a digital economy. Therefore, SMEs should consider incremental and modular adoption strategies to avoid high upfront costs. At second, the integration of DSS is not optional but essential. In this regard, findings clearly showed that DSS significantly strengthens the effectiveness of all digital technologies. Therefore, SMEs should prioritize the implementation of user-friendly cloud-based DSS platforms that can process data from various sources and convert it into actionable decisions. This is particularly useful for firms with limited analytical manpower. Third, study results also contributed to encouraging to the SMEs' decision makers and supply chain managers to shift their perspectives of their DSS from a passive support tool to a strategic enabler. DSS should be integrated early in digital transformation projects to facilitate a data-driven culture, quick anomaly detection, enhanced collaboration, and proactive planning that could help to improve SCT. Training and change management programs should also be introduced to enhance DSS adoption. Lastly, policymakers, technology providers, and business associations could draw from the study findings to develop supportive structures, subsidies, or frameworks for DSS adoption among SMEs. These may include digital maturity assessments, advisory services, or public-private partnerships aimed at integrating DSS with other digital tools. Doing so could also help to SMEs meet regulatory requirements, build stakeholder trust, and achieve transparency, compliance, and long-term sustainability.

8. Limitations and Future Directions

Various limitations are discussed. Firstly, the study was limited to manufacturing SMEs while ignoring the service sector. Therefore, future research could explore on service industry to increase the research's generalizability. Secondly, the study focused only on a cross-sectional research design while ignoring longitudinal research. Therefore, future research could be conducted on a longitudinal research design. Lastly, the study did not address the mediating variable in the conceptual framework that could increase the strength of the study. Therefore, future research could be conducted with the mediated moderated model to increase the study scope.

9. Conclusion

Research conducted to formulate the impact of digital technologies, namely RFID, IOT, BLT, AI, and SC on the SCT of manufacturing SMEs. The study also tested the moderating effect of the DSS. Quantitative cross-sectional data were collected from 305 manufacturing SMEs. SPSS was used for both demographic and regression analysis. The results shown that all digital technologies positively and significantly affect to SCT. The moderating effect also shows that DSS strengthens the relationship between digital technologies and SCT. The study findings contribute to the literature by confirming that digital technologies significantly enhance supply chain transparency in manufacturing SMEs. It further contributes by highlighting the moderating role of DCC, which strengthens the impact of these technologies. These contributions guide SME managers and policymakers to invest in integrated digital solutions for improved supply chain visibility and performance.

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