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The Impact of Technologies of Traceability and Transparency in Supply Chains

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Abstract: The key purpose of the article is to analyze the effect of digital transformations, such as blockchain technology (BCT), the social internet of things (SIoT), and artificial intelligence (AI) techniques, on the supply chain (SC) for traceability and for creating transparency. The partial least squares (PSL) structural equation modeling (SEM) method was applied in combination with SmartPLS v3.3.6. The package was employed to obtain information through a survey of SC Pakistani professionals using the snowball sampling technique. Traceability plays a crucial role in enhancing transparency and ultimately the performance of SC through BCT, SIoT, and AI. Therefore, the study recommends starting the digital transformation of the SC because this is a complex process that involves a wide range of internal and external stakeholders. The study findings show the importance of technologies of traceability and transparency as an analytical multidisciplinary approach to enhance the SC sector, although with certain limitations this can be taken into account by stakeholders. This study will be useful for decision makers investing in technologies of traceability and transparency in the SC. The study raises the awareness of traceability and transparency in the SC process, and also reveals research gaps and provides opportunities for further research. Despite the prevalence of studies in supply-chain traceability (SCT) and transparency, there is a dearth of empirical proof on how the digital transformation of the SC could lead to transparency and ultimately performance.

Keywords: supply chain; technology; traceability; transparency; tracking; tracing

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1. Introduction

Information's ability to be tracked and traced is referred to as traceability. The capacity to track a product's journey through the supply chain (SC) is traceability [1]. The interest in product safety and quality as well as regulatory, social, and economic concerns have led to the implementation of traceability systems all over the world. On the other hand, the flow of information amenably is transparency [2]. Transparency is offering relevant information in a timely manner free from bias without cost, delay, and discrimination [3]. Transparency in the SC can be achieved through the use of traceability [4]. Several logistical actions must be carried out in production alliances, which are economic relationships between numerous distinct enterprises at dispersed regional production facilities. A high quantity of communication is required, since many different stakeholders must cooperate in order to achieve the shared goal of added value, in addition to the physical flow of resources for procurement, production, distribution, and transport activities. Because of this, logistic service providers play a crucial role in the SC and are required to provide a variety of added-value services, such as organizing transportation. High-level communication is crucial, especially at SC interfaces, to ensure the cooperation indicated [5,6]. As a result of the introduction of process automation, trade processes have changed from manual to electronic communication and involve the application of innovative technologies. However, for an exceptionally long time, process design was restricted to a centralized structure. A number of issues with suitable technology adoption are present in centralized operations, such as blockchain technology (BCT), the social internet of things (SIoT), and artificial intelligence (AI) [7,8]. Both the efficiency and the interoperability that now exists between various business actors are negatively impacted by problems—for instance, poor efficiency and synchronization and low coordination.

A number of academics have added traceability to various SC scenarios to build transparency. For example, ref. [9] presented an innovative method for producing a transparent meat SC. This technology lets clients trace the meat's history. The path of meat throughout the SC may be tracked by suppliers and other participants, and also government organizations can check the quality of the meat at any point in the journey [5]. Wireless sensor networks enable the control of several underground environments that are suffering from a substantial reliability problem [10]. A global positioning system (GPS)-allowed traceability system was presented, to implement tracing and tracking from the perspective of production planning and SC event management, to determine transparency in the global SC. On the other hand, researchers [11,12] have stated that traceability through centralized methods is not very good due to the possibility of data manipulation, a single point of failure, etc. Similarly, ref. [12] addressed the centralized traceability method as an untrustworthy, unequal, and monopolistic information system. Corrupt practices, information tampering and failure of its functionalities are the problems that could result from it [13]. Contrarily, ref. [14] claimed that while business processes may already function effectively when managed by a centralized method using local databases for each actor, there is still a need for transparency across processes and strong player interactions. Real-time tracking and tracing, for instance, has long been sought after in the SC to cut down on needless wait times for the validation of information. A distributed system can be used to obtain better performance [15].

Supply-chain traceability (SCT) with full information is crucial for businesses as well as for customers. As an illustration, unwelcome cold chain contamination, such as food poisoning, could have detrimental short- and long-term health effects on customers. To protect service quality, brand reputation, and public trust, it is crucial to find and recall potentially contaminated items early in the cold chain. The SCT literature on these topics has mostly remained open. However, the SC does not have a strategy for implementing BCT, the SIoT, or AI to make the SC transparent and traceable. In light of this knowledge gap, we suggest the following study question: how can a traceability process based on emerging technologies achieve transparency in the SC? This study aims to investigate traceability to enhance the transparency of the SC processes. Among the objectives of the research are: (1) investigating the feasibility of a technologies-based traceability process; (2) examining the influence of traceability on transparency in the SC; (3) framing the hypothetical framework of technologies of traceability and transparency and evaluating the potential implications of such framework. To achieve these objectives, SmartPLS v3.3.6 was used for PLS-SEM. This study establishes hypotheses and statistically evaluates the conceptual framework utilizing surveys from Pakistani businesses. This study emphasizes theoretical, practical, and social implications. This article is ordered as follows. In Section 2, research framework based on previous literature is provided. In Section 3, the methods are presented. Analysis as well as results are offered in Section 4. Implication and findings and conclusion are examined in Sections 5 and 6, respectively, followed by references.

2. Literature Review

2.1. Supply-Chain Traceability (SCT) and Transparency

The term supply chain (SC) is an inventory management strategy that may optimize the transition from raw materials to finished products since it is an integrated system with a single aim [16,17]. Yanhu Han and Xiyu Yan 2022 [18] stated that well-managed SC may influence the advantages of construction. Manufacturers, auctions, wholesalers, importers, exporters, retailers, specialized stores, and service providers are all involved in the product supply chain (SC). The primary procedures include handling, conditioned storage, packaging, transportation, and trading, leaving the initial product's essential qualities unaltered. Raw materials are the starting point for the processing SC, which leads to processed consumer goods with increased value [9]. Energy is a prime factor in the development of the economy [19], whereas the SC is a significant manufacturing industry in the world economy [20], providing enormous advantages to individuals from all walks of life [21]. The capacity to track a product's journey through the SC is known as traceability [1]. This definition includes three essential elements: product tracking (forward and backward follow-up), product history data related to product movement in the SC, and product follow-up (backward and forward). These data are crucial for figuring out how many production portions of—and where—defective materials put into the SC at any one time have an impact. Recall management and traceability technologies can help increase value and safety in global SC [1].

Generally, the open flow of information is transparency [2]. Transparency is to provide relevant imperative information in a timely manner free from bias and without cost, delay, and discrimination [3], receiving feedback and demonstrating consistency between words and actions according to the idea 'what you see is what you get' [22]. Advance technology has improved the process of transparency [23], whereas the internet shows the transparency levels of any business [24]. (Parris et al., 2016) [3] stated that a transparent organization always internally shares information across the logistical team from both top down and bottom up, which further builds trust, engages the logisticians in their job, formulates and implements strategies, and enhances performance.

2.2. Technologies of Traceability and Transparency in Supply Chains

A number of game-changing technologies are reshaping daily SC procedures, boosting productivity, and enhancing business performance [25]. Platforms are being observed to slowly replace traditional supply chains with a modern one [26]. Digital platforms that are focused on the needs of the consumer, such as social media, mobile networks, and e-commerce, are enabling consumers to make more informed purchasing decisions. Fortunately, these same cutting-edge technologies are also assisting in the transformation of conventional SC networks into cutting-edge digital systems that allow for increased visibility, greater collaboration, increased efficiency, and quicker response times [27]. Technologies for traceability and transparency are now essential tools for information coordination and sharing between stakeholders throughout the SC [28]. The quick transfer of information during the SC depends on several platform features [29]—for example, utilizing a radio frequency identification system and a warehouse management system to monitor order status and organize a productive distribution process [30]. The success of the SC also depends on good interaction between decision-makers at different levels and operational reaction teams/personnel in the field [31]. According to [32], information systemic vulnerabilities are brought on by a lack of software that can manage humanitarian SC activities, erratic internet connectivity, subpar tools, and a shortage of skilled and knowledgeable ICT personnel. According to [33], a lack of suitable IT systems causes partners to work harder than necessary and convey information ineffectively. Because flaws in this area can lead to expensive errors and ineffective time management, poor IT infrastructure may also act as a barrier between customers and management [33,34].

There are various perspectives on SCT [35]. Studies find that SCT can occur through emerging technologies; however, studies fail to integrate and link these different forms of technologies of traceability and transparency with a systematic model. As seen in Figure 1, we offer a study framework of SCT and transparency based on emerging technologies.

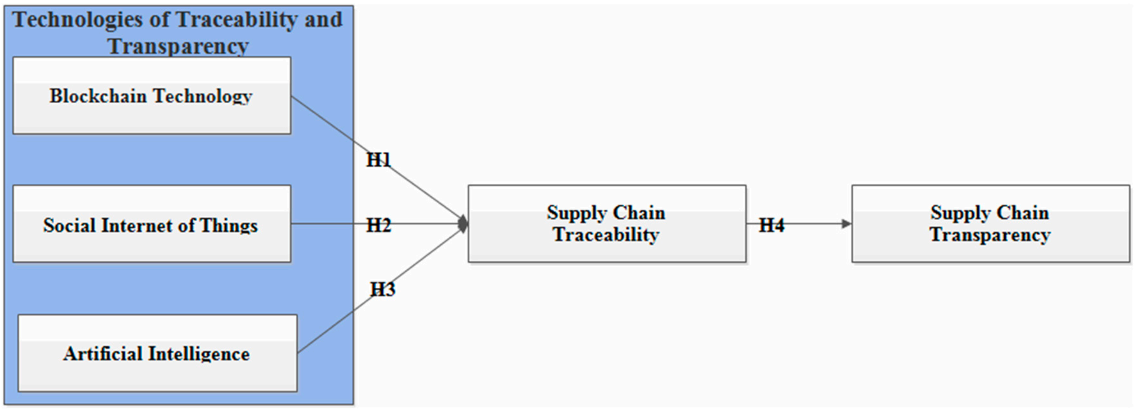

Figure 1. The Research Model.

2.3. Blockchain-Based Traceability

The first global distribution of a digital currency, called Bitcoin, has been announced [36]. Bitcoin is a digital currency that operates on a peer-to-peer (P2P) network without the use of any trustworthy third parties. Blockchain technology (BCT) is the foundation of this network [37]. BCT is a ground-breaking innovation that will bring about new information and communications technology (ICT) by supporting low-cost decentralized distributed data management that is tamper-resistant, highly available, and transparent. Traditional digital currencies are only dispersed in an area under the control of the mechanism and are centralized in that mechanism to give value to electronic data [36]. The approach to ensuring the confidentiality of a transaction using a blockchain presents a substantial problem. Processing a blockchain transaction takes longer than processing a traditional transaction, since validation by all network users is necessary. Therefore, it is difficult to increase processing performance for applications that involve a large number of transactions [36]. While BCT allows for the real-time monitoring of business processes and the synchronization of crucially updated documentation, it still has a number of technical problems, including block size, performance (transaction throughput and latency), scalability, protection, and privacy. Studies have stated that BCT may be utilized in business to cut costs and friction, address transaction inefficiency and vulnerability, and create a trustless environment all around [37]. Relationship management in the global SC is a promising BCT application that can help deal with the complexity and variety of multiple shareholders [38].

Many SCs have already adopted blockchains in order to establish traceability and hence foster transparency. One of the most important considerations in the design of the distribution network is the degree of order visibility. End users may track the complete history and provenance of halal meat products thanks to the SC's blockchain-based traceability system. A blockchain-based traceability solution was created and put into use by [39] to manage agri-food SCs. Walmart recently collaborated with International Business Machines Corporation (IBM) in the investigation of blockchain-based traceability results. According to [40], a blockchain-based traceability method built on Hyperledger Fabric was able to pinpoint the origin of mangoes in just 2.2 s, compared to the previously required seven days. In order to track and trace the events in a pharmaceutical SC, which includes a single sender and receiver and an IoT-based container as players, ref. [41] developed an Ethereum-based traceability solution [13]. Visual tracking based on a segmentation-driven structure brings about a huge amount, which becomes a hurdle in practical application [42]. A blockchain-based traceability system was set up by [12] to create transparency in the Chinese agro-food SC in particular. A new framework for determining the genuineness of wine was proposed in [13,43].

A centralized blockchain structure, however, lacks transparency and trust, according to [11]. The authors of [12] described the centralized traceability system as a dominant, asymmetric, and solid information system. This can result in problems such as information deception and corruption. Furthermore, problems, for instance, single points of failure, could suddenly stop the centralized systems from functioning. In contrast, ref. [13] discussed blockchain traceability solutions suggested for product SCs are mainly for preventing hazards. In short, blockchain traceability solutions can make the SC sustainable, resilient, and efficient. Therefore, BCT may be viewed as a long-term, searchable, and eventually unchangeable archive of public records. The following hypothesis is what we propose as a consequence:

H1. *There is a beneficial connection between blockchain technology and supply-chain traceability*.

2.4. Social Internet of Things Based Traceability

The Internet of Things (IoT) will likely be one of the most important aspects of the Internet in the foreseeable future. The IoT is a network that connects disparate devices and systems together. During this period, a new area of study evolved, and it is referred to as the SIoT. The SIoT focuses mostly on aspects of social networking. The term IoT is used to describe a network of interconnected computing devices that can communicate with one another and collaborate on their own to accomplish a certain objective. The structure, the ability to accommodate a large number of applications, and the networking services offered by the SIoT make it preferable to the IoT [44]. In the SIoT, objects can make as many acquaintances (i.e., other objects) as they need in order to obtain the appropriate services. Because of this benefit, the SIoT is more advanced than the IoT. A relationship query is used to determine the connection between two groups of people, such as friends and friends of friends. In this setting, connections between people of different backgrounds are forged on the basis of the social interests, real-life connections, and other aspects of their shared experiences. These errands are carried out according to the particular amount of trust that exists between individuals or, on occasion, between friends. As a result, the level of trust among the devices can be expanded exponentially when they communicate with each other as friends (IoT devices) [45].

Live streaming through the internet and mobile devices is a new network for trade to interact with customers and to sell products in a timely way [46]. Similarly, SIoT solves various issues, such as composition, service discovery [47], and connection, and monitors and controls the behavior of objects [44]. In a similar vein, the SIoT is well positioned to revolutionize the SC in terms of both performance efficiency and new income streams, which will become accessible as a result of increased levels of business transparency and traceability [27]. Traditional tracking techniques, including recurrent barcode scanning and checkpoints, only offer segmented data, which are insufficient. SIoT has provided the SCT with comprehensive information that was not possible with old technology. There is not a systematic or theoretical framework that encompasses all perspectives in the SCT, probably due to its novelty. By presenting a theoretical framework that incorporates SCT technologies to extend it, we are inspired to look into this issue. As a result, we suggest the following theory:

H2. *Traceability and the SIoT are closely related*.

2.5. Artificial Intelligence-Based Traceability

Artificial intelligence (AI) is a technology for creativity that replicates human intelligence and aptitude processes through technology, primarily computer systems, robots, and digital equipment [4]. This cutting-edge technology has the potential to drastically alter the SC's sustainability and performance in the future. In order to deliver crucial insights that enable better-informed decision making, deep learning is used by AI to analyze enormous volumes of data that have been gathered from numerous sources. To better allocate resources to top-selling categories, a retailer, for instance, might use AI to analyze sales to identify which products are hot and which ones are lagging. Although the technology is still in its infancy, it is anticipated to have a significant impact on how businesses execute and manage sustainability programs and initiatives [24]. Currently, the use of AI in the

SC is becoming more and more important [42]. In order to forecast consumer demand, perception, and purchasing behavior, AI approaches are applied in the food retailing phase. AI is used in inventory management to estimate regular demand and confirm that there are no inventory-related issues [43]. AI-based traceability of the product SC would permit the detection of weaknesses, defects, and adulterations of a product, hence boosting its quality and safety; consequently, a multitude of agencies, associations, and platforms were created with this perspective [44]. On the other hand, artificial intelligence (AI) is limited to the tasks for which it has been created or built, and anything outside of that can cause it to malfunction or produce useless results. In addition, there may be certain sustainability risks and concerns beyond the advantages provided by smart and computerized technologies, such as the enormous energy consumption, the e-waste problem, market concentration, employment displacement, and even its moral structure [42]. Despite drawbacks, we found considerable support for the notion that AI is regarded as a key for SCT. Concerning the role of AI in the model, AI increases traceability, which further leads to a transparent SC, thus:

H3. *Artificial intelligence is positively related to supply-chain traceability.*

2.6. Traceability and Transparency in the Supply Chain

AI is a tool for creativity that imitates human aptitude and intellective processes using technology, principally computer systems, robotics, and digital equipment [48]. The tracking performance of the closed-loop continuous time-delay teleoperation system is evaluated by Lyapunov stability theory [49]. Traceability can be defined as anything that happens to the items before, during, and after they are manufactured, packaged, and distributed [50]. The capacity to retrieve detailed information about anything that is still included in an SC is referred to as traceability. It may be related to a specific procedure, an inventory, or one of the SC members, such as a retailer or wholesaler [13]. According to (Pant, Prakash, and Farooquie, 2015) [51], the notion of traceability is the capacity to retrieve product-related records during the SC's upstream phases. Traceability can be characterized in more depth as the what, how, where, why, and when characteristics of the underlying product along an SC [52]. Tracking and tracing are directly related to the term "traceability", according to researchers [50,53,54]. The process of tracking a product begins at the point where it was manufactured and continues to the location where it was sold. Tracing is mostly performed on the way to the endpoint from the origin. (Schwägele, 2005) [55] emphasizes that the capacity to trace an item's provenance using entries in the SC is known as tracing.

Contrarily, the term "transparency" refers to the SC's general visibility. The degree to which all of an SC's stakeholders have general knowledge of and access to the product-relevant information they require, without loss, interference, delay, or distortion, is the measure of an SC's transparency [48]. The pursuit of transparency across SC processes can potentially influence decentralization and automation [37]. In today's globally connected economy, SC transparency is essential. Transparency flaws can increase one's risk exposure on several levels, from product failure and recalls to a rapid decline in brand reputation. Manufacturers, suppliers, and retailers are all actively looking into technologies to support their efforts to build a more transparent, sustainable SC as part of this effort [27]. In order to build a sustainable and resilient SC and overall successful corporate governance, transparency is thought essential [56].

The authors of [13] state that traceability enables transparency through tracing and tracking. Traceability assesses the rise in efficiency of an SCM by providing an information trail and enabling firms to manage their resources efficiently by applying new traceability information systems [4]. Organizations can boost transparency as a crucial input by implementing traceability, which can therefore make consumers feel more satisfied when perceiving safer products [50]. Hence, based on the prevailing discussion, it may be argued that traceability is mediating between emerging technologies and transparency in the SC, which was hypothesized in the present research as follows:

H4. *Traceability plays an important job as a mediator in the association between emerging technologies and transparency. Emerging technologies meaningfully increase traceability. Subsequently, traceability further leads to transparency.*

3. Method

3.1. Population and Sampling

This research adheres to the quantitative research method, as it statistically assesses the mediating role of SC traceability between emerging technologies and SC transparency. The empirical research method assists in measuring opinions and providing statistical support for the relative importance of different variables [57]. To assess the reliability, validity, goodness of fit, and psychometric soundness of the study framework, the primary data were gathered using an online questionnaire built in Google Drive as seen in Appendix A. Pakistani SC professionals were among the study's population. A non-probability technique called snowball sampling was used, since there was no sampling frame and the precise total population was unknown. To begin with, the authors asked their contacts to complete the survey, pass along information on other likely respondents, or share the link with their friends and acquaintances across the nation. Following the recommendations in reference [58], a sample size was chosen. The authors of [58] suggested a 10:1 respondent-to-indicator ratio for multivariate studies. The present article comprises five latent variables and 29 manifest variables, as seen in Figure 2. Hence, the minimum sample size for the present research can be 290 = 10 × 29.

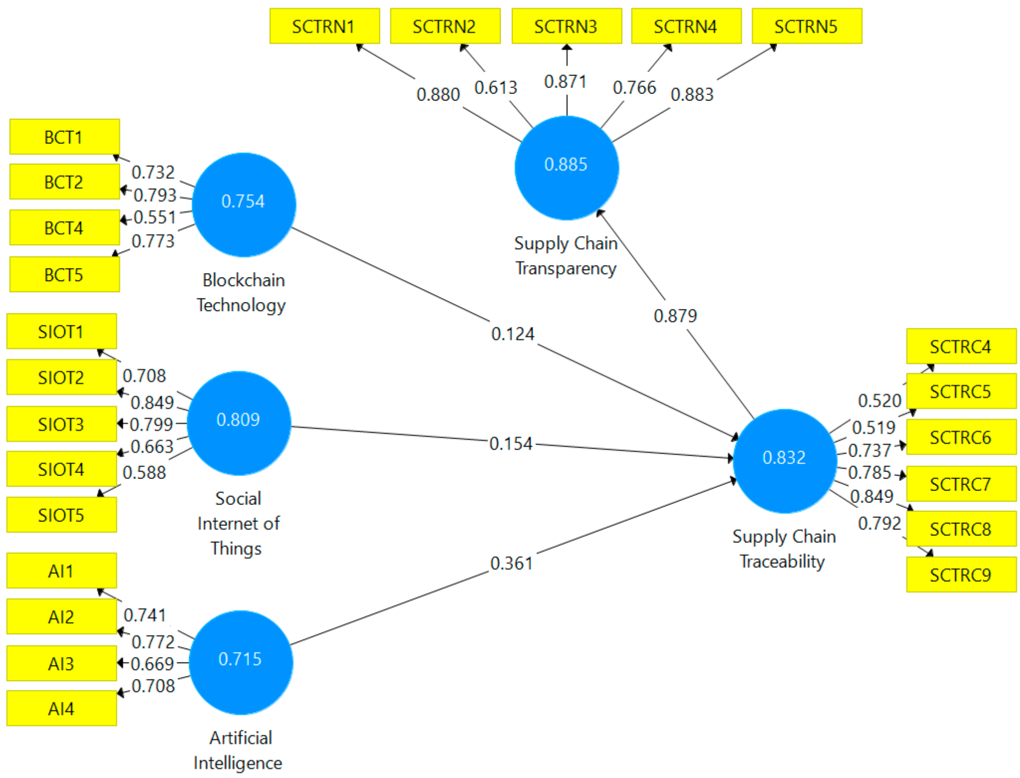

Figure 2. Composite Reliability Values: Note: BCT = Blockchain Technology, SIoT = Social Internet of Things, AI = Artificial Intelligence, SCTRC = Supply-Chain Traceability, SCTRN = Supply-Chain Transparency.

3.2. Questionnaire Development and Data Collection

This research adhered to the recommendations in [59,60] on how to develop and validate the questionnaire. To operationalize the research model, a scale was adapted from relevant existing literature. The measurement scale for technologies was adopted from [61,62]. That for SCT was adapted from [4,63,64], whereas the scale for SC transparency was modified from [57,63]. Respondents assessed twenty-nine items on a five-point Likert scale (a score of 1 indicates "Never and Strongly Disagree" while a score of 5 indicates "Always and Strongly Agree"). The indicator was created using the English language and it as a whole was constructed by basing its components on recent research. Small adjustments were made as necessary for the current circumstances. The questionnaire was reviewed by certain subject experts (professors and managers) after it had been written. In order to appropriately reflect the mediation relationship of SCT between technologies and transparency, the questionnaire was amended in response to their feedback. Minor changes were made to the questionnaire following a pilot test in order to render it ready for data collecting.

Based on the feedback of professionals and pilot-test outcomes, the questionnaire was confirmed for final data collection. The questionnaire did not request any personal data from the respondents in order to maintain their privacy and participation was voluntary. The survey was conducted between April and August 2022. With a cover letter outlining the survey's goal and ensuring each respondent that their information will be kept private and confidential, respondents were contacted by email, Facebook, WhatsApp, LinkedIn, and other social media platforms. Following three email reminders, 313 usable responses were obtained. Only 20.44% of participants are female. This percentage is similar to the global trend for the inclusion of women in the SC field (globally, women make up 17% of the SC workforce) [65].

3.3. Descriptive Statistics

As per the guidelines in [66], biased replies were compared to earlier responses (first and last 30%), and late respondents were considered to be equivalent to non-respondents. The article identified that whole manifest variables have non-statistical differences, with $p > 0.25$. Consequently, in this investigation, non-response bias was not a major issue. Gender, age (in years), region, year of experience, education level, occupational level, and SC specialty were all applied to control the data, which was then examined after normality was tested. All questionnaire procedures, guidelines, directives, and exercises were carried out in Pakistan, and 95.52% of respondents were from Pakistan. A total of 313 SC professionals participated in the study, comprising entry (10.86%), supervisor (34.50%), manager (25.56%), director (22.04%), and leader (7.03%). with the majority (30.67%) of the respondents being between the ages of 46 and 55. The majority (46.32%) had a higher education, while 26.51% were logisticians. Additionally, the mean, standard deviation, frequency, variance, skewness, and kurtosis were assessed; see Table 1.

Table 1. Demographic Information.

	Classification of Variables	Valid	Frequency	%	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
								Statistic	Std. Error	Statistic	Std. Error
Gender	Male Female	313	249 64	79.55% 20.44%	1.21	0.409	0.168	1.446	0.241	0.092	0.478
Age	<22 23–28 29–35 36–45 46–55 56–60 61+	313	3 12 74 86 96 37 5	0.96% 3.83% 23.54% 27.48% 30.67% 11.82% 1.60%	4.23	1.153	1.330	−0.142	0.241	−0.363	0.478
Region	Pakistan Other	313	299 14	95.52% 4.47%	1.04	0.197	0.039	4.767	0.241	21.144	0.478
Years of Experience	<1 2–5 6–10 11–15 16–20 21–25 26+	313	9 54 86 49 69 27 19	2.88% 17.25% 27.48% 21% 15.65% 8.63% 6.07%	3.90	1.567	2.455	0.330	0.241	−0.673	0.478

Table 1. *Cont.*

	Classification of Variables	Valid	Frequency	%	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
								Statistic	Std. Error	Statistic	Std. Error
Education level	High school or less Diploma Bachelor High Edu	313	6 19 143 145	1.91% 6.07% 45.69% 46.32%	3.36	0.689	0.475	−0.990	0.241	1.235	0.478
Occupational Level	Entry Supervisor Manager Director Leader	313	34 108 80 69 22	10.86% 34.50% 25.56% 22.04% 7.03%	2.74	1.079	1.164	0.243	0.241	−0.736	0.478
Supply-Chain Specialty	Planning Procurement Warehousing Transportation Logistics General SC	313	19 35 40 65 83 71	6.07% 11.18% 12.78% 20.77% 26.51% 22.68%	4.19	1.509	2.277	−0.547	0.241	−0.694	0.478

4. Results and Analysis

Because the objective of this research is theory building instead of confirmation, a PLS technique is preferred rather than the covariance-based (CB) technique [67]. PLS-SEM is widely used in SC research [68]. In PLS, lagging variable values are employed if the study framework is complicated. The present research consists of a complicated study framework as it has reflective items and manifest and latent variables, which have a common subject matter. Therefore, applying PLS-SEM, the study framework was examined in two phases proposed by [67] using the SmartPLS application, which is easy to use, simple, and immediate [58]. The measuring model was examined in the first stage in order to determine its validity and reliability. In the second stage, the structural model was assessed for testing hypotheses. The measurement model's reliability was ensured using composite reliability (CR) and Cronbach's alpha, and the model's validity was assessed using discriminant and convergent validity tests. The validity and reliability of the measurement model had been established before the model's hypothesis was tested. The skewness and kurtosis were utilized to evaluate the study's normality prior to employing the SmartPLS v3.3.6 software through SPSS, as shown in Table 2. The data were normal, and the figures fell within the 2 permitted ranges [69]. A variance inflation factor (VIF) test was then used to verify the multicollinearity. According to [70,71], the values of VIF must be fewer than 10, but in this study, the values of VIF were less than 3; therefore, multicollinearity was not a concern in this study.

Table 2. Descriptive and Collinearity (VIF) Statistics.

		BCT	SIoT	AI	SCTRC	SCTRN
N	Valid	313	313	313	313	313
	Missing	0	0	0	0	0
Mean		4.17	3.96	4.04	4.18	3.93
Std. Error of Mean		0.045	0.055	0.056	0.057	0.070
Median		4.20	4.00	4.00	4.20	4.00
Std. Deviation		0.448	0.550	0.560	0.573	0.695
Skewness		−0.634	−0.487	−0.146	−0.597	−0.220
Std. Error of Skewness		0.241	0.241	0.241	0.241	0.241
Kurtosis		−0.017	−0.081	−0.617	−0.588	−0.343
Std. Error of Kurtosis		0.478	0.478	0.478	0.478	0.478
VIF		1.301	1.941	1.385	1.243	1.265

Note: BCT = Blockchain Technology, SIoT = Social Internet of Things, AI = Artificial Intelligence, SCTRC = Supply-Chain Traceability, SCTRN = Supply-Chain Transparency.

4.1. Evaluation of the Measurement Model

The endogenous variables' variance values were calculated using Pearson's coefficient R square (R2) and adjusted R square (AR2). Table 3 shows that the R2 and AR2 values were extremely similar. As a result, the findings showed a large and moderate effect size and also a good model fit [63].

Table 3. Model Validity and Reliability.

	R Square	Adjusted R Square	Cronbach's Alpha	Composite Reliability	Average Variance Extracted
Blockchain Technology			0.764	0.754	0.517
Social Internet of Things			0.777	0.809	0.529
Artificial Intelligence			0.740	0.715	0.524
Supply-Chain Traceability	0.571	0.695	0.793	0.832	0.508
Supply-Chain Transparency	0.378	0.359	0.864	0.885	0.655

4.2. Measurement Model Reliability

Cronbach's alpha determines the inner reliability of the constructs, while CR determines the further lenient reliability of the constructs. For exploratory determinations, a reliability of 0.60 ≥ is appropriate, whereas Cronbach's alpha <0.60 indicates that the variables do not fit well. The Cronbach's alpha score was >the recommended value as seen in Table 3. Consequently, the model is appropriate [63]. Likewise, the CR values greater than the 0.70 threshold indicated the model fit well and demonstrated great reliability [63,72,73], (see Table 3 and Figure 2).

Model Validity

Without validity, a model is not reliable [74]. Therefore, the research used convergence and discriminant validity tests. Deleting the BCT3 item of blockchain technology, the AI5 item of artificial intelligence, and STRC1, STRC2 and STRC3 items of SC traceability, all items' factor-loadings exceeded 0.70. The AVE values were also all > than 0.50 [73] for all constructs. Thus, the value of factor loadings and model's AVE prove a prominent degree of convergence among the manifest variables in evaluating their corresponding constructs (see Table 3 and also Figure 3).

There are multiple techniques to assess the discriminant validity (DV). The DV was then assessed by applying the measurement model to check if an item accounts for more variation in its related observed construct than it demonstrates with other variables in the related model [75]. In the present study, DV of the constructs has been studied by correlation matrix acquired through SPSS and compared with the Square Root (SQRT) of the AVE of each construct. The inter-correlation matrix is represented by the diagonal elements that reflect the SQRT of the AVE values for each construct and the values below the diagonal. The correlation coefficients between each construct and another construct in the same row or column show that all SQRT of AVE values were greater than any other constructs used in this study. Overall, all of the measurement components and research constructs are suitable for estimating the generated hypotheses and structural model. As a result, Table 4′s findings demonstrate that all of the present research's constructs satisfy all DV requirements and that no DV problems were discovered employing the Fornell Larcker criterion [67]. However, ref. [76] reported that HTMT is the best method for the DV in PSL.

The HTMT values of the constructs were less than the threshold value of ≤0.85 [77], apart from SC transparency with SC traceability, the remainder of the values have no issue with DV and show a fit model and showed validity (see Figure 4).

4.3. The Predictive Validity

Cohen [78] stated that the score of predictive validity (Q2) r Stone–Geisser indicator 0.02, 0.15, and 0.35 offered small, medium, and high effect sizes, respectively. In this research, (See Table 5) the values are 0.125 and 0.483 for the endogenous construct of SC traceability and SC transparency. Therefore, the research Q2 outcomes reveal that the model has a medium degree of predictive accuracy, and the variables are necessary for the normal adjustment of the structure.

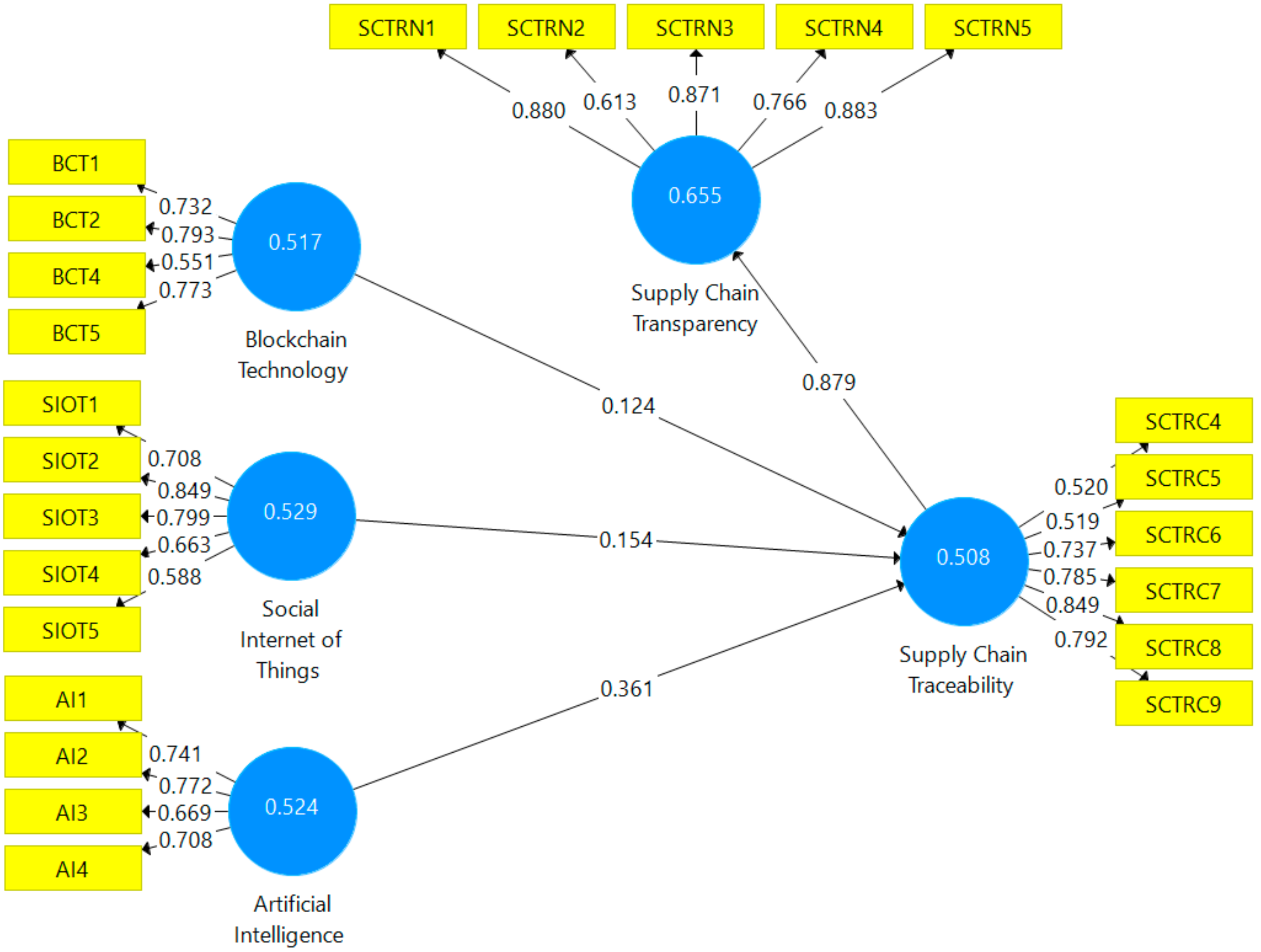

Figure 3. PLS with the AVE values, Note: BCT = Blockchain Technology, SIoT = Social Internet of Things, AI = Artificial Intelligence, SCTRC = Supply-Chain Traceability, SCTRN = Supply-Chain Transparency.

Table 4. Correlation with Fornell-Larcker Criterion.

	1	2	3	4	5
Blockchain Technology	1				
Social Internet of Things	0.336 **	1			
Artificial Intelligence	0.425 **	0.452 **	1		
Supply-Chain Traceability	0.461 **	0.478 **	0.520 **	1	.
Supply-Chain Transparency	0.454 **	0.384 **	0.308 **	0.370 **	1

Note: ** Indicates the correlation is significant at the 0.01 level (2-tailed).

4.4. Hypothesis Testing

After validation and reliability of the variables, the model is assessed for hypotheses testing. (Table 3 781, P 0.00). Hence, H1 was proved. Social Internet of Things had a substantial positive impact on supply-chain traceability (T 2.904, P 0.004) that validated H2. Artificial Intelligence had a major influence on supply-chain traceability (T 3.120, P 0.002), which validated H3. The transparency impacted the RI (T 5.392, P 0.00) validating H4 (see Figure 5 and Table 6).

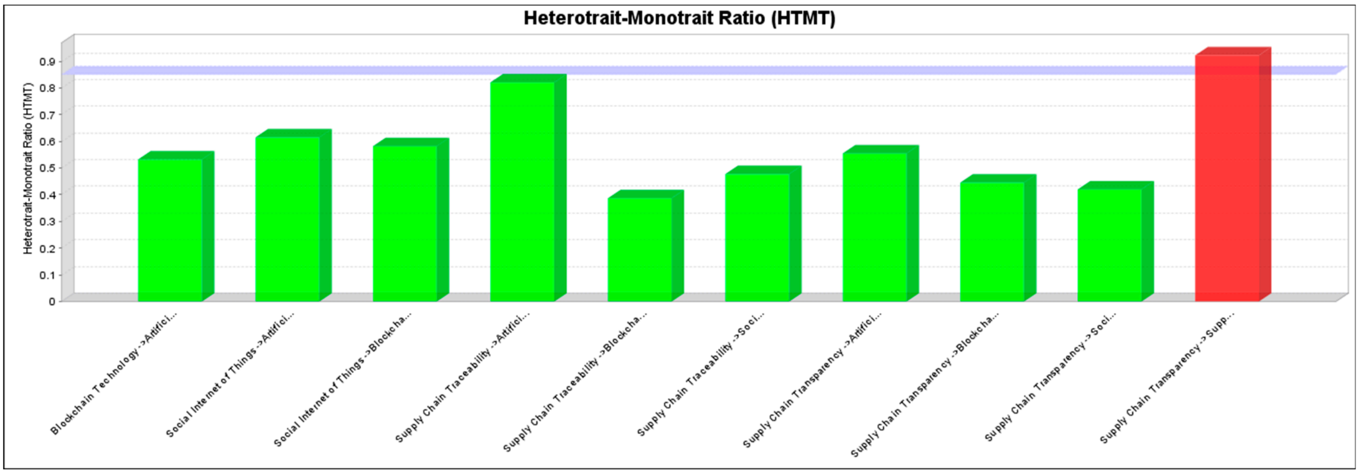

Figure 4. Determining discriminant validity using HTMT ratio.

Table 5. Predictive validity.

	SSO	SSE	Q^2 (=1 − SSE/SSO)
Blockchain Technology	400.000	400.000	
Social Internet of Things	500.000	500.000	
Artificial Intelligence	400.000	400.000	
Supply-Chain Traceability	600.000	525.193	0.125
Supply-Chain Transparency	500.000	258.654	0.483

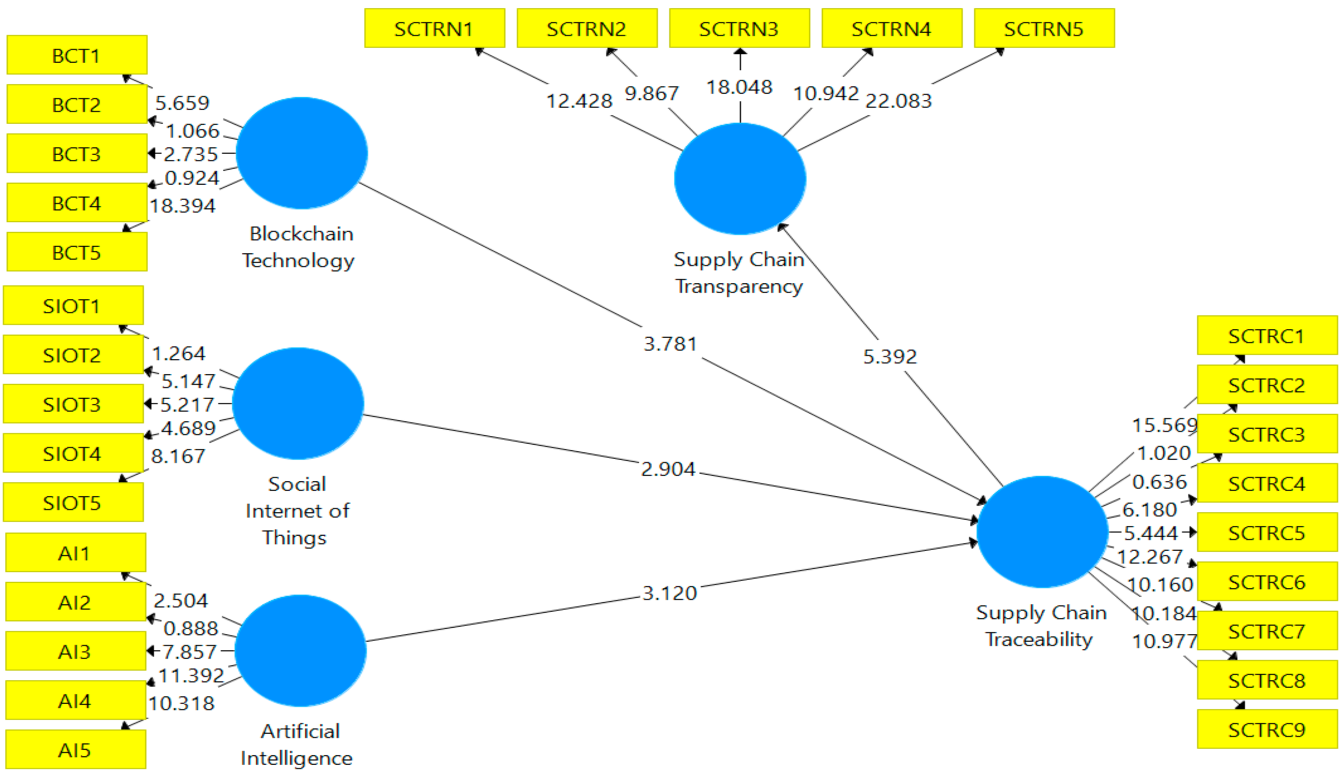

Figure 5. T-Statistic Value, Note: BCT = Blockchain Technology, SIoT = Social Internet of Things, AI = Artificial Intelligence, SCTRC = Supply-Chain Traceability, SCTRN = Supply-Chain Transparency.

Table 6. Path analysis using bootstrapping.

	Path Coefficient	Sample Mean	Std. Deviation	T Statistics	p Values	Supported?
Blockchain Technology –> Supply-Chain Traceability (HI)	0.333	0.342	0.088	3.781	0.000	Yes
Social Internet of Things –> Supply-Chain Traceability (H2)	0.262	0.280	0.090	2.904	0.004	Yes
Artificial Intelligence –> Supply-Chain Traceability (H3)	0.281	0.282	0.090	3.120	0.002	Yes
Supply-Chain Traceability > Transparency (H4)	0.399	0.432	0.074	5.392	0.000	Yes

5. Findings and Implications

Previous research has revealed the importance of emerging technologies and value outcomes when emerging technologies are implemented successfully. Evidence from the literature shows how emerging technologies can benefit the SCT and transparency. Motivated by emerging technologies, such as BCT, SIoT, and AI, we attempted to fill a gap in the present literature by examining various assessments of traceability that to our knowledge have rarely been examined. So far, there is still no common consensus concerning the identification degree and its pros and cons in the SC. We contend that in the SC sector, business-process traceability may be crucial and we have framed a research model to bridge the role of emerging technologies of traceability. The results of this research align with findings from the literature [1,5,13,79], further showing that emerging technologies significantly impact SCT and transparency. We contend that numerous traceability issues in the SC can be simply addressed using the process traceability model that is given in this paper. The proposed framework might provide chances to alter the conventional business process if it produces a more effective response.

5.1. Contribution to Theory

In this study we predict and develop a theory to investigate whether the BCT, SIoT, and AI can bring about SCT and ultimately transparency. It might be argued that this article makes some valuable theoretical contributions based on the study's findings. Firstly, BCT facilitates the tracking of company activity in real time. The results of this research, which show the impact of traceability, align with the results of [37]. Second, ref. [27] stated that the SIoT is posed to convert the SC with both performance efficiencies and new income opportunities made available because of growing levels of business traceability and transparency. Thus, the empirical results of this research openly suggest that the SIoT significantly enhances SCT and transparency. Third, ref. [80] highlighted how AI methods are used to forecast daily demand and make sure there are no inventory-related issues. (Sunny et al., 2020) [13] detailed the way traceability enables transparency through tracing and tracking. (Bosona and Gebresenbet, 2013) [4] mentioned that traceability enhances the efficiency of SCM by providing information trails and allowing businesses to effectively manage their resources with the use of new traceability information systems. The findings of the present research recommend that AI provides a way to increase traceability in SC activities and further offer transparency. Last but not least, firms can raise transparency as a major input and, in turn, boost firm performance and consumer happiness by implementing traceability [50]. In the context of the SC, this work empirically improved arguments that emerging technologies-based traceability solutions can enhance transparency and ultimately performance.

5.2. Managerial Implications

This research helps organizations make decisions about investing in transforming the SC process digitally. The application of technologies of traceability and transparency in the SC increases trust and transparency between the involved parties. It is recommended to start with emerging-technologies-based traceability solutions because this involves the use of substantial amounts of data and involves many different parties internally and externally. Organizations could strengthen their digital transformation agendas to generate competitive advantage from their SCT and transparency. The results show that a digital SC could be a game changer in a competitive market. Professionals who participated in the questionnaires from different industries and different occupational levels confirmed that successful digital transformation in the SC led to competitive advantage. Due to several challenges in the future for the product and numerous factors such as population expansion, technological advancement, and the condition of natural resources (water, etc.), the implications of digital technologies at different stages of the SC for improved traceability and transparency and ultimately performance are urgent.

5.3. Limitations and Future Research Directions

Growing a better and fuller SC is complicated because this requires a deeper knowledge of real activities from various perspectives—for example, accounting for legal, economic, technological, and social concerns. As a result, traceability may be studied in the SC. Consequently, there are some limitations to this research that may be addressed with future research, such as the following: first, this research is the first to empirically investigate the combination of the BCT, SIoT, and AI for SCT in Pakistan; although this was not intended in targeting the sample, it may be considered one of the study's limitations. As its findings may not be generalized to other developed countries, this study can serve as a source for more investigation. Second, this study used a quantitative method; using a qualitative method for further in-depth investigation and other mixed methods are recommended. Third, the timeframe for collecting data was relatively short, although the response rate was sufficient compared to other SC studies. However, a longer time frame could strengthen the results further. Lastly, it is noteworthy that this study does not consider the challenges of successful digital transformation, which is an emergent area for future research. Moreover, specific technology such as big data (BD), augmented reality, machine learning, and robotics could be considered drivers and change enablers for digital transformation and these could be investigated in future research.

6. Conclusions

By utilizing a quantitative study design, this study primarily offers an understanding of the possibilities of traceability solutions based on emerging technologies. Better transparency in SC can be achieved by implementing traceability solutions based on emerging technology. A framework for SC has been designed to show the potential of traceability based on emerging technologies in enhancing SC transparency. The findings of the study show that SCT significantly mediates the association between independent variables (the BCT, SIoT, and AI) and the dependent variable (transparency), as seen in Figure 1. In addition, it revealed that emerging technologies based on traceability resolutions play a key role in increasing SC transparency and ultimately performance. Furthermore, the findings of the article contribute meaningfully by providing companies and the participating parties with a process for deciding the imperative aspects that enhance performance. Although the current study's findings have some limitations, they will pave the way for future research examining the functions of BCT, the SIoT, and AI. While challenges persist, the future of the incorporation of these technologies is promising.

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Appendix A

Construct Operationalization

S/No	Constructs and Items	References
	Blockchain Technology (BCT)	
1	We use distributed ledger technology for traceability in supply chain (BT1).	[62]
2	We use distributed ledger technology as it helps to maintain confidentiality, integrity, and availability of the data (BT2).	
3	We use distributed ledger technology to improve traceability in supply chain (BT3).	
4	We routinely use distributed ledger technology as a data platform that traces the origins, use, and destination of supplies (BT4).	
5	We routinely use distributed ledger technology to avoid confusion among partners engaged in supply chain (BT5).	
	Social Internet of Things (SIoT)	
1	My company utilizes social IoT for inter-organization traceability (SIoT1).	[62]
2	My company utilizes social IoT for intra-organization traceability (SIoT2).	
3	My company utilizes social IoT to trace and track the information for future use (SIoT3).	
4	My company utilizes social IoT for management of supply chain (SIoT4).	
5	I agree with the development of my company's tracing of the origin of products and ingredients through social IoT (SIoT5).	
	Artificial Intelligence	
1	Artificial intelligence checks human judgment in supply chain (AI1).	[61,62]
2	Artificial intelligence may prevent errors, it helps to maintain confidentiality (AI2).	
3	Computers can deal with personal data more carefully than humans to improve traceability in supply chain (AI3).	
4	In my opinion, humans make more errors than computers (AI4).	
5	My company uses the artificial intelligence for the tracing and tracking to meet supply chain sustainability (AI5).	
	Supply-Chain Traceability (SCTRC)	
1	Traceability can overcome continuous and sustainable ambiguities in the SC (SCTRC1).	[4,63,64]
2	Through technology of traceability, the management can control procurement and effectively plan inventory management (SCTRC2).	
3	I agree with increasing consumers' confidence in our product and reducing customer complaints (SCTRC3).	
4	Technology and Traceability can help in increasing the number of customers (SCTRC4).	
5	We constantly stay in touch with stakeholders until the product reached the consumers (SCTRC5).	
6	Our company traceability system enables to share of most information regularly and proactively with the stakeholders (SCTRC6).	
7	Our company traceability system increases access to contracts and markets (SCTRC7).	
8	Our company regularly traces that product is sourced from appropriate sources (SCTRC8).	
9	Our company traceability system improves competitiveness of the members of supply chain (SCTRC9).	
	Supply-Chain Transparency (SCTRN)	
1	Traceability enables us to share our supply chain operational plans (SCTRN1).	[57,63]
2	Through traceability, we routinely gather strategic information related to supply chain (SCTRN2).	
3	Due to tracking and tracing, we routinely share strategic information (SCTRN3).	
4	Through, traceability, the entire process of the supply chain in my company is accurately and transparently disclosed (SCTRN4).	
5	Due to traceability, my company facilitates the stakeholders to get the information they need (SCTRN5).	

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