Blockchain Technology in Supply Chain Sustainability

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Technological advancements have played a critical role in enhancing supply chain management from varied dimensions. While advancements in information technology have significantly improved various facets of the supply chain, supply chain visibility still lags in tracking and tracing capabilities. The disruptive and emergent blockchain technology (BCT) presents enormous potential to address issues of supply chain sustainability.

sustainable supply chain | blockchain technology | traceability | provenance

1. Supply Chain Visibility

As asserted in most of the supply chain management (SCM) literature, supply chain visibility goes beyond tracking of parts, components, and finished products from upstream partners to final consumers. The construct also entails access and transparency to accurate and timely content of relevant information within the supply chain network. Informed decisions are facilitated through the timely access of information among supply chain partners. Many traditional supply chain networks have poor upstream and downstream visibility with little shared information [1]. Consequently, traditional supply chains lack traceability and transparency, which becomes an industry-wide challenge causing painful inefficiency with delays, errors, and increased costs [2]. According to [3], supply chain visibility (SCV) refers to making informed decisions using the timely and accurate exchange of information between participants as materials move in the supply chain. In sharing information between supply chain participants, the process and access to content must be agreed upon due to reasons of competitive advantage and other security related concerns. Ref. [4] defined supply chain visibility (SCV) as the extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations and which they consider of mutual benefit.

The concept of supply chain visibility (SCV) overlaps across several areas of SCM research; hence, there is not yet consensus about the exact definition of SCV [5]. However, these varied viewpoints do converge to some degree around the issue of sustainability. Without an appropriate level of visibility, a sustainable supply chain will find meeting its sustainability objectives challenging [6]. Irrespective of the lens through which SCV is viewed, information technology remains the primary enabler in contemporary supply chain management. Enhancing traceability using complex, modern-day technology is highly sought-after, especially in the pharmaceutical industry. Enterprise applications and cloud-enabled technologies have improved multiple areas of SCV utilization. However, these centralized systems also present limitations as far as the scope of visibility is concerned. Provenance of finished products from a consumer point of view is highly dependent upon effective implementation of SCV, using

seamless technologies in the entire network. A broken or incomplete link in the information pipeline will potentially compromise data accuracy and availability. The objectives of a visible and accessible SCV are more aligned with those of the decentralized blockchain technology, which can provide greater traceability, security, and trust. There is considerable room to improve the supply chain in terms of end-to-end traceability, speed of product delivery, coordination, and financing [7], and BCT can be a powerful tool in addressing these issues.

2. Supply Chain Sustainability

Sustainability standards have become controversial, fueled by the fact that there is not a widely accepted, unified model to measure sustainability within a diverse global economic network. Sustainability in the global supply chain is receiving significant attention, since over 93 percent of the world's 250 largest firms report on sustainability [8]. The inability to define and acquire sustainability related data in the global supply chain is also a growing concern. An approach ensuring a sustainable supply chain, therefore, must rudimentarily consider proper identification of measurable attributes, which may differ from one supply chain to the next. Beyond the process of identification, attributes need to be categorized based on the principal dimensions of sustainability. In the sustainability literature, the common theme that arises from different definitions presented by researchers and professional organizations is concurrent realization of three dimensions of performance: economic, environmental, and social [9]. The three dimensions are in line with the triple-bottom-line (TBL) principle that considers a sustainable organization as one in which the sustainability evaluation process goes beyond traditional and financial bottom-lines [10]. The evaluation process must be stringent and consider social, environmental, and economic dimensions.

In view of this holistic perspective regarding supply chain sustainability, a comprehensive definition of the construct is important. Ref. [11] defined sustainable supply chain management (SSCM) as "the creation of coordinated supply chains through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information, and capital flows associated with procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the short- and long-term." Furthermore, supply chain sustainability also entails good governance practices throughout the life cycle of products and services. SSCM and SCS, therefore, complement each other. The overarching context of these definitions also facilitates the incorporation of SCV to establish an integrative pathway towards sustainable supply chain visibility. Sustainable supply chain visibility extends traditional supply chain visibility to encompass economic, environmental, and social objectives of the supply chain [6]. An integrated approach is critical to building a conceptual platform that can examine the effectiveness of blockchain technology in a supply chain context.

3. Blockchain Technology

Mechanisms and technological approaches such as radio frequency identification (RFID), serialization, bar codes, and e-pedigree that enable visibility across the supply chain, have experienced certain limitations. The main reason

is due to their centralized operational approach. Consequently, critical features of security and privacy may be compromised using a centralized approach. Security and privacy are critical for high levels of trust. In a system where security and privacy constitute primary objectives, trust remains the common denominator among constituent components. BCT in its decentralized operational approach possesses enormous potential to resolve issues of trust within supply chain networks. Nonetheless, most studies that explored BCT adoption are either conceptual or address the issue from an individual perspective and lack empirical evidence [12].

High-level definitions of blockchain vary in the literature. It is described as a network by some, but meanwhile others have given it a database delineation. Satoshi Nakamoto (name used by pseudonymous person or persons) conceptualized blockchain in 2008. Its first application was bitcoin, which later gave rise to a variety of cryptocurrencies. There is no doubt that the financial domain has profited the most from this innovation, but that does not restrict further usages, especially in supply chain management. Blockchain is a distributed ledger or database running simultaneously on many (possibly millions of) nodes that can be distributed geographically and across many organizations or individuals [13]. Based on the described framework, data shares on a peer-to-peer network in the distributed ledger. “The network members (nodes) communicate and validate the data following a pre-defined protocol without a central authority” [14]. In contrast to the fact that the centralized approach presents issues of trust in existing technologies, BCT is very secure. Distributed ledgers can be either decentralized, giving equal rights to all users, or centralized, providing specific users with special rights [14]. These structures allow for three sub-categories of networks; that is, public, private, and federated blockchains. Whereas anyone (node) can anonymously join and be allowed to transact without permission in a public blockchain, both private and federated blockchains are permissioned blockchains [6]. However, whatever approach blockchain implementation adopts, transparency among nodes in the network cannot be compromised. The potential of BCT is not limited to its decentralized orientation, but is further amplified by auxiliary features including, distributed ledgers, immutability, consensus, and smart contracts. Recent advancements such as the internet of things (IOT) and artificial intelligence (AI) constitute leading technologies to complement BCT for SCM. Ref. [15] demonstrated that combining blockchain technology with IoT and smart contract provides a seamless supply chain automation environment, which can achieve cryptographic verifiability and significant cost and time savings.

4. Blockchain Research in Supply Chain Sustainability

BCT is gaining increasing attention and interest in supply chain sustainability. The recency of the phenomenon necessitated data collection only within a restricted period between 2016 to March of 2022. The time trend clearly depicts a progression of research interest based on the number of publications. However, there is an inconsistency as seen in the chart, which indicates a decrease in the number of publications in 2020. This could be explained by several factors, including the unprecedented COVID 19 pandemic and a limited leverage of publication databases. In a recent study that proposed an analytical approach to assessing the impact of BCT on sustainable supply chain performance, ref. [16] compared their conceptual model to those of 10 recent studies, which displayed models in assessing supply chain performance and sustainability in mining supply chains. The capabilities of BCT for efficient supply chain management have become more pervasive in recent years [16]. Prospects of studies seeking

trajectories to uncover capabilities of BCT in traceability across integrated functional areas have increased significantly. Ref. [17] for instance, aspires to extend the scope of an investigation of BCT in the iron and steel enterprises beyond the logistic chain. Integrating the financial chain, production chain and supply chain will provide better data resource leverage and make capital flow and information flow more secure and reliable [17]. Blockchain, with its unique characteristics, has received growing attention from engineers, researchers, and practitioners in the last decade [18]. There is no doubt that this research area will enjoy continued growth in both academic and practical application sectors.

5. Benefits of BCT to Supply Chain Visibility

Recent literature on BCT indicates significant benefits from a supply chain visibility point of view. Irrespective of the fact that the typical benefits of BCT have mostly been conceptually demonstrated, their impact can also be corroborated by a few recent successful applications. One such success is exemplified by the blockchain-based supply chain solution developed by SIMBA Chain in collaboration with the University of Notre Dame for Toks (a fast-food/casual restaurant chain based in Mexico). The application has made it possible for Toks to extensively track coffee bean distribution throughout its value chain, and eliminate several intermediaries in the supply chain, thereby increasing the average farmer's income by 700%. This case not only substantiates the features of BCT as earlier discussed, but clearly demonstrates the implications of both economic and social dimensions of sustainability. Furthermore, implementation of blockchain-based traceability solutions has succeeded in sectors such as cobalt mining [19]. This is because of the production of lithium-ion batteries, which necessitates suppliers abide by legal and responsible sourcing practices [20]. The food supply chain safety arena also has presented advancements in the leverage of blockchain technology. Ref. [21] accentuated two blockchain projects launched by Walmart in partnership with IBM to streamline pork imports from China and mango imports from America. IBM developed a Food Trust system based on Hyperledger Fabric for improving food supply chain management [22]. The [23] solution to enable agri-food supply chain traceability in China further exemplifies a scenario whereby BCT complements radio frequency identification (RFID) technology to enhance supply chain visibility. Ambrosus and Modum, two Swiss startups, have developed a system that merges internet-of-things (IoT), BCT, and real-time sensors to trace and transmit a products' information during the whole of the manufacturing process [24]. They share a similar objective to optimize supply chain visibility and quality assurance in the food and pharmaceutical sectors. While the Ambrosus network uses tags, tracers, and sensors to track products throughout their lifecycles [24] in the food and pharmaceutical supply chains, the Modum network focuses on monitoring shipments to ensure safe delivery of products specifically in the pharmaceutical supply chain. In addition to traceability, BCT provides opportunities in supply chain anti-counterfeiting. To better prevent risks and overcome threats with vulnerabilities initiated by centralized architecture, BCT (or other distributed ledger technologies built with decentralized networks) stands out as a potential framework to establish a modernized, decentralized, trustworthy, accountable, transparent, and secured supply chain innovation against counterfeiting attacks when compared with those developed based on a centralized architecture [25].

6. BCT Challenges in Supply Chain Provenance

Supply chain provenance continues to gain significant importance in sustainable development. Ref. [26] contended that firms establishing product provenance may gain competitive advantage due to increasing skepticism manifested by consumers. Provenance knowledge comes from supply chain transparency in terms of how products were manufactured, stored, and delivered to customers [27]. While the reviewed articles found immense benefits from BCT to supply chain sustainability as indicated in the previous section, several important challenges were also raised. Evaluating provenance of physical goods, or supply chain provenance, has been more difficult because so many goods are handled in complex, international supply chains where granular tracking of physical characteristics and product whereabouts has not been possible [27]. The advent of IoT and blockchain technologies in recent years has begun to facilitate traceability efforts in supply chains. These technologies, however, remain a work in progress despite some successful deployments, and therefore it is critical to point out impediments that could be improved. By 2022, 80% of blockchain supply chain initiatives will remain at a proof-of-concept or pilot stage [28]. The divergent and contested positions articulated by various actors in both academia and practice over blockchain capabilities is a potential drawback. According to [28], a lack of consensus on blockchain capabilities, irrespective of discussions across the board on potential and hype, presents a significant barrier to adoption. Ref. [29] developed a conceptual model which applied six core influencing factors and four moderating effects to interrogate the potential of BCT in supply chain management. Among these factors and effects, control, scalability, knowledge, and regulation appear to be key challenges to supply chain provenance. Controllability is dependent on external and internal decisions, which makes it even more difficult to regulate [29]. The issue of scalability is addressed from many fronts in the blockchain literature. Practically, it is impossible to maximize scalability alongside security and privacy, which are core features of blockchain technology. Interestingly, the co-founder of Ethereum (i.e., one of the most widely used cryptocurrencies, along with Bitcoin) coined the term “scalability trilemma” to indicate the difficulty of combining decentralization, scalability, and security [30]. While a blockchain-enabled supply chain network with a large amount of participates (nodes) can increase the security dimension, it then requires a longer time for the nodes to reach a consensus. Moreover, to achieve the maximum potential of blockchain in the supply chain, all participants within the supply chain must share the same level of knowledge regarding the technology, its functions, and purpose [29]. Ref [2] buttresses this argument from a supply chain visibility point of view, by purporting that supply chain participants need a unified view of production, shipment, delivery, and sales data, while still verifying transactions independently and privately.

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