THE TRANSFORMATIVE ROLE OF BLOCKCHAIN TECHNOLOGY IN SUPPLY CHAIN MANAGEMENT
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Abstract

This study analyzes the impact of blockchain technology in transforming the discipline of supply chain management (SCM) focusing on its benefits and challenges, as well as its level of readiness for implementation across different sectors. The objective is to explore how blockchain will resolve problems regarding transparency, security, and efficiency in modern supply chains. A quantitative strategy was selected for this research, which was in the form of a survey directed to 250 supply chain managers from different sectors. The survey captured data regarding participants' perception, awareness, and readiness relating to the adoption of blockchain technology in SCM. Data analysis was conducted with the help of SPSS-29 and the primary outputs were presented through frequency distributions, bar graphs, pie charts, and tables illustrating the primary trends and insights. Data collected noted that respondents perceive blockchain technology as a revolutionary solution that improves the transparency, traceability, and security of the supply chain. However, insufficient adoption is driven by severe implementation cost, regulatory ambiguity, and technological sophistication. Despite these prospective scenarios, industries such as food and pharmaceuticals exhibit keen interest in the technology's possibilities alongside logistics. Adoption acceleration was identified by respondents to require stronger government initiatives, industry case studies, and enhanced training programs. This work adds to the existing scholarship on the application of blockchain technology in supply chain management by examining the advantages and obstacles to adoption. It details the level of adoption of blockchain by various processes and the basic actions that need to be taken to address organizational challenges. The findings of the study will be useful to companies and other stakeholders interested in policy and academic research intending to improve supply chain performance and practices through blockchain technology.

Keywords: Blockchain, Supply Chain Management, Transparency, Adoption Barriers, Smart Contracts

I. INTRODUCTION

Every industry around the world is being affected by the changes in digital technologies. One of the most fundamental inventions in recent years is blockchain technology. Along with Bitcoin, blockchain was created for cryptocurrencies, but it has since received widespread attention for its potential uses well beyond digital currency. Blockchain technology has the potential to transform supply chain management (SCM), causing considerable interest in academia and industry. As supply chains around the world become more complex and interlinked, blockchain offers a new way to deepen transparency, security, and efficiency in supply chain practices.

Encompassing the production, movement, and selling of goods and services, supply chain management is pivotal to global trading activities [1]. Due to pervasive fraud, unexplainable delays, and lack of

transparency, traditional supply chains are poorly maintained, operationally disruptive, and costly. Businesses are constantly on their toes trying to keep up with an ever-evolving market, and the availability of more steadfast and verifiable transparent systems is felt without question [2]. Such challenges, in great number, are capable of being dealt with through blockchain technology because of its immutable and decentralized properties.

Simply put, a blockchain is a type of distributed ledger technology (DLT) which stores a record of transactions across different computers in such a way that no single person possesses unilateral control over the data. Because of this decentralization, there is no need for intermediaries in the system, which assures a secure, transparent, and tamper resistant means of recording transactions [3]. These attributes make blockchain particularly useful in dealing with supply chains where trust and data integrity are of utmost importance.

Traditional supply chains do not have a single integrated system for storing data associated with movement of goods, payments, and contracts which is epicentered in a specific place [6]. This disintegration of systems makes it near impossible to trace the product's origin, verifiable authenticity, or track the movement of goods in real-time. Blockchain solves all these problems by offering a single platform from which every single participant in the supply chain has access to a single source of truth [4]. With Blockchain, every single transaction is recorded in such a manner that is visible to all authorized parties, furthermore, the possibility of changing or deleting the information in the blockchain is virtually impossible without the agreement of the majority of the network. Hence, there is more transparency, decreased fraud, increased responsibility along the supply chain [5].

One of the main supply chain struggles in modern times comes with ensuring product traceability and verifying item authenticity. This is especially true for the food and drug industry, as well as the luxury item market, where clients demand clear answers regarding the production provenance and quality of products [7]. With blockchain's capability of guaranteeing an unalterable and clear record of all transactions, consumers are assured that they will be able to trace the product from its origin to the final location [8]. A chronologically accurate supply chain provides blockchain with the capability to track raw material sourcing, manufacturing processes, and delivery, which results in real-time product verification, authenticity, and visibility. This effect is great for the industry's deepest problems with counterfeiting and fraud as blockchain guarantees an easy-to-follow trail which cannot be altered or falsified [9].

Moreover, blockchain technology increases the ease of carrying out supply chain activities by automating them via smart contracts. Smart contracts are agreements that are executed automatically when certain conditions are satisfied without the intervention of any party. In supply chains, smart contracts can be applied to automate payments, inventory monitoring, and order execution [10]. For instance, a smart contract could be designed to make automatic payments after the delivery and verification of goods are completed on the blockchain. Payment intermediaries can be eliminated which cuts down administrative expenses, streamlines the flow of goods and payments in the supply chain, and improves related processes. Additionally, the automation of these processes minimizes the chances of human error, thereby increasing operational efficiency [11].

A different main benefit of blockchain technology is applicable to expense reduction in supply chain management. In the traditional supply chain, there are many intermediaries involved, each adding a cost to the process as outlined in [12]. The costs can be cut significantly with blockchain technology because first, intermediaries are removed and crucial processes are automated. The costs that come with managing goods and transactions are minimized due to the automation of fraud, delays, and administrative processes brought by blockchain [13]. This is particularly relevant to companies that participate in global supply chains as the expenses associated with coordination, logistics, and cross-border transactions are often high [14].

The use of blockchain technology in supply chain management comes with hurdles. One of the most significant impeding adoption is the lack of knowledge, awareness, and understanding of blockchain technology and its associated benefits. Even when technology like blockchain has the potential to transform supply chains, most organizations are reluctant to embrace change due to the perceived complexity, expense, and integration challenges with legacy systems [15]. In addition, the scalability of blockchain networks is

another apprehension as the level of computational resources required for transaction processing poses challenges in its applicability to supply chains on a massive scale [16].

Another challenge lies in collaboration across the industry. It requires all the players in the supply chain, from suppliers to manufacturers to distributors, to adopt the same technology and follow the same rules for blockchain to function optimally [17]. However, these prerequisites necessitate an unprecedented level of collaboration among rivals which may be problematic in fully competitive and dynamic industries. Aside from this, the technology provides a unique level of security and transparency, but does not mitigate issues dealing with the credibility and the reliability of the data being provided in the inputs and, therefore, cannot guarantee the accuracy. Manipulation of data fed into the blockchain compromises system integrity, which puts the blockchain technology at risk [18].

Even with these issues, the possible advantages of blockchain technology in supply chain management remain high. Given that sectors are paying more attention to digital transformation, it seems that blockchain will definitely influence the future of supply chains. The increasing interest in blockchain technology is seen in the many pilot projects and case studies that are being undertaken in different sectors. To illustrate, IBM and Maersk are already incorporating blockchain technology to enhance efficiency and transparency within the shipping and logistics supply chains with their proprietary systems of platforms [17]. These platforms are intended to create secure and accurate mechanisms for the accomplishing of tracking, transaction verification, and supply chain business process automation [19].

Incorporating blockchain technology into supply chains has a more far-reaching influence concerning the social responsibility of the businesses towards sustainable development. With the rising availability of consumers for sustainable and ethically produced goods, blockchain serves as a mechanism to ensure that such goods have been verified for their ecological and socio environmental impacts during their life cycle. Because blockchain captures every part of a supply chain, companies are able to prove their commitment towards sustainability through offering verifiable claims of responsible sourcing, production, and distribution processes. The availability of such informations increases the trust consumers have toward products that are produced through ethically responsible means [20].

To conclude, the technology of blockchain could transform supply chain management by adding transparency to track movements, heightening security during transactions, and increasing efficiency in various processes. Although still in its infancy regarding adoption, many industries are already considering its numerous applications, suggesting its transformative potential. Nonetheless, obstacles such as lack of awareness, scaling issues, and collaborative inter-industry relations need to be tackled for widespread adoption of blockchain to become mainstream, particularly in supply chains. While businesses continue to allocate resources towards digitization, this technology will inevitably be vital distinguishing factor of integrated global supply chains.

A. Problem Statement

The implementation of blockchain technology into supply chain management faces major hurdles such as inadequate comprehension from industry practitioners, difficulties with scalability, and the intricacy related to system integration. Although it has the potential to improve security as well as increase the efficiency and transparency of business processes, most companies ignore the benefits of blockchain due to apprehensions concerning the steep technical, monetary, and cooperative costs associated with it. This study seeks to analyze these obstacles and assess the impact of blockchain's transformative potential to resolve inefficiencies in supply chain management processes.

B. Objectives of the Study

1. To evaluate the potential benefits and challenges of implementing blockchain technology in supply chain management, focusing on transparency, security, and efficiency.
2. To assess the readiness of organizations in adopting blockchain for supply chain operations, including the availability of infrastructure, technical expertise, and resources.
3. To explore the impact of blockchain integration on operational efficiency, cost reduction, and decision-making processes within supply chains across different industries.

II. LITERATURE REVIEW

Initially developed for Bitcoin, blockchain technology has now advanced to other industries outside of pertaining to cryptocurrency. Among these industries, blockchain technology. The technology's potential in Supply Chain Management (SCM) is one of the most groundbreaking and promising. This literature review will emphasize on the integration of blockchain technology within SCM, concentrating on the most important components: transparency and security, operational efficiency, and other associated challenges, while focusing on the impact the technology brings on supply chains.

A. Blockchain in Supply Chain Management

The implementation of blockchain technology in supply chain management systems is fueled by the need to decentralize, immutably store and transparently record transactions. These factors enable solutions to significant problems associated with traditional supply chains such as inefficiency, fraud and lack of transparency. Blockchain empowers supply chains through it's pseudonymous network where anyone can verify transactions and everyone has access to a universal ledger – single source of truth, as mentioned [21]. The inability to alter data universally accepted without consensus decreases the chances of fraud or error drastically across the tailored blockchain infrastructure, making this technology highly reliable for enhanced trust and accountability in supply chains.

The visibility and traceability level accessible to stakeholders allows them to monitor the movements of goods starting from the place of origin to the end consumer which is unprecedented due to blockchain's capability of recording transactions in real-time [7]. Additionally, this transparency further improves supply chain efficiency since delays, errors, or bottlenecks can be identified instantly. In addition, blockchain guarantees that the information inputted into the system is immutable, meaning that once a transaction has been entered into the system, it cannot be changed or removed in any way. This characteristic is incredibly useful to sectors that deal with food, pharmaceuticals, and luxury goods, as the authenticity and traceability of the products are paramount [22].

B. Improving Transparency and Traceability

A primary benefit of incorporating blockchain technology in the supply chain is the increase in transparency and traceability. Supply chains in traditional form have a lot of information scattered in multiple organizations which increases difficulties in tracking movement of goods or verifying product authenticity. Everyone involved in the supply chain is provided with a transparent and verifiable record of transactions on blockchain which creates an audit trail from origin to delivery [23].

Blockchain can be of great significance in consumer sensitive products such as food items and pharmaceuticals. In the food sector, for example, blockchain can be implemented to track a product's journey from farm to table. This assures that the food is of safe quality and provides an added bonus of proving the origin of the food [24]. In addition, tampering can lead to the production of fake drugs. Blockchain counteracts tampering by providing an immutable record of each transaction made by the manufacturer, distributors, and consumers [25].

With the implementation of Blockchain, all parties in the supply chain are capable of monitoring and tracking the status of their goods within the system, all in real time. This is exceptionally useful for sectors with intricate and international supply chains, since it assists in confirming that the products are being fetched in a timely manner and are in good condition. Enhanced tracking accuracy may reduce the need for hands on checking and enhance the quality of decisions made, because relevant up to date data concerning active information on shipment, inventory and production is available to the stakeholders [26].

C. Enhancing Security through Blockchain

Another key benefit of blockchain in supply chain management is enhancing its security. Every block in the chain is securely linked to the preceding block, which makes it possible to record transactions securely. This mechanism is referred to as cryptographichashing, and it creates a reliable system that assures data accuracy. The threat of forgery is greatly reduced. Block chains holds promise positive for fraud and risk management of decentralized systems. The requirement of a trusted third party, bank, or clearinghouse to

authenticate transactions is suspended and reduces chances of fraud, abuse or manipulation by central authorities [27].

The technology opens doors to different avneues of securing information with the implementation of smart contracts. These are promise agreements that automatically put forth the requirements of a contract when certain conditions of the contract are fulfilled through automation. In these agreements, delivery of the product would means the client would trigger payment. This means the tercnants are reduced which improve security [28]. It assures execution, respect to supply limit and other terms mitigating non-compliance or disputes, serving as check mechanism within the supply chain system.

In addition, the sophisticated cryptographic techniques employed in blockchain technology guarantee secure information storage and transfer, shielding confidential data from potential breaches. This is especially pertinent in areas where privacy is of utmost importance like the medical and financial accounts. Blockchain technology can alleviate risks relating to data compromise, deceitful activities, and digital assaults by offering a safe and clear-cut method for documenting events [29].

D. Streamlining Supply Chain Processes with Smart Contracts

Smart contracts enabled via blockchain provide remarkable opportunities for automating crucial activities, eliminating intermediaries, and enhancing the efficiency of supply chain systems. A smart contract is a automation contract which has the stipulations of the contract inscribed in a computer program. This technology can be applied in automating processes such as payment collection, inventory control, and order processing in supply chains [30]. For example, within a blockchain enabled value chain, a smart contract could execute payment for goods immediately after they are delivered to and accepted by all the requisite players. Such automation minimizes manual work, accelerates productivity, and reduces administrative expenditure.

With smart contracts, accuracy is more pronounced due to human errors being completely eliminated. The manual nature of traditional supply chains which rely on order processing, invoicing and inventory monitoring often results in mistakes that lead to delays, discrepancies and inefficiencies. Smart contracts guarantee operation automation through locking certain executables within a certain set of conditions making blockchain infrastructures operational contracts, enhancing efficiency greatly [31].

Beyond automating repetitive processes, smart contracts could enable the automation of complex activities such as compliance monitoring and regulatory reporting. For instance, a smart contract could be scheduled to check compliance with local regulation of a shipment before it is allowed to proceed. This guarantees that all stakeholders observe the legal steps required of them and lowers the burden associated with compliance verification [32].

E. Barriers to Blockchain Adoption in Supply Chains

Blockchain technology has the potential to greatly improve supply chain management, yet it remains underutilized. This is, in part, because supply chain managers lack the necessary training to fully utilize new technologies like blockchain. Even with abundant academic literature and industry discussions on blockchain, numerous organizations, [33] suggests, remain blanketed in confusion regarding the application of the technology to their particular supply chain processes necessitating operations.

Concerns over blockchain's ability to process large sets of information due to its proven success rate in limited applications is another challenge. The extensive computational power needed for processing blockchain transactions considerably hampers the feasibility of larger supply chains, [34] argue identify this scalability concern as one of the most significant barriers for broader blockchain application in supply chains.

Moreover, the combination of blockchain technology with pre-existing supply chain frameworks poses significant challenges and incurs high costs. A number of enterprises still operate with older systems which do not support blockchain technology, and these companies would have to invest heavily into modernizing their systems with new technologies [35].

Ultimately, the adoption of blockchain in supply chains requires all parties to work together. For blockchain to function properly, there needs to be consensus from all participants in the supply chain such as suppliers, manufacturers, distributors, and retailers to implement the technology and follow agreed-upon

standards. Achieving that level of industry-wide cooperation tends to be very difficult, especially in highly competitive market environments [2].

F. Future Directions for Blockchain In Supply Chains

Looking into the future, the possibilities of blockchain within supply chain management are enormous. It is anticipated that blockchain will gain more acceptance in the areas where business organizations value transparency, security, and efficiency as its benefits are recognized by more companies. Its conjunction with other emerging technologies like the Internet of Things (IoT) as well as Artificial Intelligence (AI) have the potential to further boost supply chain processes. For instance, IoT devices can furnish real-time information concerning the movement of goods which can be recorded in the blockchain to aid in visibility and traceability [36].

In addition, the emergence of blockchain standards and protocols will likely help next address some of the current constraints with scalability and interoperability. The more organizations integrate blockchain technology into their operations, the more there will be an impetus to vertically align in cross industry coalitions to develop unified standards for enabling interconnectivity among diverse blockchain systems [37].

As discussed throughout the paper, blockchain offers an innovative approach to supply chains through heightened transparency, security, and overall streamlined processes. While hurdles still exist, it seems inevitable that ongoing developments in technology will enhance the interest toward blockchain applications, resulting in increased adoption over the next few years. By focusing investments on infrastructure, education, and partnerships, it is evident that blockchain has the potential to revolutionize supply chain management and trade on a global scale.

III. METHODOLOGY

This research employs a quantitative approach to evaluate the impact of blockchain technology on supply chain management (SCM). The main goal is to assess the level of understanding, appreciation, challenges, and readiness for adopting blockchain technology amongst practitioners in supply chain management. A survey was formulated and administered through electronic means to a sample of 200 participants selected from different sectors dealing with supply chain management and blockchain technology. The survey included multiple choice questions, structured Likert-scale statements, and demographic questions aimed at assessing participants' knowledge about blockchain, its advantages, the challenges posed by its adoption, and their overall perception regarding integration with other emerging technologies.

SPSS-29 software was utilized to analyze the survey data in order to enhance accuracy and reliability regarding the results. Descriptive statistics were applied to summarize the data, taking count of frequency distributions along with percentage breakdowns for responses across various categories. Bar graphs and pie charts were created for several questions to reveal the most significant benefits of SCM blockchain, their perceived barriers to adoption, and the industries most affected by the technology. These visualizations were useful in making simpler figures of the respondents' opinions while identifying trends and insights.

The involved analysis covered multiple dimensions regarding blockchain adoption which included the main benefits as noted by the respondents such as transparency, traceability, reduction in fraud, and Trust as built through the immutable records. The study also looked into the organizational challenges in adopting blockchains such as exorbitant costs, absence of regulations, and the integration of technology complexities. The participants were also grouped according to socio-demographics like type of industry, their position within SCM, and their total years with the scm industry so that any differences in perceptions and readiness could be explored across different subsets of populations.

The methodology in this research was designed to provide participants with a better understanding of the challenges hindering the adoption of blockchain technologies in the supply chains. The quantitative methods employed in this study were directed towards identifying the most significant barriers and accelerators, through extensive data analysis using SPSS, which could potentially transform the processes involved in supply chain management. It seeks to explore the relevant body of literature on blockchain

technologies and their relation with supply chain management, illustrating pathways for corporations and government institutions wishing to adopt blockchains within their supply chain system.

IV. DATA ANALYSIS

The analysis of the data in this research was completed using SPSS software, where survey data was analyzed through descriptive statistics and frequency distributions. The findings were displayed in the form of tables and charts, which depict the level of readiness for blockchain adoption and its anticipated consequences in supply chain management.
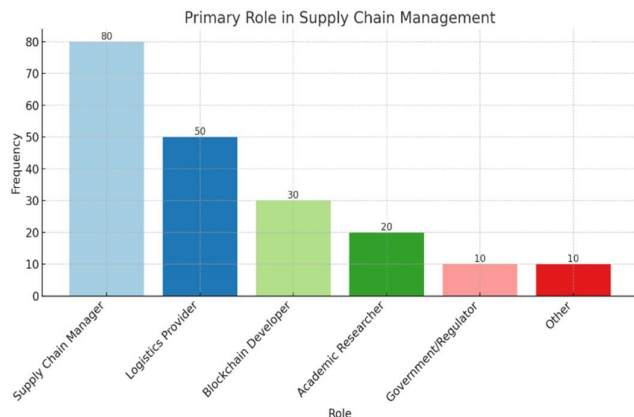

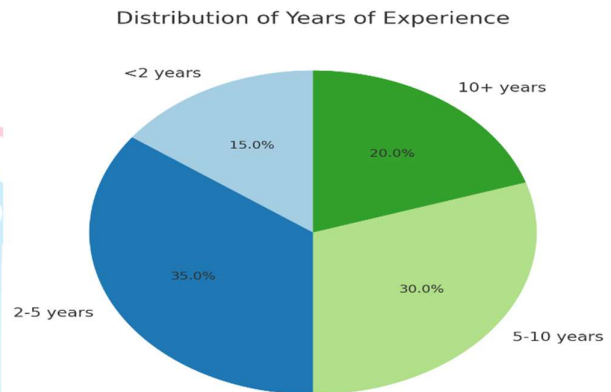Figure No.1 Primary role of the respondent in SCM   Figure No. 2 Year of Experience the respondents

The Figure No.1 highlights the distribution of primary roles in the supply chain management (SCM) field as per survey respondents. From the data, it can be seen that the greatest number of respondents (80, or 40%) profiled the role of Supply Chain Manager. Almost half of the respondents were Logistics Providers, with 50 respondents constituting 25%, confirming the importance of logistics within the SCM. Respondents identifying as Blockchain Developers were 30, accounting for 15% of the total participants, indicating that interest in the application of blockchain technology within SCM is growing, though still minimal relative to other roles.

Academic Researchers and Government/Regulators each represents 10 respondents (5% each), which illustrates less participation from the research and regulatory wings of the supply chain in operations, but indicates some activity within the domain. Finally, Other roles, which includes an assortment of positions allied to SCM, constitutes the remainder 5% of the sample. Generally speaking, the information illustrates that claims such as "the management of supply chains and logistics continues to hold notable prominence" and "are reputable as leaders" intersect with "emerging and growing fields such as blockchain development capture attention, albeit marginally." This might suggest that there is some level of appreciation toward the possibility of blockchain's SCM transforming potential, but at the same time also indicates that the technology is still in its infancy stages of being embraced in the field.

The analysis of *Figure No.2* regarding the respondents' years of experience gives a notable understanding in several aspects. A considerable share of the respondents, 70 participants (35%), reported having 2–5 years of experience, indicating that the workforce is indeed relatively younger and possesses at least some exposure to supply chain management. The second-largest group with 5–10 years of experience was also notable, constituting 60 respondents (30%); suggesting that this is a moderately experienced group, albeit likely having a greater understanding of the intricacies of the industry.

Somewhat less, but still considerable share of respondents having less than two years of experience stood at 30 respondents (15%), which shows that there are some newcomers interested in the field. On the extreme other side, 40 respondents (20%) reported having more than 10 years of experience, which shows that

these respondents form a more seasoned group with considerable experience and long-term view of how supply chain management has changed over the years.

In any case, these results do appear to indicate that the participants have a symmetrical distribution of years of experience, with a larger cohort in the 2–10 year span. This indicates that the respondents include a MSME professionals who have lower years of working experience alongside those who have, comparatively, higher levels of experience, along with significant qualitative insight into the profession's demands.

TABLE NO.1
GENERAL AWARENESS

Question	Option	Frequency	Percentage
Familiarity with Block chain	Not familiar at all	20	10%
	Slightly familiar	50	25%
	Moderately familiar	70	35%
	Familiar	40	20%
	Very familiar	20	10%
Industries Impacted *(Multiple)*	Pharmaceuticals	150	75%
	Automotive	120	60%
	Retail & E-commerce	90	45%
	Logistics & Shipping	100	50%
	Logistics & Shipping	140	70%

The information given in the Table 1 General Awareness analysis is critical in understanding how much the participants are aware of the primary themes of the blockchain technology and the sectors they think are mostly affected by it.

On the understanding of the blockchain, an important proportion of the respondents (70 out of 200: 35%) said that they have some moderate understanding of the technology. This indicates that blockchain is increasingly known, but is still not clear to a large number of participants. A good number of respondents (50: 25%) said that they have some basic understanding, which means they have some understanding, but no substantial knowledge. On the contrary, 20 respondents (10%) did not have any understanding of blockchain at all, which shows that a part of the population still does not have access to the technology. Interestingly, 40 participants (20%) said they are very familiar with the technology and 20(10%) claimed to have expert knowledge which indicates that relatively smaller group has deeper understanding of the potential applications of blockchain technology.

In conjunction with the various questionnaire answers, the authors received responses from different industries that speculated the impact Blockchain technology would have. The respondents noted that the Food and Agri Business industries seemed most reckoned with in the context of Blockchain technology with a staggering 75 percent boastfully viewing it as an industry-experiencing disturbance. Logistics and shipping followed as an industry labeling Blockchain's impact, or at least noting it, alongside 70 percent recognition towards the use to improve global supply chains. 120 respondents, or 60 percent, acknowledging Blockchains ability to monitor claim assessments pertaining to counterfeit drugs and tracking medical products, cited pharmaceuticals. Some responses also included Retail and E commerce for which 50 percent of respondents recognized Blockchain's impacts on customer transactions associated with enhanced trust. The automotive respondents also incorporated their expectations towards blockchain imagining its influence to transcend by improving supply chain processes with 90 respondents, or 45 percent, claiming these assumptions. The responses pinpointed the emerging impacts of blockchain over an array of sectors, especially pertaining those that support transactions that need to be recorded securely.

All in all the data seem to suggest there is limited yet growing awareness around the impact of Blockchain technology across multiple businesses, specifically supply chains and logistics where they anticipate the application of the technology would revolutionize clarity, convenience, and trust among users.

TABLE NO. 2
BLOCKCHAIN BENEFITS IN SCM

Question	Option	Frequency	Percentage
Most Significant Advantage	Transparency & Traceability	90	45%
	Reduced Fraud	50	25%
	Smart Contracts	30	15%
	Lower Costs	20	10%
	Sustainability Compliance	10	5%
Improving Trust	Immutable Records	60	30%
	Real-time Tracking	50	25%
	Decentralized Verification	40	20%
	All of the above	50	25%

The information given in Table No. 2: Blockchain Benefits in SCM depicts the possible advantages of blockchain technology in SCM considering the impact of the responses received during the survey.

Respondents were asked about the most significant advantage of blockchain in SCM, and Transparency & Traceability emerged as the most crucial benefit for 90 respondents (45%). This shows that participants view blockchain as an effective instrument towards enhancing product visibility as it passes through different stages of the supply chain, which is important for product quality, authenticity, and compliance with legislative regulations. Reduced Fraud was the second most popular response at 50 respondents (25%), stating that blockchain's ability to eliminate fraudulent activities due to the tamper-proof and open nature of blockchain is a considerable benefit. Smart Contracts was the third most popular response offered by 30 participants (15%), which indicates the interest in the automation and self-executing nature of contracts on blockchain. Lower Costs (20 responses, 10%) and Sustainability Compliance (10 responses, 5%) received less attention and were considered more as secondary benefits, alongside self-executing contracts, in comparison to transparency and fraud mitigation.

To improve trust in SCM, Immutable Records were considered the most important feature by 60 respondents (30%) due to the fact that blockchain builds confidence that data captured cannot be modified or deleted. 50 participants (25%), which underlines the significance of monitoring goods in transit and tracking achievements instantaneously, captured real-time Tracking. Decentralized Verification was noted by 40 respondents (20%), showing that the absence of an overseeing institution authority in transaction validation is a noticeable trust-enhancing feature. Finally, 50 participants (25%) chose. All of the Above, contending that the comprehensive advantages of blockchain, including cost, trust, transparency, traceability, and trust are mutually inclusive. The information gathered suggests that blockchain's ability to add the survey's respondents view transparency and traceability to supply chains as the greatest advantage. Moreover, the capability of reducing fraud, improving trust through unchangeable records, and enabling real-time tracking are equally important and serve as changes to SCM.

TABLE NO. 3
CHALLENGES & ADOPTION

Question	Option	Frequency	Percentage
Biggest Adoption Barrier	High Costs	70	35%
	Lack of Regulations	60	30%
	Tech Complexity	40	20%
	Stakeholder Resistance	20	10%
	Scalability Issues	10	5%
Adoption Accelerator	Government Support	80	40%
	Industry Case Studies	60	30%
	Interoperability	40	20%
	Awareness & Training	20	10%

The information highlighted in Table No. 3: Challenges & Adoption explains the blockchain barriers in the supply chain domain alongside the factors that may help in accelerating its execution.

Among the barriers to adoption, 70 respondents (35%) identified high costs as a major hurdle as the top issue. It indicates that organizations are hesitant to adopt their blockchain due to the financial expenditures concerning infrastructure, development, and maintenance. This was closely followed by Lack of Regulations, which had 60 responses (30%). It shows that there is no legal framework or set of industry norms governing the utilization of blocks, thus curtailing its widespread adoption. Tech Complexity also stood out with 40 respondents (20%) illustrating the challenges posed by integrating new technology into pre-existing systems as one of the hurdles. Observer stakeholder resistance (20 responses or 10%) indicates some obscured reluctance from stakeholders due to the perception of change or threat to established systems unreasonably defendable, albeit noteworthy. Finally, 10 respondents (5%) suggesting concerns regarding blockchains ability to manage and execute processes supply chains of larger sizes cited Scalability Issues.

Adoption accelerators, in contrast, focus on factors that can help integrate blockchain technologies into supply chains. Support from the Government was noted by 80 respondents (40%) as the most important determinant of enabling blockchain adoption, which suggests that policies, funding, and regulatory frameworks by the government could indeed assist in overcoming adoption hurdles. Industry Case Studies were cited by 60 participants (30%) as being a compelling motivating factor, indicating that documented narratives of actual struggles and achievements can serve to underline the usefulness of blockchain and motivate others in the industry towards adopting it. Respondents noted Interoperability (40 responses or 20%) as crucial for seamless integration with existing systems, while Awareness & Training (20 responses or 10%) were deemed essential for adequately preparing stakeholders to adopt blockchain technologies.

To conclude, the data outlines overwhelmingly expensive costs in addition to a scarcity of regulations as the most prominent underlying difficulties for the adoption of blockchain technologies. Government support and industry case studies emerge as the primary leverage points for expediting implementation within supply chain management. These barriers may be mitigated with appropriate regulatory policies, funding, and educational programs designed to facilitate more effortless integration of blockchain with existing technologies.

TABLE 4
FUTURE OUTLOOK

Question	Option	Frequency	Percentage
Emerging Tech Combo	AI	80	40%
	IoT	70	35%
	Big Data Analytics	30	15%
	5G Networks	20	10%
Time to Mainstream	Already Mainstream	10	5%
	Within 3 Years	50	25%
	5–10 Years	100	50%
	>10 Years	30	15%
	Never	10	5%

The information provided in Table 4: Future Outlook captures the expected amalgamation of new technologies in supply chain management (SCM) alongside the speculative timeline for blockchain technology adoption.

In analysis of the emerging technologies combinations, Artificial Intelligence (AI) was nominated by 80 respondents (40%) as the most probable accompanying technology to blockchain in relation to supply chains. This indicates AI technology's highly automated decision-making and predictive capabilities are regarded as to synergize well with the transparency and traceability aspects of blockchain. IoT received 70 votes from participants which translates to 35%. This implies that the application of IoT with blockchain for

real-time data capturing and monitoring is viewed as an outstanding possibility for advancement in SCM. Others were Big Data Analytics which had 30 respondents or 15% supporting them suggesting that the ability to analyze huge volumes of data could support the recorded and stored data in transaction blockchain. Lastly, 20 respondents or 10% identified 5G Networks which indicates the possibility of faster and more reliable data transmission, thereby increasing the efficiency of real-time monitoring of the supply chain on the blockchain.

In terms of the timeline sssical for mainstream adoption of blockchain technology in supply chains, an estimated 50% of participants (100 respondents) predict that blockchain will gain mainstream recognition in the next 5–10 years. This shows a strong consensus that adoption is in the preliminary stages, but significant growth is expected within the decade. There were 50 participants (25%) who predicted this would be possible within 3 years, highlighting some optimism around the pace of blockchain's integration into supply chains. A smaller portion of respondents foreshadowing a staggered adoption approach includes 30 respondents (15%) who believe it will hit the mainstream in over 10 years, while only 10 participants (5%) consider it purely mainstream, indicating that the technology is not widely adopted. Interestingly, 10 respondents (5%) assert that the technology will never reach the mainstream void in supply chains, logically suggesting a disbelief in the sustained adaptability or integration challenges scaling poses.

To summarize, the research indicates that AI and IoT are considered the most significant technologies expected to synergize with blockchain in changing supply chains, while the widespread use of blockchain technology is forecasted to be within the next 5–10 years, although more optimistically within 3 years for its use. Regardless of the optimism, there are a few lingering concerns regarding the speed of adoption, as some respondents noted the potential detrimental consequences on the industry's future.

V. DISCUSSION

The results from this study indicate that blockchain technology may profoundly change supply chain management (SCM) due to improvements in transparency, security, and efficiency of operations. The respondents' overwhelming recognition of blockchain's transparency and traceability capabilities in supply chains is a reflection of the majority who considered these advantages as the most noteworthy benefits of the technology [8]. The ability of participants in a supply chain to monitor and verify transactions in a secure, tamper-proof environment is made possible with the combination of immutable records, real time tracking, and decentralized verification. However, even with increasing awareness and understanding of blockchain advantages, its application in supply chains is still encountering significant hurdles, mostly pertaining to high costs and absent governing policies [15]. These obstacles point out the need for clear guidelines and zoning policies, as well as financial resources from governing bodies or join institutions aimed at promoting the use of blockchain technology and alleviating the barriers.

Responses to emerging technology combinations show a clear willingness to fuse blockchain with other technologies like Artificial Intelligence (AI) and Internet of Things (IoT). Such an alliance is critical for the amplification of AI-powered automation in decision-making and real-time data provision by the IoT for blockchain systems to enhance supply chain management [25]. This would lead to improved operational efficiency, greater data accuracy, and the automation of vital processes such as inventory control and order fulfillment. Nevertheless, these technologies are still very difficult to incorporate into existing supply chain frameworks. Technology gaps and insufficient blockchain technical knowledge are two of the most notable impediments to broader adoption [32]. In this context, though, there is a need to improve the overall level of technical information and training available to professionals working in the supply chain field before blockchain can be fully integrated with AI and IoT.

On the cadence of adoption, the results indicate that blockchain technology is still in its formative stages of being integrated into supply chains as a considerable portion of respondents expect it to be mainstream in the next 5-10 years. This is in sync with the current level of adoption where pilot projects and small scale implementations are commonplace, although broad-based acceptance continues to be encumbered by scalability considerations and the integration difficulties posed by older systems. Optimism certainly exists regarding blockchain's potential in various fields such as logistics, food, and pharmaceuticals, but stubborn

resistance from system participants coupled with expensive implementation renders delay to widespread utilization. Trends indicate that an increased effort towards mitigating the barriers will expand the role of blockchain technology in supply chains, but realizing its full potential will require monumental spending on infrastructure, policy building, collaboration, and stakeholder engagement.

VI. CONCLUSION

Implementing blockchain technology in Supply Chain Management (SCM) provides solutions to important industry problems such as fraud, operational inefficiency, lack of transparency, and high operational costs. This study demonstrates that blockchain is particularly beneficial due to its ability to improve transparency and traceability across supply chains, especially for critical and sensitive products such as food, pharmaceuticals, and luxury goods. The records provided are immutable and thus products can be traced from their origins to the endpoints as consumers demand for authenticity and safety with regard to the products they purchase.

Despite its potential benefits, SCM practitioners have been slow to adopt blockchain due to technological cost barriers, gaps in regulation, and overall complexity. The complexity of these challenges suggests that more governmental aid is necessary alongside well-defined policies relating to blockchain technology and user-friendly solutions for integration into existing supply chain networks. Additionally, cross-industry collaborations and scalability are among the most important challenges highlighted in this context and must be addressed to ensure that blockchain is able to support vast global supply chains.

Notwithstanding the obstacles identified with blockchain implementation in Supply Chain Management (SCM), blockchain is expected to change the industry for the better. The growing application motivation, fortified by business case studies and government engagements, showcases blockchain's capacity. Most notably, the partnership of blockchain with other emerging technologies, including AI, IoT, and big data, will amplify supply chain security and operational efficiency. As the technology develops, it is foreseen that blockchain will join the supply chain ecosystem, which will promote clearer, more efficient, secure trade on a global scale.

Nevertheless, regardless of the fact, the technology is still in its nascent stages, the opportunities it holds to fundamentally improve SCM practices outlines its significance. The development of regulative guidelines, refined technical implementations, consortium efforts, and interdisciplinary efforts amalgamated will surely aid towards removing obstacles to harness the utmost power of blockchain technology. With increasing interest towards digital transformation, it will serve as a centerpiece to revolution how supply chain management is executed by significantly boosting the level of transparency, security, and effectiveness.

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