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RESEARCH ARTICLE

Prediction of Mutual Interdependencies Among the Drivers of Blockchain for Enhancing the Supply Chain Dynamics

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Abstract: Nowadays, demand for customized products is increasing in the era of globalization and competitiveness. But this has burdened the supply chain (SC) performance and demands for the digitalization of its operation to enhance the transparency within its operation. As SCs are operating across regional boundaries, their dynamics need to be aligned with the paradigm of industry 4.0 technologies. Blockchain is one among those, which promises to enhance product traceability and bring transparency to its operation. But, the adoption of blockchain is not getting much attention, which indicates the need of an analysis of its drivers. As the avenues of information technology are getting attention, drivers of blockchain adoption are identified in this study. Furthermore, to reveal the mutual interrelationships between the drivers interpretive structural modelling-Cross-Impact Matrix Multiplication Applied to Classification (ISM-MICMAC) analysis is exercised. Driving factors are further analyzed by the Neutrosophic-based robust ranking, resulting in the primacy of the drivers. The outcomes of the present work substantially outrank the drivers, relative to its impact in the adoption of blockchain operations in SC performance systems. It provides a structured approach to managers for aligning SC operations with blockchain technology.

Keywords: performance system, ISM-MICMAC, neutrosophic set, Neutrosophic-based ranking

1. Introduction

The current era of industrial engineering is relying upon the adoption of various breakthrough technologies, which are shoring various supply chain (SC) activities toward digitalization [1]. Perspectives allied with these technologies are reliant enough to withstand the waves of globalization in the competitive market arena. The adoption of digital technologies has the potential to transform traditional SC practices and adds value to the chain operations by evoking a better mutual consensus between the suppliers, manufacturers, distributors, and consumers to unearth the various miniatures of the market [2]. It is being estimated that an abundance of various digitalized technologies can automate 60% of the existing processing facilities [3].

Nowadays, implying blockchain technology empowers to achieve end-to-end transparency [4]. Owing to the same, it is gaining popularity in streamlining the various operational protocols of the SC performance system by deploying a strong peer-to-peer network which tends to authenticate and share the data [5]. It comprises a sophisticated decentralized environment, where in correspondence to every transaction of the SC, all changes are recorded in its ledger, which is accessible to all of its users [6]. A typical blockchain network integrates the perspectives of the end-user and data safety and promotes transparency in its network for effectively monitoring the various miniatures and portfolios of the SC [7]. Its implication shores the existing SC toward the paradigms of the industry 4.0 practices [8].

Winds of globalization, consistent changes in the socio-economic status of the consumers, and awareness about sustainable perspectives are adding complicacy to the existing SC network [9]. Effective and efficient management of the SC networks is becoming critical to safeguarding organizational perspectives. Hence, the need arises to enact various technological advancements with the dynamics of the SC to excel toward the goal of continuous improvement [10]. Deployment of the blockchain felicitates the monitoring of the inventory, product flows, and traces during the phase of distribution and governs the influx and outflux of the working capital within the SCs [11]. Furthermore, the avenues of reliability and visibility in the various transactional ledgers integrate the various operational tiers of SCs, which bridges the gap between supply and demand. In nutshell, blockchain adoption benefits the SCs in terms of better traceability, improved audibility, user, and data security and manages the complete flow of information through its network.

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It is projected that blockchain-based SCs have the potential to secure a market valuing $9.8 billion by the year 2025 [12]. Furthermore, it is estimated that globally, the contribution of the blockchain to the SC market is set to rise by $424 million by the year 2023 [13]. Alone, in Australia, it is predicted that nearly 51% of companies are favoring the adoption of blockchains to escalate their SC potencies in terms of transparency and fostering mutual collaborations between partners [14]. But, still, nearly 11% of the companies are utilizing and relying upon the solution rendered by the blockchain [15]. It can be understood from the projected figures that the adoption of the blockchain within the SC has prosperous avenues.

Digitalization of SCs is getting momentum nowadays, leaping forward toward a knowledge-based economy [16]. Various field advancements in the domain of information technology, enabling the Internet of Things (IoT)-based cloud storage and retrieval-based systems, have enabled remote monitoring and bought the cyber-physical systems from agenda to reality [17]. Integrating the IoT systems with the blockchain proves to be a shredder of the darkness allied with the dynamics of traditional SCs. It is a framework that interconnects the various stakeholder across the globe, in which various transactions can be shared through the public or private network [18]. Its integration gives the SC a leading edge in terms of the progression of information, its accessibility, mapping of the information with the material stream, and capsizing the data infringement and misrepresentation-based vulnerabilities, along with the real-time monitoring of product flow.

In continuation to the prosperous avenues bundled with the adoption of blockchain technology in the SC performance system, the present work is exercised. It is aimed to answer the following research questions (RQs):

RQ1: How to explore the key drivers felicitating the adoption of the blockchain in the SC performance system?
RQ2: How to handle the various mutual interdependencies allied with these drivers, to ease its adoption?
RQ3: How to secure the primacy of the drivers, to escalate the implication of blockchain technology in the SCs?

2. Literature Review

SC management is a colossal domain, which is having a broad range of operations and acts as a Skelton for every industrial arena. Traditional SCs are not sufficient and reliant to map the existing demand with the product supply. Furthermore, these SCs are not enough versatile and transparent to handle the enhanced traffic of the product flow through its various networks and allied tributaries. In the current era of industry 4.0, enabling blockchain seems to be a way of organizing the record in their respective portfolios using a consensus mechanism [19]. Aligning dynamics of the SC with the walks of blockchain technology is thriving the SCs by featuring transparency, trust, and security, authenticity, disintermediation, cost reduction, and effective and efficient operations [20]. Furthermore, blockchains felicitate automation of the manufacturing facilities by extending the smart contracting mechanisms [6], and it also eradicates the ripple effect in the SCs by minimizing the various disruptions. Deployment of the blockchain in the SCs strengthens the bonds between the various stakeholders, promoting trust in the activities and streamlining the various operational procedures [21].

Min [22] reviewed blockchain technology adoption as a source to promote resilience in SC activities. Wang et al. [23] designed the blockchain-enabled SC. Hastig and Sodhi [24] assessed the various success factors allied with the adoption of blockchain technologies in the SC performance system. Moosavi et al. [11] reviewed the scenarios of the blockchain in the dynamics of the SC by rendering network analysis. Treiblmaier [25] reviewed the impact of the blockchain on SCs by opting for the theoretical working approach. Esmaeilian et al. [26] reviewed the blockchain as an enabler of sustainability in the walks of SC management. Durach et al. [27] explored the avenues of various blockchain-based applications in SC transactions. Nezhadkian et al. [28] implied the fundamentals of fuzzy set theory in assessing the scope of new product development in business ventures. Hidayat et al. [29] detailed the machine learning-based intrusion system based on the experimental comparison. Tyagi et al. [30] reviewed the inventory models in manufacturing sectors.

Sharma and Tyagi [31] assessed the endorsers of e-business retailing in the food SCs. Barma and Modibbo [32] developed a multi-objective problem for the economic assessment of the waste recycling/reuse of products.

2.1. Theoretical framework

The adoption of blockchain technologies is in its nascent stage in the context of developing economies [24]. Owing to the prosperous avenues bundled with it, aimed to upscale the potencies of the SC, its various drivers are clustered in the present work.

2.1.1. Corruption reduction (DV1)

Blockchain technology has great potential to reduce corruption [33]. It can help bring transparency and traceability to the system. It can be used to prevent Electronic Voting Machine (EVM) tampering, carry out fair elections, provide unique identities to individuals, and can provide transparency to the use of taxpayer money [34]. It can help detect corruption in government circles, expose criminal practices, and limit power abuse and social, economic, and environmental impacts [35].

2.1.2. Easy tracing of carbon footprints (DV2)

The customers by scanning the QR code on the product through smartphones will be able to see the whole journey of the product from source to destination and how much carbon footprints it is producing throughout the journey [36]. This will make companies adopt sustainable practices to reduce the carbon footprints associated with their products [37]. Tracing carbon footprints becomes easier with blockchain technology as compared to traditional methods [38].

2.1.3. Time and cost reduction (DV3)

Eliminating paper records, digitizing physical processes, eliminating middlemen involved, and reducing interactions will lead to less time taken and cost reduction [39]. There is also a reduced cost of conducting or validating a transaction, reduced cost of the measure to prevent the attack, and reduced cost of recalling the whole product line in case of bad products are found [40]. The inventory management and transportation cost in a SC will also be reduced due to better forecasts and reduced interactions, respectively, through blockchain technology [21].

2.1.4. Improved SC objectives (DV4)

Blockchain technology can bring improvement in SC objectives like cost, speed, dependability, sustainability, flexibility, and risk reduction by reducing the number of people involved and reducing interactions and paperwork required [41]. This technology helps in tracking and better management of resources which will lead to better forecasts and less inventory required [42]. Blockchain can also be a solution to the bullwhip effect in the SC [23].

2.1.5. Better customer satisfaction (DV5)

Blockchain technology provides transparency about a product's information and warranty management and can help in authenticating the product's origin leading to better customer satisfaction [43]. This technology will assure customers of fair treatment by the businesses in which they are investing their money. This will help in building trust and can help in making lifelong customers [44].

2.1.6. Competitive advantage (DV6)

Blockchain has applications in many sectors, namely banking, finance, health care, cryptocurrency, etc., and its capabilities include transparency, smart contracts, anti-counterfeiting, digital identities, etc. [22]. Transparency in operations, tracking, and traceability of products and better customer satisfaction provided by this technology give its user a competitive advantage over others [45].

2.1.7. Improvement in tracking and traceability of products (DV7)

Transparency in SC operations helps in better tracking and traceability of products, especially in food SCs against low-quality and bad food products [46]. Any member of the SC can track the current status of the product through this technology. Any information can be traced to its root which will bring transparency and better management of resources [7].

2.1.8. Encouragement of sustainable practices (DV8)

Customers will be able to know about the product's carbon footprint level through this technology due to transparency in operations. So companies making products with high carbon footprint levels will encourage sustainable practices to reduce carbon footprints to avoid high tax imposition [47]. This will ensure products are made without harming the environment or workforce.

2.1.9. Making system lean (DV9)

Encouragement of sustainable practices will lead to waste reduction and the promotion of reusing and recycling products [48]. As blockchain technology eliminates middlemen, product wastage and reduces carbon emissions making the system lean [49].

2.1.10. Fair pricing of products (DV10)

Lack of transparency in SC operations and costs imposed by various intermediary parties increase the final cost of the product [50]. This also prevents customers from knowing the working conditions of the SC of the product they are consuming and how much each member of the SC earns [51]. Middlemen removal, wastage reduction, corruption reduction, and losses minimization will contribute to fair pricing of products [52].

2.1.11. Minimization of losses due to human error (DV11)

Blockchain technology accompanied by artificial intelligence leads to the minimization of physical and financial losses due to human error [35]. This will improve the quality of the product and will build consumer trust [53].

2.1.12. Wastage reduction (DV12)

Blockchain technology can be a solution to wastage reduction, especially in food waste management as waste disposal has also become a problem nowadays [54]. This technology can trace products at any time due to which contaminated food can be traced easily and then send for disposal [55]. Transparency in operations and encouragement of sustainable practices will lead to less waste generated. Reusing and recycling products will also reduce waste generation. Smart contracts can prove beneficial in minimizing waste across the SC [56].

2.1.13. Trading in trust environment without middlemen (DV13)

Two unknown parties can transact or trade freely without any third party involved, eliminating middlemen. Validation of transactions is achieved through a process called mining which ensures trust and security. Middlemen's removal will lead to reduced corruption and fair pricing of products [57].

3. Research Methodology

The present work is exercised to assess the various drivers of blockchain adoption in the SC performance system. This study bridges the gaps of past studies, citing the need for the empirical analysis of the driver's/success factors/enactors of blockchain adoption in the SC, as research literature is having a plethora of studies that imply the theoretical working approaches [49, 58, 59]. Hence, the need arises to understand and explore the various mutual interrelationship between the various drivers of the technological adoption of blockchain, for securing its priority. Bridging the same presented study clusters the various drivers felicitating the adoption of the blockchain in SCs, which advances toward its empirical analysis. Thirteen drivers of blockchain adoption are initially analyzed for the mutual interrelationships by the methodology of the interpretative structural modeling (ISM), which is further enriched by the extending MICMAC analysis. Driving factors achieved by the ISM-MICMAC analysis are further analyzed by the robust neutrosophic set-based ranking methodology to secure the primacy of the drivers.

3.1. Interpretive structural modeling

This approach identifies the contextual relationship between the various factors, which have a close association with the main goal under consideration. It indulges an interpretative approach, which results in the outcomes summing the judgemental inputs governing the relationship between the factors under consideration [60]. This methodology effectively quantifies the contextual relationships between the points, seeding the development of the structural self-interaction matrix (SSIM).

Based on this, the reachability matrix (RM) is evaluated, which validates the transitivity of the matrix. Finally, it is converted to its equivalent conical form, which divides the upper diagonal with the "0" as an element and the lower half comprises of unitary elements. Relationships persisting within the RM develop the graphical plots, which indicate the mutual interrelationship between the factors nullifying the dimension of transitivity. In context to the same, for ease of visualization and understanding, the methodology (Figure 1) is developed.

3.2. Neutrosophic based robust ranking approach (NRRA)

In real-time decision-based scenarios, it becomes cumbersome to quantify the vagueness bundled with the judgemental insights [61]. It becomes quite imprecise to encompass the vagueness, indeterminacy, and uncertainty allied with the gathered assessments [62]. To tackle the same, neutrosophic sets are introduced by Smarandache [63]. It is extracted from the existing theory of intuitionistic fuzzy sets, natively having the membership function value in terms of the truth, indeterminacy, and falsity function values [64]. Although the fuzzy set theory answers the uncertainties in the decision-making process, it could not effectively handle the indeterminate and inconsistent information [65]. Voskoglou [66] detailed the utility of soft set theory and grey numbers in the decision-making process. Al-Hamido [67] developed some new neutrosophic algebraic structures.

Definition 1. [68]: Let us assume *"Z"* as a space encompassing the points, where $z \varepsilon Z$. A typical neutrosophic set, *[Q]*, is defined by its truth-membership function as [$TM_Q(z)$], its allied indeterminacy-membership function as [$IM_Q(z)$], and associated with its falsity membership function value [$FM_Q(z)$] within the space "*Z*".

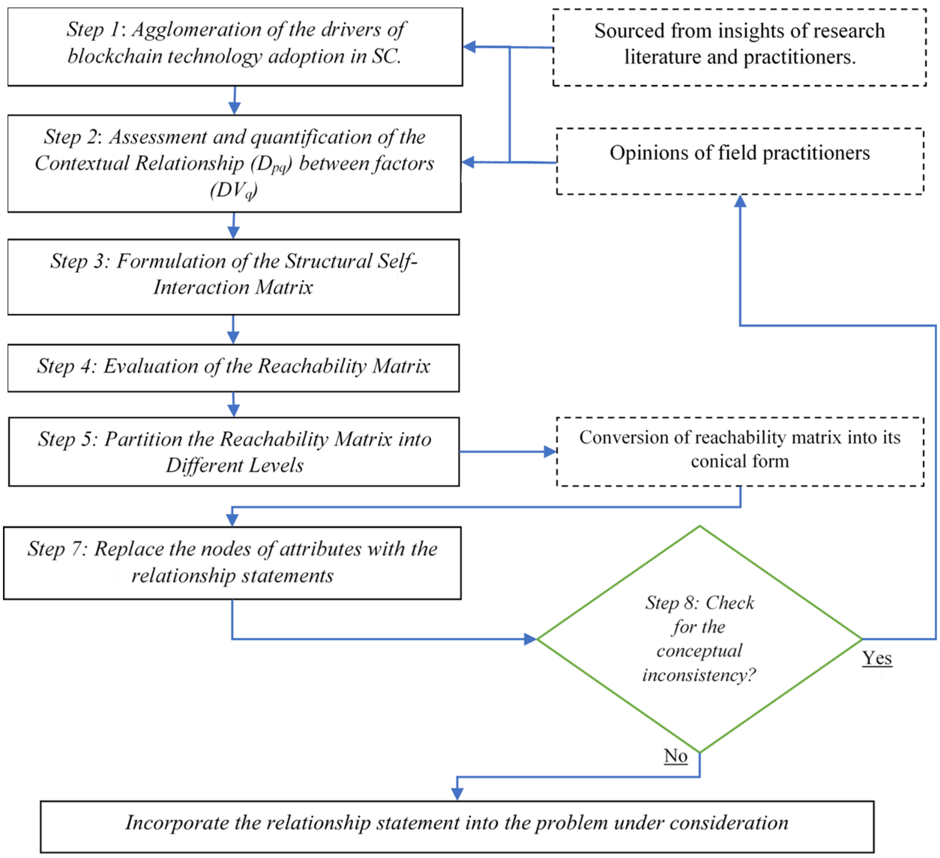
Definition 2. [69]: For the considered *"Z"* as the universe of discourse. A single-valued "Q_s" lying in discourse *"Z"* presumes its mathematical form as: $Q = \{z, TM_Q(z), IM_Q(z), FM_Q(z)\}$, where $TM_Q(z): Z - [0,1]$, $IM_Q(z): Z - [0,1]$ and $FM_Q(z): Z - [0,1]$, binding the condition $0 \leq TM_Q(z) + IM_Q(x) + FM_Q(x) \leq 3$, where $z \varepsilon Z$.

Definition 3. *Neutrosophic based* [70]: Assume $\vartheta_r,\ \mu,\ \rho_r \in [0,1]$ and $r_1, r_2, r_3, r_4 \varepsilon R$, where R denotes the real line set values of single-valued "Q_s" depicted by "r". Then, it is represented single-valued as, $r = \langle (r_1, r_2, r_3, r_4);\ \vartheta_r, \mu_r, \rho_r \rangle$, whose membership, indeterminacy, and falsity membership function values are evaluated as shown in Equation 1.

$$TM_r(z) = \begin{cases} \vartheta_r\left(\frac{z-r_1}{r_2-r_1}\right) & (r_1 \leq z < r_2) \\ \vartheta_r & (r_2 \leq z \leq r_3) \\ \vartheta_r\left(\frac{r_4-z}{r_4-r_3}\right) & (r_3 \leq z < r_4) \\ 0 & Otherwise \end{cases};$$

$$IM_r(z) = \begin{cases} \left(\frac{r_2-z+\mu_r(z-r_1)}{r_2-r_1}\right) & (r_1 \leq z < r_2) \\ \vartheta_r & (r_2 \leq z \leq r_3) \\ \left(\frac{(z-r_3+\mu_r(r_4-z)}{r_4-r_3}\right) & (r_3 \leq z < r_4) \\ 1 & Otherwise \end{cases}$$

Figure 1
Insights of the proposed methodology



$$FM_r(z) = \begin{cases} \left(\frac{r_2 - z + \rho_r(z - r_1)}{r_2 - r_1}\right) & (r_1 \le z < r_2) \\ \vartheta_r & (r_2 \le z \le r_3) \\ \left(\frac{(z - r_3 + \rho_r(r_4 - z)}{r_4 - r_3}\right) & (r_3 \le z < r_4) \\ 1 & Otherwise \end{cases} \quad (1)$$

In Equation 1, $\vartheta_r,\ \mu_r,\ and\ \rho_r$ indicate the maximum truth membership function value, minimum indeterminacy, and minimum falsity membership degree values, respectively.

Definition 4. [71]: Assume $\widetilde{m}$ and $\widetilde{n}$ be two distinct single-valued trapezoidal-based neutrosophic numbers comprising of elements as: $\widetilde{m} = \langle(m_1, m_2, m_3, m_4);\ \vartheta_m, \mu_m, \gamma_m\rangle$ and $\widetilde{n} = \langle(n_1, n_2, n_3, n_4);\ \vartheta_n, \mu_n, \gamma_n\rangle$; their basic operations of addition, subtraction, multiplication, and division are executed in Equations (2)–(5), respectively.

$$\text{Addition}: \widetilde{m} + \widetilde{n} = \langle(m_1 + n_1, m_2 + n_2, m_3 + n_3, m_4 + n_4);\ \vartheta_m \wedge \vartheta_n,\ \mu_m \vee \mu_n,\ \rho_m \vee \rho_n\rangle \quad (2)$$

$$\text{Subtraction}: \widetilde{m} - \widetilde{n} = \langle(m_1 - n_4,\ m_2 - n_3,\ m_3 - n_2,\ m_4 - n_1);\ \vartheta_m \wedge \vartheta_n,\ \mu_m \vee \mu_n,\ \rho_m \vee \rho_n\rangle \quad (3)$$

$$\text{Multiplication}: m, n = \begin{cases} \langle(m_1 n_1,\ m_2 n_2, m_3 n_3, m_4 n_4);\ \vartheta_m \wedge \vartheta_n,\ \mu_m \vee \mu_n,\ \rho_m \vee \rho_n\rangle & if\ (m_4 > 0,\ n_4 > 0) \\ \langle(m_1 n_4,\ m_2 n_3, m_3 n_2, m_4 n_1);\ \vartheta_m \wedge \vartheta_n,\ \mu_m \vee \mu_n,\ \rho_m \vee \rho_n\rangle & if\ (m_4 < 0,\ n_4 > 0) \\ \langle(m_4 n_4,\ m_3 n_3, m_2 n_2, m_1 n_1);\ \vartheta_m \wedge \vartheta_n,\ \mu_m \vee \mu_n,\ \rho_m \vee \rho_n\rangle & if\ (m_4 < 0,\ n_4 < 0) \end{cases} \quad (4)$$

Division:

$$m, n = \begin{cases} \langle\frac{m_1}{n_4}, \frac{m_2}{n_3}, \frac{m_3}{n_2}, \frac{m_4}{n_1};\ \vartheta_m \wedge \vartheta_n,\ \mu_m \vee \mu_n,\ \rho_m \vee \rho_n\rangle & if\ (m_4 > 0,\ n_4 > 0) \\ \langle\frac{m_4}{n_4}, \frac{m_3}{n_3}, \frac{m_2}{n_2}, \frac{m_1}{n_1};\ \vartheta_m \wedge \vartheta_n,\ \mu_m \vee \mu_n,\ \rho_m \vee \rho_n\rangle & if\ (m_4 < 0,\ n_4 > 0) \\ \langle\frac{m_4}{n_1}, \frac{m_3}{n_2}, \frac{m_2}{n_3}, \frac{m_1}{n_4};\ \vartheta_m \wedge \vartheta_n,\ \mu_m \vee \mu_n,\ \rho_m \vee \rho_n\rangle & if\ (m_4 < 0,\ n_4 < 0) \end{cases} \quad (5)$$

Initially, pairwise comparisons are made for the drivers based upon the fundamentals of the trapezoidal neutrosophic set *[Q]*, seeding the development of the initial pairwise comparison matrix as shown in Equation (6).

$$\begin{bmatrix} 0 & \cdots & (m_{1mp}, m_{1mq}, m_{1mk}, m_{1ml};\ \vartheta_m, \mu_m, \rho_m) \\ (m_{21}, m_{22}, m_{23}, m_{24};\ \vartheta_m, \mu_m, \rho\rho_m) & \cdots & \vdots \\ \vdots & \ddots & \vdots \\ (m_{f1p}, m_{f2q}, m_{f3k}, m_{f4l};\ \vartheta_m, \mu_m, \rho_m) & \cdots & (m_{fmp}, m_{fmq}, m_{fmk}, m_{fml};\ \vartheta_m, \mu_m, \rho_m) \end{bmatrix} \quad (6)$$

Trapezoidal neutrosophic set-based assessments are converted into their equivalent crisp number values by implying the formulation revealed in Equation (7). Obtained crisp values are used for the evaluation of average value, by averaging the elements of the row as shown in Equation (8).

$$C(m_{fe}) = \tfrac{1}{16}\left[m_{1p} + m_{2q} + m_{3k} + m_{4l}\right] * (2 + \vartheta_e - \mu_e - \rho_e) \quad (7)$$

$$RW_{fe} = \frac{Crisp_{1f} + Crisp_{2f} + Crisp_{3f} \ldots\ldots\ldots + Crisp_{ef}}{f} \quad (8)$$

Values evaluated from Equation (8) are bifurcated into the *Lower Limit* $(\overline{LO})$ and *Upper Limit* $(\overline{UP})$. In between these limits trapezoidal neutrosophic, *"g"* and *"h"* are substituted, to succeed toward the robust ranking. This implies the set of equations mentioned in Equation (9). Here, evaluated value $S(\bar{A})$ secures the primacy of the factors under consideration.

$$\bar{A} = (\overline{LO}, g, h, \overline{UP});\quad using$$
$$\bar{A}_y = \left[(\overline{LO} + (g - \overline{LO})y),\ (\overline{UP} - (\overline{UP} - h)y)\ \right]\ and$$
$$S(\bar{A}) = \frac{1}{2}\int_0^1 \left[\bar{A}_y^{-LO}; \bar{A}_y^{-UP}\right] dz$$

$$(\bar{A}) = \tfrac{1}{2}\int_0^1 \left[(\overline{LO} + (g - \overline{LO})y),\ (\overline{UP} - (\overline{UP} - h)y)\right] dy \quad where\ y = [0, 1] \quad (9)$$

4. Modeling the Drivers of Blockchain Technology with the Proposed Methodology

In this study, the clustered drivers of the blockchain adoption in the SC are assessed empirically by implying duo approaches. Initially, the drivers are evaluated by the iterative procedure of ISM methodology, which advances toward the MICMAC analysis, resulting in the categorization of the drivers into the class of autonomous, dependent, linkage, and driving factors, respectively. Finally, the drivers belonging to linkage factors are further analyzed by the NRRA based upon which primacy is secured and inferences are grounded. A visualization of the same is pictured in Figure 2.

The present work clusters the 13 distinct drivers of blockchain adoption in the SC performance system. Initially, the methodology of the ISM is implied to handle the mutual interrelationships between the various drivers under consideration. The same SSIM is developed, which reveals the interrelationship between the *"x"* and *"z"*. The interrelationship between the drivers is depicted broadly by the four symbols having interpretation as:

- *V* depicts the influence of factor *x* over factor *z*.
- A depicts the influence of the factors *z* over the factor *x*.
- X depicts the mutual influence of the factors *x* and *z*.
- O depicts the non-conformity between the factors *x* and *z*.

Developed SSIM felicitates the development of a RM, which showcases the relationship between drivers mutually, in a binary form. Previously, notations are replaced by the binary inputs of 0 and 1, respectively. It is based upon the following set of conditions:

Figure 2
Working approach

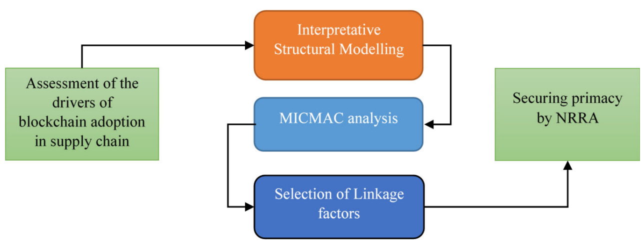
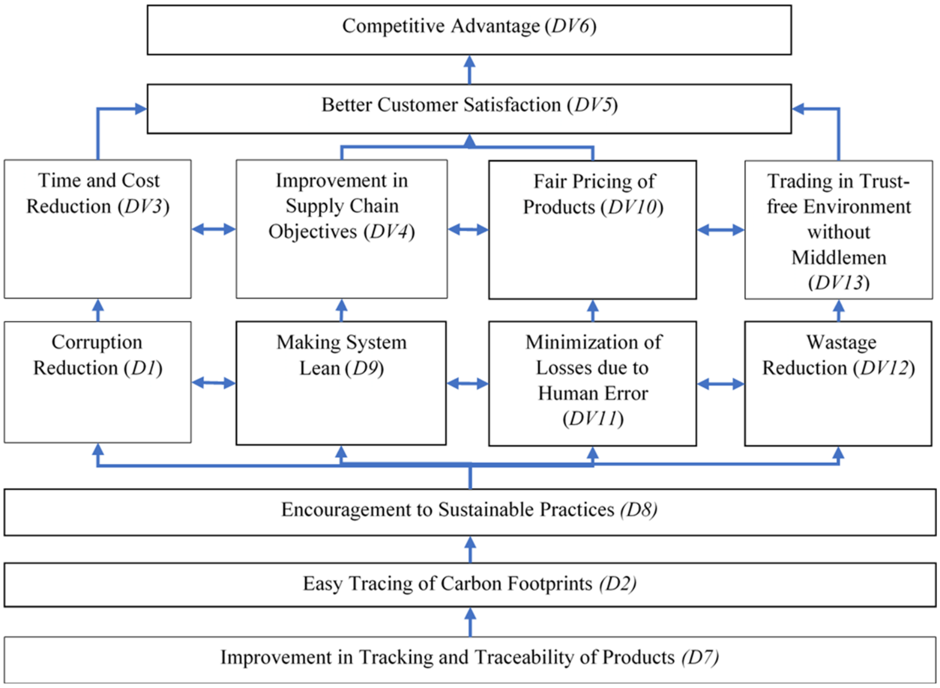


Figure 3
ISM-based hierarchical model of drivers



- If in SSIM for the factors *(x,z)* assigned value is *V,* then in place of the same "1" is placed in RM, for the vice versa of same "0" is assigned respectively.
- If in SSIM for the factors *(x,z)* assigned value is *A,* then in place of the same "0" is placed in RM, for the vice versa of same "1" is assigned.
- If in SSIM for the factors *(x,z)* assigned value is *X,* then in place of the same "1" is placed in RM, for the vice versa of same "1" is assigned.
- If in SSIM for the factors *(x,z)* assigned value is *O,* then in place of the same "0" is placed in RM, for the vice versa of same "0" is assigned.

Development of the final RM relies upon the incorporation of the transitivity. It encloses the relationship between the various drivers. For instance, if a relationship persists within the X and Y, similarly in between Y and Z, it is seemly prominent between the X and Z.

The final RM of the drivers clusters them into the antecedent and reachability sets, respectively. Various horizontal arranged drivers belong to the antecedent set, whereas vertical ones should be underpinned in the reachability set. Factors that have the same elemental values in both antecedent and reachability sets are placed at the top level of the hierarchy of the developed ISM model as shown in Figure 3. Similarly, iterative work is implied for the selection of the various hierarchical levels and placing their suitability in the developed model. It felicitates the development of the relationship diagraphs. In Table 1, outcomes of the iterative procedural are implied.

Based upon the RM, conical matrix is developed, which clusters the various factors at the same level, relative to its rows and column. Driving power allied with the drivers is assessed by summing the ones

Table 1
Level partition table for drivers (iteration 1–7)

Drivers	Reachability set	Antecedent set	Intersection set	Iteration no. and level
DV6	6	1,2,3,4,5,6,7,8,9,10,11,12,13	6	I
DV5	5	1,2,3,4,5,6,7,8,9,10,11,12,13	5	II
DV3	1,3,4,9,10,11,12,13	1,2,7,8,9,11,12	1,3,4,9,10,11,12,13	III
DV4	1,3,4,9,10,11,12,13	1,2,3,4,7,8,9,10,11,12,13	1,3,4,9,10,11,12,13	III
DV10	3,4,10,13	1,2,3,4,7,8,9,10,11,12,13	3,4,10,13	III
DV13	1,3,4,9,10,11,12,13	1,2,3,4,7,8,9,10,11,12,13	1,3,4,9,10,11,12,13	III
DV1	1,9,11,12	1,2,7,8,9,11,12	1,9,11,12	IV
DV9	1,9,11,12	1,2,7,8,9,11,12	1,9,11,12	IV
DV11	1,9,11,12	1,2,7,8,9,11,12	1,9,11,12	IV
DV12	1,9,11,12	1,2,7,8,9,11,12	1,9,11,12	IV
DV8	8	2,7,8	8	V
DV2	2	2,7	2	VI
DV7	7	7	7	VII

Table 2
Developed pairwise comparison matrix of the drivers in quadrant 3 of MICMAC analysis

	DV1	DV3	DV4	DV9	DV11	DV12	DV13
DV1	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.5,0.6,0.7,0.8);0.7,0.3,0.3>	<(0.4,0.5,0.6,0.7);0.8,0,0.1>	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>
DV3	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.1,0.1,0.1,0.1);0.5,0.3,0.3>	<(0.1,0.1,0.1,0.1);0.5,0.3,0.3>	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>	<(0.4,0.5,0.6,0.7);0.8,0,0.1>	<(0.5,0.6,0.7,0.8);0.7,0.3,0.3>	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>
DV4	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>	<(0.5,0.6,0.7,0.8);0.7,0.3,0.3>	<(0.4,0.5,0.6,0.7);0.8,0,0.1>	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.1,0.1,0.1,0.1);0.5,0.3,0.3>	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>	<(0.5,0.6,0.7,0.8);0.7,0.3,0.3>
DV9	<(0.1,0.1,0.1,0.1);0.5,0.3,0.3>	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.5,0.6,0.7,0.8);0.7,0.3,0.3>	<(0.4,0.5,0.6,0.7);0.8,0,0.1>	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>	<(0.4,0.5,0.6,0.7);0.8,0,0.1>	<(0.1,0.1,0.1,0.1);0.5,0.3,0.3>
DV11	<(0.5,0.6,0.7,0.8);0.7,0.3,0.3>	<(0.5,0.6,0.7,0.8);0.7,0.3,0.3>	<(0.1,0.1,0.1,0.1);0.5,0.3,0.3>	<(0.4,0.5,0.6,0.7);0.8,0,0.1>	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.1,0.1,0.1,0.1);0.5,0.3,0.3>	<(0.4,0.5,0.6,0.7);0.8,0,0.1>
DV12	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.5,0.6,0.7,0.8);0.7,0.3,0.3>	<(0.5,0.6,0.7,0.8);0.7,0.3,0.3>	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.5,0.6,0.7,0.8);0.7,0.3,0.3>
DV13	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.1,0.1,0.1,0.1);0.5,0.3,0.3>	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>	<(0.2,0.3,0.4,0.5);0.6,0.2,0.2>	<(0.3,0.4,0.5,0.6);0.7,0.1,0.1>

Table 3
Operational limits of the drivers

[1]	Crisp number-based average	***UP***[2]	***g***[3]	***h***	***LO***[4]
DV1	0.2900	0.29	0.230	0.25	0.21
DV3	0.2232	0.25	0.230	0.23	0.22
DV4	0.2652	0.27	0.250	0.26	0.24
DV9	0.2361	0.24	0.220	0.24	0.16
DV11	0.2446	0.29	0.220	0.23	0.24
DV12	0.2689	0.27	0.250	0.27	0.19
DV13	0.2098	0.24	0.170	0.18	0.21

[1] *DV* depicts the drivers of the blockchain as detailed in theoretical framework development (Section 2.1).
[2] *UP* is the upper limit.
[3] "*g*" and "*h*" are trapezoidal neutrosophic numbers between *UP and LO*.
[4] "*LO*" is the lower limit.

in a row and its equivalent dependence is evaluated by adding ones in the column of the matrix. The dependence-based ranking is allotted by rendering the highest primacy to the driver having a maximum count of the ones in the rows and columns, respectively.

Furthermore, MICMAC analysis is exercised to analyze the dependence and driving power allied with the barriers under consideration. Broadly, this analysis develops four clusters, namely autonomous, dependent, linkage, and driving, respectively, where barriers are placed by overviewing the nature of the interrelationship between the driving and dependence of barriers.

Based on the outcomes of the MICMAC analysis, drivers abbreviated as *DV1, DV3, DV4, DV9, DV11, DV12,* and *DV13* have strong driving power along with the strong linkage. Hence, these seven drivers are further analyzed by the NRRA, for securing robust primacy of them. Based on Equation (6), the pairwise comparison matrix is developed by complying with the fundamentals of the trapezoidal neutrosophic sets, as shown in Table 2.

Implying the formulation mentioned in Equations (7) and (8), trapezoidal-based neutrosophic assessments are converted into their equivalent crisp values, which are further averaged, and evaluated values are shown in Table 3. It is further analyzed for the upper and lower limits allied with the same, respectively.

5. Results and Discussion

The present work implies the analysis of the various drivers of the adoption of blockchain technology within the various walks of the SC performance system. This study exercises the empirical investigation of drivers to handle the mutual interdependencies. and interrelationships. In context to same a duo of the ISM-MICMAC and NRRA is implied, where the output of the first methodology is further analyzed to secure the robust primacy of the drivers. Outcomes of the MICMAC analysis result in the categorization of the drivers broadly into autonomous, dependent, linkage, and driving factors distinctly, same is depicted in Figure 4.

It is evident from the MICMAC analysis that the seven drivers of the blockchain belong to linkage factors. Hence, the need arises to further assess these drivers owing to their high dependency and driving potential. The implication of the NRRA secures the primacy of the drivers falling in the category of linkage factors; outcomes of the same are obtained by implying Equation (9), resulting in the outranking based as shown in Table 4. Plot for the same is developed in Figure 5.

Figure 4
MICMAC analysis

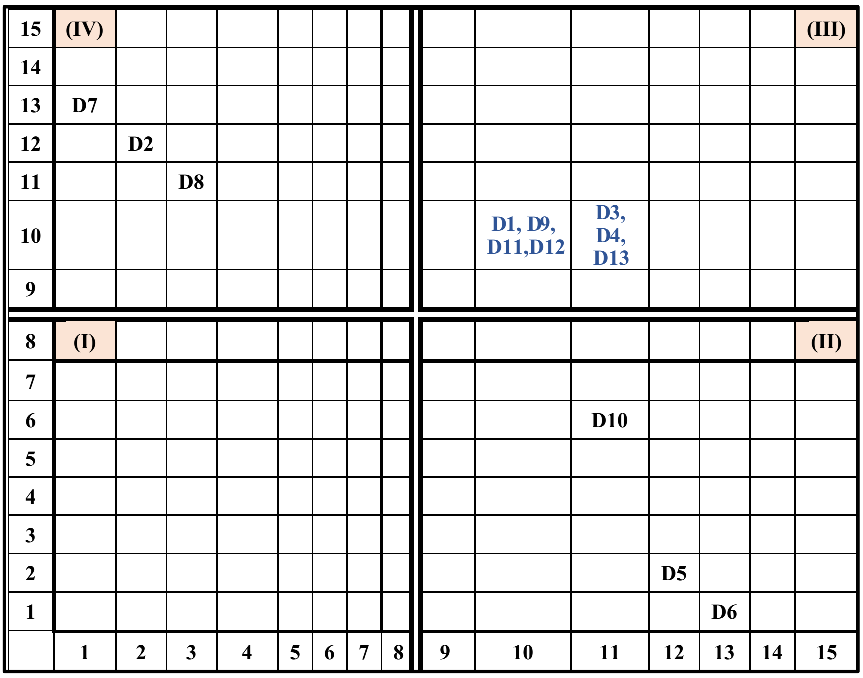
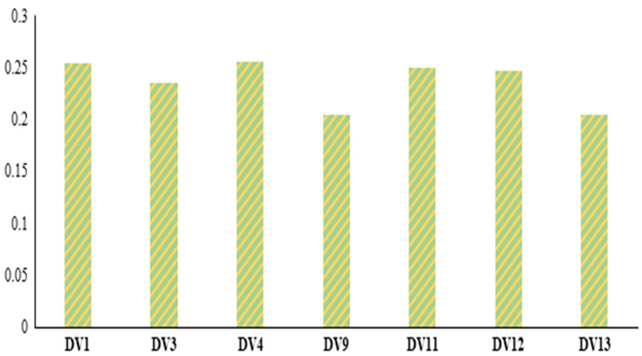


Table 4
Outcomes of the proposed methodology of NRRA

	Lower integral value	Upper integral value	Sum lower and upper integral	Ranking according to the sum
DV1	0.1405	0.1141	0.2546	2
DV3	0.1216	0.1133	0.23485	5
DV4	0.1307	0.1258	0.2565	1
DV9	0.0859	0.1190	0.20491	6
DV11	0.1192	0.1308	0.25003	3
DV12	0.1321	0.1148	0.24684	4
DV13	0.1000	0.1040	0.20398	7

Figure 5
Outranking plots of the drivers of blockchain adoption in the supply chain



It is evident from the results that driver improved supply chain objectives (DV4) secure the highest primacy with a value of 0.2565. It is prominent that the adoption of blockchain-based technology turns the fortunes of the SC in terms of enhanced transparency, enabling traceability of the products between the various tiers of the SC. Nowadays, prosperous avenues are bundled with information technology and field advancements in terms of IoT-based deployments, shoring toward the industry 4.0 paradigm having the potential to flip the dark side allied with the dynamics of the SC performance system. It can be understood from the fact that enveloping the blockchain within the various SC operations of Walmart resulted in gaining the trust of the consumers in the chain-based pork SC and the drastic reduction in the traceability of mangoes in the US-based SC [72]. In China, blockchain implementation was utilized for uploading certificates of authenticity allied with the pork SC, which was a serious concern in traditional working approaches, whereas, in the USA, the traceability of the mangoes was enhanced by reducing their provenance initially, from 7 days to merely 2.2 seconds. It aids SCs toward the perspectives of the financial gains, as well as real-time monitoring of the various products. Its adoption also safeguards the consumer perspectives from the dimension of the malpractices like contamination, adulteration, theft, and shortened product shelf life, ensuring quality and conforming product flow. It has the potential to sustain SC practices in the direction of corruption reduction (DV1), which enhances the profitability of the SCs.

Blockchain technology implies a ledger-based distribution system. It is capable to record minute changes in the state of the product flowing through its peripherals in monitored and recorded. It is away from the external disruptions, biases, and conflicting influences between the stakeholders, which impact the efficiency of the SCs adversely. It is tended to minimize losses due to human error (DV11), which capsizes the pace of the product SCs and causes the bullwhip effect generation. Hence, featuring transparency, reliability, and hassle-free data storage and retrieval improves SCs and endures them toward agility and resilience. Blockchain adoption in the SC operations features real-time scenarios of product monitoring, overcoming various operation-related bottlenecks. This reduces the wastage (DV12) of the man, materials, and resources, which contribute primarily to product flow to the markets in the era of volatile consumer demand. Its adoption aids the automation of the various manufacturing facilities, enhancing the capacity utilization of the production/processing resources and ensuring an error/hassle experience to end consumers. Its adoption reflects the key to curtailing the processing time and reducing the various costing (DV3) significantly. Its scope falls within the organizational goals, streamlining its various operational protocols and consistently upgrading its various portfolios. Blockchain adoption is having the potential to makeshift the existing SC close to trading in a trusted environment without middlemen (DV13). It is going to be a game changer, in terms of reduced product delivery times and cost reduction, enabling the managers to have better control over the operational perspectives of the SCs. As the existing network of the SC is highly tangled in terms of a large count of stakeholders, and operation tiers. This blurs the transparency in chain functioning. Hence, it is prominent that the SC is going to be highly fitted with the adoption of blockchain-based cutting-edge technologies in the era of industry 4.0.

6. Conclusion

The present work identifies the various drivers of the adoption of blockchain technology. As the drivers are very few, if they are analyzed properly, it has the potential to improve the organization's performance. In this study, 13 distinct drivers of blockchain adoption in the SC are identified, which are further classified into the driving factors having strong and weak dependence by carrying out ISM-MICMAC analysis. Primarily, factors *DV1, DV3, DV4, DV9, DV11, DV12,* and *DV13* have strong driving power along with strong linkage. This helps managers to determine the factors of high dependency and their relative importance in the adoption of blockchain-based initiatives. Furthermore, the developed hierarchy of the drivers reveals the mutual interrelationship between the factors under consideration. The driving factors are further contemplated by the methodology of the neutrosophic based robust ranking, resulting in the primacy of the drivers. This results in the outranking of the drivers, acting as a substantial approach to step closer to the adoption of blockchain in the dynamics of the SC. It can be concluded from the outcomes that the adoption of blockchain initiatives induces transparency in the supply–demand patterns and enhances product traceability. This reduces product wastage, minimizes losses, and gains the trust of the stakeholders.

7. Work Implications

Furthermore, the implications of the present work can be extended to various multi-disciplinary domains, comprising the industrial arena, academics, and the ruling government. In developing economies, managers are not much aware of such state-of-the-art facilities. Hence, the present work is structured to capture the various knowledge-based insights allied with such technologies, to overcome the various misconceptions allied with them. Furthermore, securing the primacy allied with the drivers aids managers to ramp up a structured working approach taking closer toward induction of blockchain-based SCs. It is evident from the results that managers should materialize various key decisions, formulations, and strategic and tactical frameworks, which can help their organization meet the SC-based objectives. Its adoption promotes the hassle-free functioning of the SC, curtailing the stakeholder's bias and promoting transparency in financial concerns. Outcomes of the present work aid the top management of the industries to bind a consecutive working approach, escalating toward blockchain adoption. It has the potential to reduce product delivery times and gain consumer trust, capturing a heft market share. Furthermore, academicians can share their expertise with the industries, to felicitate the development of such cyber-physical systems and step closer to industry 4.0 practices. Budding researchers can use this work to conceptualize the various perspectives of the blockchain, and SC practices to bridge the gap between the same. Academicians can ramp the various cost-effective procedures which can felicitate the managers for the makeshift of their existing SCs toward the blockchain technology, without impacting the working capital. Efforts should be lauded in the direction to enhance the return rate of the initial investment allied with the enacting of blockchain technology. In context to the same, academicians and concerned bodies can collaborate to ramp up the infrastructural needs and strengthen the mechanism allied with information technology. Concerned governmental bodies can use the secured primacy as a working approach to step closer to the avenues of digitalization, automation of the manufacturing/processing industries, and imparting pace to SCs. Hence, a collaborative approach associated with the implication of the outcomes of this study is having the potential to flip the dark side of the existing SC, by advancing its operating mechanism and enacting it toward digitalization, which is the need of the current time.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

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