JOURNAL OF GOVERNANCE AND INTEGRITY
ISSN: 2600-7479 e-ISSN: 2600-786X
VOL. 7, ISSUE 1, 2024, 723 - 736
DOI: https://doi.org/10.15282/jgi.7.1.2024.10374

RESEARCH ARTICLE

FROM COMPLEXITY TO CLARITY: A DEMATEL ANALYSIS OF CRITICAL BLOCKCHAIN TECHNOLOGY ADOPTION FACTORS

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ABSTRACT - This exploration is initiated with resolute authentic intention of unravelling complex and intricate topics surrounding the adoption of blockchain technology in supply chain management. Thus, through the operation of DEMATEL (Decision Making Trial and Evaluation Laboratory) analysis, a methodological approach known for capturing and evaluating complex relationships is rather crucial as it could transition the complexity inherent in these factors to a state of clarity. It delves into three influences of technological factors namely, scalability, interoperability, and security that serve as decisive influence on blockchain adoption. The study explores the influence of those technological factors and the dynamic of collective impact on decision-making process in blockchain adoption within the supply chain context. The findings produced from this study hold strong implications for practitioners, policymakers, and researchers seeking to enhance the strategic adoption of blockchain technology in supply chain ecosystems.

ARTICLE HISTORY
Received : 25-2-2024
Revised : 16-4-2024
Accepted : 18-4-2024
Published : 30-6-2024

KEYWORDS
Blockchain
Supply chain
DEMATEL
Critical analysis
Adoption factors

INTRODUCTION

The advent of blockchain technology has emerged as a transformative force, offering novel solutions to the challenges faced by contemporary supply chain management. In recent years, blockchain started as a technological breakthrough in temper-resistant solutions. It provides high-level security and trust in data transactions, which became an underlying technology for cryptocurrencies, which is a peer-to-peer electronic cash system (Nakamoto, 2008). Over the years, it has gained substantial attention for its potential use to revolutionize supply chains' operations, as it relies heavily on data transactions for every trifling action (Iansiti & Lakhani, 2017). However, it is arguable that such oversimplification does not guarantee all supply chain processes with revolutionary benefits as the applicability and success rate significantly vary across industries and contexts. This research embarks on a comprehensive examination and balanced perspective of how blockchain technology, with its inherent features of decentralization and transparency, is capable of influencing and shaping the landscape of supply chain management to a further innovative degree with consideration of potential challenges, contextual variations, and acknowledging broader implications of blockchain adoption.

In short, blockchain is essentially a decentralized and distributed ledger technology that facilitates secure and transparent recording of data transactions. Wu et al. (2019) stated that the adoption of blockchain in supply chain management holds the capability of enhancing traceability, reducing fraud, and improving overall efficiency in the perspectives of data transactions. Nonetheless, Swan (2015) argued that the importance of acknowledging blockchain is not entirely immune to security and vulnerability challenges. The primary purpose of this research is to unravel the intricacies of the blockchain technology adoption process by investigating key technological factors, specifically scalability, interoperability, and security. Through the utilization of the Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology, the research seeks to elucidate the roles of these factors in fostering the adoption of blockchain technology in supply chain management.

The reasoning behind the selection of technological factors is closely tied to the characteristics of the technology itself. This research investigates the side of technological factors to better understand the technological requirements that play into the factors of adoption decisions. Understanding technological factors is crucial as an insight into the potential for innovation in supply chain management, and a comprehensive understanding directly contributes to the effective integration of blockchain technology into supply chain processes. Orlikowski and Iacono (2001) suggested avoiding the oversimplification of complex dynamics at play through a narrow view of technological determinism and including the consideration of influence by a combination of factors.

Thus, this research delves into the interplay between different enablers, examining how their synergies impact the decision-making process for adopting blockchain alongside potential conflicts or challenges arising from these synergies (Zhang & Lee, 2018). As businesses increasingly recognize the transformative potential of blockchain in optimizing supply chain processes, this research contributes valuable insights that bridge the gap between complexity and clarity, offering a nuanced understanding of the multifaceted relationship between technological factors and the adoption

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dynamics within the supply chain management context. Nevertheless, a balanced perspective devoid of over-optimism is required as there are countless implementation challenges from regulatory hurdles, resistance to change, and even collaborative essence among stakeholders, which might prove to be difficult (Buchmann et al., 2018).

Therefore, this current research seeks to clarify the role of technological factors (scalability, interoperability, and security) in driving the adoption of blockchain. Second, this research also aims to unravel the interconnected dynamics of diverse enablers and their collective influence on the decision-making process within supply chain management. The following research questions are as follows:

RQ1: What is the role of technological factors in promoting the adoption of blockchain technology in supply chain management?

RQ2: What is the influence between different enablers and their combined impact on the decision-making process for adopting blockchain in supply chain management?

LITERATURE REVIEW

Technological Factors

It is undeniable that blockchain technology has emerged as a transformative force that could potentially change the basic operation of the supply chain, which is the major reason it has garnered significant attention over recent years. The possibilities of blockchain technology integration could significantly influence the revolution of traditional operations practices through a secure, transparent, and decentralized ledger system that is tamper-proof (Lee et al., 2017). On the other hand, it is important to acknowledge that it might need more than technology alone to reach the state of effective transformation, as a holistic view should encompass non-technological factors and efforts that are equally vital.

Numerous studies in recent years have highlighted the pivotal role of technological factors in driving blockchain adoption. To complement an important and informed decision, it is crucial to grasp the understanding of intricate details of technological factors and how that insight could further contribute to the adoption process. The enablers of scalability are identified as critical enablers by Ivanov and Dolgui (2019); these enablers catalyze accommodating a higher volume of data transactions in the supply chain system compounded over time. Data trails in supply chain operations tend to thrive in complexity, and the volume of transactions will gradually escalate into tremendous figures.

Afterwards, to maintain a cohesive and efficient network of supply chains, it is vital for seamless integration of new technology with existing technology, as mentioned by Trakintas and Fleisch (2019) on the imperative enabler of interoperability as the base of requirements. Interoperability often refers to the seamless integration of blockchain systems with existing technologies and platforms, as it could save enormous time, cost and resources while minimizing the risk of supply chain disruption or possible downtime. Nonetheless, interoperable blockchain solutions can facilitate efficient communication and data exchanges across diverse supply chain participants and technologies.

As for the third enabler, security plays a critical role in addressing trust issues by fortifying data security levels, transparency, and access (Caro et al., 2019). Security is a fundamental concern in supply chain management, and blockchain technology is renowned for its robust security features. Cyber protection is indeed necessary to ensure data reliability and discourage malicious intentions from the very beginning as a mechanism of prevention. One of Blockchain's prominent features is the capability of enhancing data security and transparency, providing an immutable and tamper-resistant ledger that mitigates the risk of fraud and unauthorized access into the supply chain network.

The depiction of technological factors in this study might seem oversimplified as the blockchain adoption process is a very complex dynamic in nature. Zhang et al. (2019) understand that the reality of these factors is interconnected and often influences each other. This showcased that the three depictions of technological enablers are indeed in intricate relationships with each other.

As of current stature, existing research provides vast and beneficial insights into the multifaceted dimensions of blockchain adoption in supply chain management. However, a comprehensive understanding requires further exploration, prompting the present study to employ a DEMATEL analysis. It may not address all possible dimensions of complexity as it is dependent on the comprehensiveness of the considered factors (Wang et al., 2016). By delving into the complexities of scalability, interoperability, and security and assessing the collective impact of diverse enablers, this research aims to bridge the gap between complexity and clarity, offering nuanced perspectives that contribute to both practical implementation and academic discourse. Acknowledging challenges, considering broader dimensions, and adopting a holistic approach will contribute to a more balanced understanding of the complexities surrounding blockchain adoption.

Organizational Factors

Moving beyond the singular focus on technological factors, the literature also reveals a growing interest in the interplay between different enablers and their combined impact on decision-making processes. A study conducted by Lacity et al. (2020) advocates for a holistic approach, acknowledging the interconnected dynamics of various factors such as technological, organizational, regulatory, and economic aspects.

Organizational aspects often include leadership support, organizational culture, and resource availability, all of which play crucial roles in the decision-making process. The study by Lacity et al. (2020) further explores these organizational factors and their interconnectedness with technological enablers, asserting that a supportive organizational environment is essential for successful blockchain adoption. However, different organizations may face unique challenges and have distinct cultures. Regardless, there are no universal solutions for all, necessitating tailored recommendations for diverse organizational contexts (Mumford, 2006).

The probability and success rate of technological adoption into complex structures of networks such as supply chains is highly dependent on the inclusion of organizational factors as it is rather indispensable. This significance was discovered in a study conducted by Lacity et al. (2020), which showcased that technology adoption and implementation outcomes heavily rely on organizational factors. The absence of this crucial factor is not limited to the deprivation of understanding of organizational context but also hinders the development of effective strategies for blockchain integration efforts.

Table 1. Organizational's enablers

Enablers	Sub-factors	Enabler's Description	References
E1	Technical Knowledge	The ability to comprehend the technical aspects of blockchain technology.	Tapscott & Tapscott (2016); Behnke & Janssen (2020); Mendling et al. (2018)
E2	Technical Skills	The practical abilities to develop, deploy, and maintain blockchain solutions.	Iansiti and Lakhani (2017); S. Kamble et al. (2019)
E3	Education and Training	Comprehensive programs are designed to equip individuals with the necessary knowledge and skills for blockchain adoption.	Iansiti and Lakhani (2017); Kearns & Sabherwal (2006); Kleijnen et al. (2009); Leimeister et al. (2007)
E4	Quality and Integrity	The reliability and trustworthiness of data and processes within blockchain systems.	Tapscott & Tapscott (2016)
E13	Authority	Refers to the organization's level of authority over its supply chain operations through the implementation of blockchain technology.	Iansiti and Lakhani (2017); Kraft (2016); Mainelli & Smith (2015); Zyskind et al (2015)
E17	Business Process Standardization	Align and streamline supply chain processes to improve efficiency and consistency.	O'Dwyer (2019); Bealt et al. (2016); Kritchanchai et al. (2018); Meng et al. (2020)
E21	Common Objectives	Refer to shared goals, vision, and purpose among stakeholders involved in blockchain initiatives within the supply chain.	Tapscott & Tapscott (2016); Babich & Hilary (2019); Kouhizadeh et al. (2021); Wang et al. (2021)
E22	Open to changes and adaptation	Organization's culture and mindset towards innovation and transformation	Iansiti and Lakhani (2017); Chang & Chen (2020); Gökalp et al. (2022); Wang et al. (2021)
E24	Integration	Refers to the level of integration between blockchain technology and supply chain operations.	Lacity et al. (2020); Clohessy & Acton (2019)
E26	Technological Infrastructure	Tools and equipment required to support blockchain implementation.	O'Dwyer (2019); Öztürk & Yildizbaşi (2020)
E27	Change Management	Systematic transition involving individuals, teams, and organizations to the future states of context.	Iansiti and Lakhani (2017); Martin et al. (2020); Moezkarimi et al. (2019)

Through the lens of organizational context, insight and comprehension of internal dynamics, readiness, and challenges within organizations could be established well. This holistic understanding enables the formulation of recommendations and guidelines aligned with the organizational context, which could further foster a smoother and more successful implementation of blockchain into the supply chain.

Regulatory Factors

The domain of rules and regulations exerts substantial influence on the inner workings of blockchain adoption in supply chain management. Regulatory frameworks are necessary in the migration of blockchain adoption efforts as they could shape the legal and operational landscape in supply chain operations. The regulatory environment carries a significant role, as emphasized by Lacity et al. (2020), due to the success rate of blockchain adoption relies on it. The interplay between regulatory requirements and technological solutions is a delicate balance that requires sophisticated strategy and planning for organizations to navigate adeptly.

The inclusion of regulatory factors in the study is imperative due to the profound impact of these factors on the overall adoption journey. Apart from the mandatory requirement of legal obligation in place, regulatory factors also serve as a fundamental pillar for establishing trust and credibility in the process of blockchain technology integration (Mougayar, 2016). Additionally, compliance with established regulations holds great value and confidence among stakeholders with a high perception of fostering a conducive environment for the adoption and sustained use of blockchain solutions in supply chain operations in the long term. Nevertheless, it is wise to mention that this generalization might not be the case for different contexts or sector-specific attributes, and it is imperative to build a tailored proposition (Iansiti & Lakhani, 2017).

It is beyond necessary to build knowledge and perception and incorporate regulatory factors as an insight into the intricate challenges and opportunities presented by the legal environment. This holistic comprehension is essential for the development of effective strategies and recommendations. Aligning blockchain initiatives with regulatory standards can mitigate the risk of legal and regulatory challenges, which ensures adoption implementation with a higher success rate.

The legal environment surrounding blockchain adoption is dynamic and multifaceted, encompassing data protection, privacy laws, and sector-specific regulations (Zhang et al., 2019). This signals a need for further understanding of the nuances of these regulatory intricacies to offer tailored guidance for the practical use cases. Challenges in rapid regulatory changes are eminent as the legal landscape continuously evolves, and proactive measures are necessary. A comprehensive understanding of the evolving legal landscape could potentially empower decision-makers to proactively address compliance issues and develop strategies that capitalize on the advantages of blockchain and adhere to legal standards (Swan, 2015).

Table 2. Regulatory's enablers

Enablers	Sub-factors	Enabler's Description	References
E11	Rules and Standard	Represent industry-specific guidelines and best practices to govern blockchain implementation and operation.	Mendling et al (2018); Wang & Kogan (2018)
E14	Traceability	To track and verify the origin, movement, and authenticity of products throughout the supply chain to ensure safety, quality control, and compliance with industry regulations.	Taudes & Tian (2018); Behnke & Janssen (2020); S. Kamble et al (2020)
E16	Verifiability of transactions	The ability to validate and authenticate transactions recorded on the blockchain to prevent illicit activities.	Galal & Youssef (2018); Zhang et al (2018)
E18	Credible and Accurate Data	The availability of credible and accurate data to support decision-making and auditing processes to ensure compliance with data accuracy requirements.	Ølnes et al (2017); Wang et al (2021); Lacity et al (2020)
E20	Common rules on data disclosure	Standardization of protocols and procedures for sharing and disclosing data within the supply chain ecosystem for consumer protection and regulatory oversight.	Kouhizadeh et al (2021); Tapscott & Tapscott (2016)
E25	Rules and Governance	Legal and regulatory frameworks for blockchain governance, consensus mechanisms, and decision-making processes within supply chain networks to ensure the integrity, security, and stability of blockchain systems.	Gökalp et al (2022); Wang & Kogan (2018); Iansiti & Lakhani (2017)

As organizations increasingly grapple with the intricacies of regulatory compliance in blockchain adoption, research that provides a deep understanding of the regulatory landscape becomes invaluable. It equips stakeholders with the knowledge needed to proactively navigate legal challenges, fostering an environment where blockchain can be seamlessly integrated into supply chain management while ensuring adherence to established regulations.

Economic Factors

Economic considerations play a pivotal role in the decision-making process for adopting blockchain in supply chain management. The research conducted by Lacity et al. (2020) illuminates the multifaceted economic impact of blockchain adoption and highlights its intricate interconnections with technological and organizational factors. This interplay significantly shapes the overall business case for integrating blockchain solutions into the supply chain.

The compulsion for the inclusion of economic considerations is paramount in the dominion of the decision-making process for the effort of blockchain adoption into the supply chain to become a reality. The justification has been highlighted in a previous study conducted by Lacity et al. (2020) that illuminates the multifaceted economic impact of blockchain adoption and highlights its intricate influence with factors such as technological and organizational. The economic factors are imperative due to their direct and intangible impact on the financial aspects of blockchain adoption in an organization; this extends beyond cost-effectiveness and encompasses the evaluation of return on investment (ROI) and financial viability. Thus, these factors became rather crucial determinants in the process of integral decision-making, guiding resource allocation, budget formulation, and ultimately, constructing a robust business case for the adoption of blockchain technology.

The challenges associated with the blockchain adoption process are undoubtedly an emphasis on economic constraints. Lee et al. (2017) highlighted the importance of strategically identifying and addressing those constraints by ensuring the feasibility and success of blockchain integration.

Understanding the economic landscape, became a nuanced insight on financial implications and constraints that might occur as a result of going through the process of new technology adoption. However, this requires an extensive examination of several components associated with the benefits of technology integration, such as operational expenditure, potential cost preservation, and the long-term economic benefits of an enhanced supply chain. This knowledge development could significantly contribute to a feasible and sustainable solution aligned with current economic realities that acknowledge the technological advantages of blockchain.

Table 3. Economic's enablers

Enablers	Sub-factors	Enabler's Description	References
E5	Return on Investment (ROI) Analysis	Comprehensive ROI analyses to evaluate the financial benefits and returns associated with implementing blockchain technology in the supply chain	Xia et al. (2017)
E6	Financial Resources Allocation Framework	Pertains to the establishment of frameworks for allocating financial resources to support blockchain initiatives in the supply chain.	Iansiti & Lakhani (2017)
E7	Hardware and Software Provision	The provisioning of hardware and software infrastructure required for deploying blockchain solutions in the supply chain.	Tapscott & Tapscott (2016)
E9	Cost Efficiency Design	This involves the design of cost-efficient blockchain solutions capable of optimizing resource utilization and minimising operational costs in the supply chain.	Hileman & Rauchs (2017); Batubara et al (2018)
E15	Network Infrastructure Management	The improvements of quality on all existing, internal, external, networks or even new network creation.	Swan (2015); Kouhizadeh et al (2021); Pawczuk et al (2020)
E19	Cost Transparency and Accountability	Cost transparency and accountability are important for ensuring efficient resource allocation and financial governance.	Tasca et al (2018)
E23	Funding and Investment Strategy	The development of strategic funding and investment in securing the necessary financial resources for blockchain initiatives.	Yli-Huumo et al (2016)

Moreover, this substantiates the feasibility of inaugurating economic factors as it extends beyond the initial adoption phase of new technology, thereby involving assessing the scalability of blockchain solutions, ongoing operational costs, and the potential for long-term returns. Nonetheless, economic considerations vary across industries and contexts, which demand tailored exploration to gain a holistic view (Iansiti & Lakhani, 2017). At last, this factor undoubtedly maximizes the benefits of evolving the intricate landscape of technological advancement through intellectual, and economic navigation by informed strategic development despite the fact mentioned by Zhang et al. (2019) that there are limitations on the operational implications during the process.

METHODOLOGY

The research adopts a quantitative research methodology to explore various facets influencing the adoption of blockchain technology in supply chain management (Liu & Xiao, 2021). The primary data collection method involves using a survey instrument strategically designed to gather organized and measurable responses from a diverse group of experts in the field. Thus, the purposive sampling technique resulted in 25 participants with solid professional backgrounds and expertise. Then, participants are deliberately selected from a heterogeneous pool, including professionals with expertise in supply chain management, information technology, and blockchain technology. This diverse selection ensures a comprehensive analysis of factors facilitating blockchain technology adoption.

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique is employed as the analytical tool. Recognized for its proficiency in revealing complex causal relationships, DEMATEL systematically establishes hierarchies, outlines interdependencies, and visually depicts causal connections between variables. Its flexibility and effectiveness make it apt for analyzing intricate decision-making processes in this research setting (Chang & Chen, 2015).

Stringent measures are implemented to enhance the accuracy and consistency of collected data, as highlighted by Bryman (2016). The survey questionnaire undergoes careful crafting to ensure face validity, and a pre-test on a subset of participants helps identify and resolve potential concerns, ensuring clarity and precision. The inclusion of expert judgments from a panel with extensive knowledge in supply chain management and blockchain technology further reinforces the data's veracity. The DEMATEL technique ensures data reliability by giving equal weight to expert viewpoints and minimizing bias.

DEMATEL Design

As this research delves deeper into the analysis of blockchain adoption in supply chain management, the utilization of DEMATEL proves indispensable. This section introduces the DEMATEL design employed in this study, shedding light on its significance in dissecting the nuanced connections between crucial factors. The complexity of the adoption process for blockchain technology in supply chain management necessitates a method that can not only discern the individual impact of technological factors but also illuminate the interconnected dynamics of diverse enablers shaping decision-making:

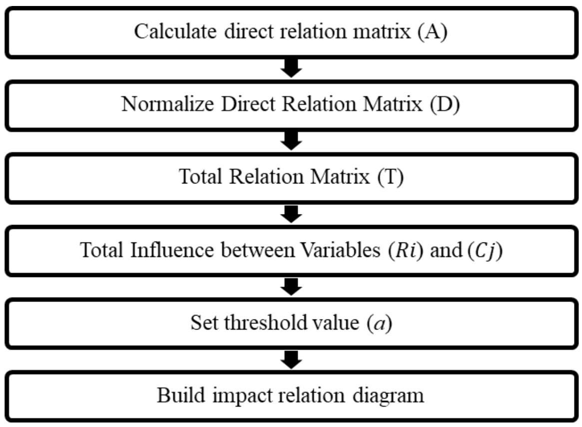

Figure 1. DEMATEL design flowchart

In the first step shown in Figure 1, the direct relation matrix (A) is constructed based on expert assessments or survey responses. This matrix represents the direct relationships between pairs of variables, indicating how one variable directly influences another. The elements of the matrix (a_ij) denote the direct relationships.

$$A = \frac{1}{k}\sum_{k-1}^{k} Ak \qquad (1)$$

The direct relation matrix (A) is then normalized to create the normalized direct relation matrix (D). Normalization ensures that the values in the matrix fall within a standardized range, typically between 0 and 1. This step is crucial for maintaining consistency in the subsequent calculations.

$$S = \max_{1\leq j\leq n} \sum_{j=1}^{n} zij \quad , \quad B = \frac{1}{s}A \qquad (2)$$

The total relation matrix (T) is calculated by summing the normalized direct relation matrix (D) columns. Each column in the total relation matrix represents the total influence of a variable, considering both direct and indirect influences from other variables.

$$T = B + B^2 + B^3 + B^4 \ldots = B(1-B)^{-1} \qquad (3)$$

The total influence between variables is calculated for both rows (Ri) and columns (Cj) of the total relation matrix (T). These calculations involve summing the elements in each row and column, respectively. These totals represent the overall influence each variable has on the others (Sumrit & Anuntavoranich, 2013).

$$R_i = \sum_{j-1}^{n} t_{ij};\ i,j \in [1,n] \quad , \quad C_j = \sum_{i=1}^{n} t_{ij};\ i,j \in [1,n] \qquad (4)$$

A threshold value (a) is set to filter out weaker influences and focus on significant relationships. This allows the elimination of minor elements effects present in matrix T (Yang et al., 2008). Variables with total influences below the threshold are considered negligible and are often excluded from further analysis.

$$S = \max_{1 \leq j \leq n} \sum_{j=1}^{n} zij \tag{5}$$

Finally, the impact relation diagram is constructed based on the thresholded total relation matrix. This diagram visually represents the significant relationships and influences among variables, which allows the envisioning of complex interrelationships (Shieh et al., 2010; Yang et al., 2008). The impact relation diagram helps interpret the findings, providing a clear visualization of the influential factors and their interconnections.

FINDINGS

The data was collected from participants around Malaysia from four major geographical locations. The highest is 48%, from Kuala Lumpur, followed by Selangor, Penang, and Kedah. The majority of the participants were male, which comprised a total of 60% of the 25 respondents. However, the most important part of the findings is the participant's competency level, job position, and industry affiliation. The reason is that the more insight that could be acquired from specific experts on the topics discussed in this study, the better the outcome of the analysed data and the drawn conclusion. Detailed information on competency level is presented in Table 4:

Table 4. Respondent's competency level

Competency Level	Number of Respondents	Percentage (%)
Novice	4	16%
Intermediate	10	40%
Advanced	11	44%

Then, the majority of respondents hold a higher position in their respective careers, which contributes significantly towards their specialization and expertise in their domain alongside the possession of authority and responsibility at the decision-making level in the organization. In general, the highest number of respondents is observed at 40%, with the position of supply chain managers, and the lowest figure is for the categorization of blockchain developers, with only a mere 8%. The rest of the data is observable in Table 5:

Table 5. Respondent's employment level

Employment Level	Number of Respondents	Percentage (%)
Supply Chain Manager	10	40%
Blockchain Developer/Expert	2	8%
Logistics Disposition Manager	8	32%
IT Specialist	5	20%

Furthermore, Table 6 shows data on the nature of the industry with which the participants are associated. The data provides significant insights from diverse backgrounds and industry perspectives on this study's topic, which adds value to the study's objectives and questions. It would allow further analysis by evaluating how this data influences key factors in this study. There are five different industries, with the highest figure coming from the semiconductor sector at 32%, followed by logistics and transportation at 24%. It could be concluded that most respondents came from a strong background in supply chain management and operations.

Table 6. Respondent's industry affiliation

Industry Affiliation	Number of Respondents	Percentage (%)
Semiconductor	8	32%
Logistics/Transportation	6	24%
Oil & Gas	4	16%
Financial Services	3	12%
IT Services	4	16%

In summary, the flow of DEMATEL involves constructing the direct relation matrix, normalizing it, calculating the total relation matrix, determining the total influence between variables, setting a threshold value, and building an impact relation diagram. This systematic process allows researchers to uncover and visualize the intricate relationships within a complex dataset, facilitating a deeper understanding of the factors at play.

Total Influence between variables (Ri) and (Cj)

The computation done for the total influence resulted in two sections of net effect: the cause and the effect, which are also (Ri) and (Cj). This is achievable through the summation of elements within the corresponding column (Cj) of the matrix (T), which indicates the influence of variables (j) originating from other sources.

Table 7. Factor's enablers of net effect (cause)

Rank	Factor's Enablers	Cause
1	E22 - Open to changes and adaptation (Organizational)	1.895
2	E15 - Network Infrastructure Management (Economics)	0.766
3	E21 - Common Objectives (Organizational)	0.647
4	E20 - Common Rules on Data Disclosure (Regulatory)	0.524
5	E7 - Hardware and Software Provision (Economics)	0.508
6	E23 - Funding and Investment Strategy (Economics)	0.454
7	E14 – Traceability (Regulatory)	0.427
8	E19 - Cost Transparency and Accountability (Economics)	0.386
9	E18 - Credible and Accurate Data (Regulatory)	0.366
10	E8 - Security (Technological)	0.347
11	E13 - Authority (Organizational)	0.342
12	E10 – Scalability (Technological)	0.282
13	E5 - Return on Investment (ROI) Analysis (Economics)	0.169
14	E6 - Financial Resources Allocation Framework (Economics)	0.142
15	E9 – Cost Efficiency Design (Economics)	0.117
16	E11 - Rules and Standard (Organizational)	0.012

Table 7 showcases the ranking of factors based on the net casual impact towards the adoption of blockchain into supply chain management. The numbers portrayed indicate the significant aspect of both the magnitude and direction of the impact; those of higher values assume the roles of favourable influence.

In detail, organizational aspects encompass cultural significance in change adaptation and mutual objectives. Albeit there are many enablers of factors qualified in the section of the positive figure (net cause), the highest significance is always indicated in the top 5 echelons, which can provide valuable insights into the pivotal role of these enablers. This discernment proves invaluable for decision-makers tasked with implementing blockchain solutions and potential advancement in the industry.

Table 8. Factor's enablers of net effect (receive)

Rank	Factor's Enablers	Effect
1	E2 - Technical Skills (Organizational)	-1.261
2	E12 –Interoperability (Technological)	-1.167
3	E27 – Change Management (Organizational)	-1.021
4	E3 - Education and Training (Organizational)	-0.841
5	E25 - Rules and Governance (Regulatory)	-0.790
6	E17 - Business Process Standardization (Organizational)	-0.653
7	E24 - Integration (Organizational)	-0.524
8	E4 - Quality and Integrity (Organizational)	-0.523
9	E1 - Technical Knowledge (Organizational)	-0.260
10	E26 – Technological Infrastructure (Organizational)	-0.257
11	E16 - Verifiability of transactions (Regulatory)	-0.085

In Table 8, the enablers displayed indicate negative values, which signify the potential challenges and hurdles in the effort of blockchain adoption into supply chain management. The top 5 lowest values in negative figures exhibit the most notable adverse effect. In contrast, the highest figures on the path of positive descending on the hierarchy have a relatively lesser detrimental effect. The data underscores challenges in adoption related to technological factors in interoperability; this signifies the need for attentive and perhaps innovative solutions to conquer these particular hurdles to ensure seamless integration of blockchain technology into existing technology and systems.

Threshold Value (*a*)

In intricate systems, numerous variables and interdependencies often come into play. This study underscores the substantial interconnectedness present. Introducing a threshold proves instrumental in handling this complexity by directing attention to the most influential connections. For this comparison, a threshold value of 0.622 has been employed.

Threshold value (a) purpose is to filter out weaker influences and focus on significant relationships. Variables with total influences below the threshold are considered negligible and will be excluded from further analysis as they hold lesser weight in the decision-making process. As presented in Table 9, the relationships between various factors are expressed in terms of values. These values represent the strength of the causal relationships between pairs of factors through comparative analysis between the relationship values and threshold value.

To ensure the validity of the DEMATEL analysis, Wu et al. (2007) suggested carefully selecting an appropriate threshold value based on the study's specific context and the desired level of sensitivity in identifying causal relationships.

Table 9. Top 15 Highest values of interconnected influence

Rank	Relationships	Values
1	E1 – E7	0.703
2	E2 – E1	0.693
3	E1 – E22	0.690
4	E1 – E6	0.686
5	E1 – E15	0.685
6	E2 – E7	0.685
7	E3 – E7	0.684
8	E1 – E8	0.682
9	E2 – E6	0.681
10	E2 – E15	0.681
11	E6 – E1	0.680
12	E27 – E22	0.680
13	E4 – E1	0.679
14	E4 – E6	0.679
15	E1 – E21	0.678

Impact Relation Diagram

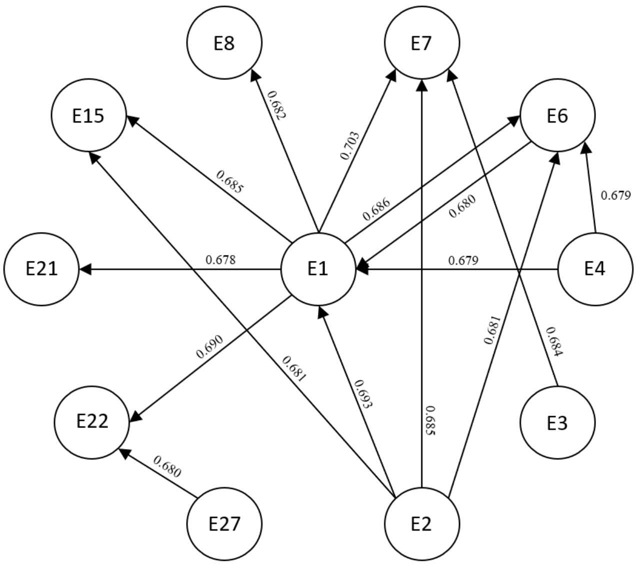

Figure 2. Impact relation diagram with the top 15 highest values

The visual representation from Figure 2 exhibits the interrelationships between factors alongside the values of influence. However, among all these display factors' enablers of relationships between each other, only one particular enabler came from technological factors, which are Security (E8), and the rest are from organizational, economic and regulatory factors.

On top of this, security (E8) is derived from technical knowledge (E1), which is a part of organizational factors. According to the upheld threshold, these interrelationships are ranked in the eighth position in terms of significant impact. As for the top 5 highest value, it highly involved the interrelationships between two factors, which are organizational and economic. This indicates the strong significance of adoption involving the requirements of organizational and economic factors into the consideration and insights of decision-making.

Results Interpretation

The strongest interrelationships highlight technical knowledge (E1) with the highest influence, positively impacting hardware and software provision (E7), the organization's openness to change and adaptation (E22), and the ability to handle financial resources (E6). This suggests that a strong foundation in technical knowledge within the organization is crucial for acquiring necessary resources, fostering adaptability, and managing finances effectively.

Technical skill (E2) closely follows, with a strong influence on technical knowledge (E1) and hardware and software provision (E7). This emphasizes the importance of skill development in tandem with foundational knowledge. Organizational factors, such as openness to change (E22) and common objectives (E21), are positively influenced by technical knowledge (E1). This indicates that a well-informed and technically adept organization will likely embrace change and work toward common objectives. The framework of financial allocation (E6) significantly impacts technical factors (E1, E2) and economic factors such as hardware and software provision (E7) and network infrastructure management (E15). Adequate financial backing is essential for both the technical and economic aspects of blockchain adoption.

Technical knowledge (E1) positively influences security considerations (E8), emphasizing that a robust technical foundation enhances the overall security of the blockchain. Change management (E27) is influenced by the organization's openness to change and adaptation (E22), indicating that effective change management practices align with the organization's willingness to embrace change. Several relationships (e.g., E2 – E1, E1 – E6) show reciprocal influences, highlighting the interconnected nature of enablers. For instance, technical skills (E2) and technical knowledge (E1) mutually reinforce each other, emphasizing the importance of a holistic approach.

In summary, the DEMATEL analysis emphasizes several notable interconnectedness of enablers that underscore the importance of a well-rounded strategy that can be considered by decision-makers to prioritize building technical knowledge and skills, allocating financial resources effectively, and fostering an organizational culture that embraces change. Ultimately, the findings underscore the need for a comprehensive strategy that addresses both technical and non-technical aspects for successful blockchain adoption in supply chain management.

RESULTS AND DISCUSSION

Technical Basis as Priority

This study has discovered a few critical discussions that put a vital stipulation in place for adoption efforts to even take place. Technical foundations might be an absolute necessity encompassing technical knowledge (E1) and technical skills (E2). These factors have a cascading positive repercussion on various aspects of blockchain adoption efforts that include several enablers. However, they consistently underscore the fundamental role of knowledge, skills, education, and resources. It is undeniably vital to have a knowledgeable and skilful workforce to navigate the complexities of blockchain. However, it is arguable that with rapid technological changes, it may be challenging to keep up with the latest advancements while effectively making continuous education and skill development. This demands a holistic understanding, incorporating other insights from different domains for a more transparent and bigger picture to tackle such dynamic challenges.

Complex Interdependencies among Enablers

The study reveals complex interdependencies among key enablers influencing blockchain implementation in supply chain management. Success or challenges are not solely determined by individual factors but by their interplay. Tapscott and Tapscott (2016) pointed out that the acknowledgement of the interconnected nature of blockchain enablers could promote synergy and efficiency by leveraging the enabler's influence. While it is important to better understand interdependencies, Iansiti and Lakhani (2017) found that it poses quite a formidable challenge to navigate the intricate web of complex relationships, which requires careful consideration in the decision-making process to avoid unintended consequences.

Strategic decision-making requires more substantial support from the perspectives of the enabler's interconnected insights. Every relationship portrayed and drawn from DEMATEL analysis unlocked information that could serve as guidance for balanced perspectives in strategic decision-making; realistic views are rather necessary than idealistic views to better understand how decisions should progress. For example, the financial resources allocation framework (E6) is influenced by technical knowledge (E1), which emphasizes the need for strategic resource allocation to eventually guide decision-makers into optimizing resource utilization in the adoption process. Nonetheless, there are risks associated with interconnectedness. The vulnerabilities lie in how an organization is structured in managing the dependencies, and any slight mismanagement would cause failure in the optimization of resources. This study offers comprehensive views of the influencing factors and synergistic benefits that could lead to a well-balanced and successful integration of blockchain in supply chain operations.

Strategic Allocation of Financial Resources

As identified in the study, the financial resources allocation framework (E6) exerts a substantial influence on both technical and economic dimensions, showcasing their crucial role in the effort of fostering successful adoption. Furthermore, financial resources are a necessary investment for organizations to fund into necessary areas to build a robust technological foundation for integration. These findings align with Lacity et al. (2020), emphasising the importance of financial investment into components that serve as the foundational efforts of blockchain integration.

Moreover, financial resources have a strong impact on economic factors, which involves the requirements of effective resource allocation within the network to ensure optimal performances that underline the interconnected nature of financial decisions and economic outcomes in the context of blockchain adoption.

Nevertheless, some hurdles must be addressed in determining the appropriate allocation of financial resources in the context of strategic conditions. It is essential to navigate complexities in budgeting and weigh the potential risks associated with underinvestment or misallocation. Thus, striking a balance between technical requirements and economic considerations becomes a delicate task, requiring careful consideration and strategic planning.

CONCLUSION

This study discovered valuable insights into critical factors and their influence on blockchain technology adoption; the findings contributed to a nuanced understanding of the complex interrelationships involved in the adoption process. The discovery made in this study contributes to further understanding surrounding the complexities of technology adoption in supply chain contexts, and practically, it constitutes detailed insight into interdependencies among enablers for decision-makers to develop comprehensive strategies to approach blockchain adoption.

Regardless, some limitations should be acknowledged within this study despite its valuable insights. The study employed DEMATEL methodology that is capable of pinpointing a snapshot of relationships at a specific point in time, and due to this, the dynamic nature of technology adoption may not be fully captured. Furthermore, other factors that are capable of influencing blockchain adoption are not considered in this study, and the generalizability of findings may limit certain specific industries or organizational contexts.

In consideration of future research, there are potential avenues for exploring the temporal dynamics of enabler relationships that could unlock further understanding of how these factors evolve. Also, considering the contextual variations in different industries may uncover nuanced insights, and addressing specific challenges faced by small and medium enterprises in adopting blockchain technology could potentially lower the barriers to entry even further to integrate, streamline, and optimize supply chain operations.

Researchers suggest that future studies incorporate longitudinal approaches to capture the evolving nature of technology adoption, explore a broader set of enablers, and conduct comparative analyses across diverse industries to improve the generalizability of findings. Additionally, collaborative research initiatives involving industry stakeholders could provide real-world insights and validate the theoretical foundations established in this study.

ACKNOWLEDGEMENT

The authors thank the Ministry of Higher Education (Malaysia) for providing financial support under the Prototype Research Grant Scheme (PRGS) No. PRGS/1/2023/SS06/UMP/02/1 (University Reference RDU230801) and Universiti Malaysia Pahang Al-Sultan Abdullah for computer laboratory facilities.

CONFLICT OF INTEREST

The author(s), as noted, certify that they have NO affiliations with or involvement in any organisation or agency with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, jobs, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, expertise or beliefs) in the subject matter or materials addressed in this manuscript.

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