Optimizing UAE Food Supply Chain Management: Leveraging Fuzzy AHP for Strategic Selection of Optimal Blockchain Platforms

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Abstract: The United Arab Emirates faces significant challenges in food security due to heavy reliance on imported food and vulnerabilities in global supply chains. Blockchain offers decentralized, immutable solutions to improve food supply chain transparency, traceability, and quality assurance. This research focuses on developing a decision-making framework using the Fuzzy Analytical Hierarchy Process to select the optimal blockchain platform tailored to the UAE context. The study reviews blockchain's fundamental components and applications, highlighting its transformative potential in supply chain management. Methodologically, Fuzzy AHP evaluates criteria like technical feasibility, security, regulatory compliance, and cost-effectiveness, prioritizing factors crucial for UAE's food supply chain. Interviews were conducted with 15 experts and stakeholders in the UAE's food supply chain. Results emphasize technical factors such as platform usability, interoperability, and consensus mechanisms as pivotal in platform selection. This study underscores blockchain's potential to enhance transparency, reduce inefficiencies, and build trust in UAE's food supply chain, offering a structured approach for decision-makers to navigate adoption challenges effectively. The theoretical contribution lies in providing a structured approach for decision-makers to navigate the complexities of blockchain adoption in food supply chain management, addressing both technological feasibility and regulatory challenges.

1 INTRODUCTION

The United Arab Emirates (UAE) has a unique challenge in food security, a combination of several factors predisposing the UAE to future food insecurity risks. According to Ammar [1], the UAE imports 80-90% of all the food consumed in the country. Depending on food sourced from the global market poses distinct challenges for the UAE due to the risks of price hikes and disruptions in the global food supply chain. Moreover, the dangers of climate change have increased the risk of harsh weather in the UAE, which diminishes the prospects of producing food in the future; climate change has led to changes in how food is produced and transported to consumers, while advocacy for climate-neutral food production has led to changes in conventional food systems [2].

The blockchain has emerged as an attractive technology for managing food supply chains by encompassing a set of solutions that embrace decentralized systems for immutable data storage and access [3]. According to Bashir [4], blockchain technology is an innovative database system facilitating transparent data sharing among business network members. A blockchain database organizes data into interconnected blocks, forming a sequential chain. Its chronological consistency is because the chain cannot be changed or removed without consensus from the network; by utilizing blockchain technology to create an unchangeable or immutable ledger, orders, payments, accounts, and other transactions can all be tracked. Unauthorized transaction inputs are prevented by built-in system features, ensuring consistency in the shared view of these transactions.

In the food supply chain, blockchain provides 100% traceability of food-related data and multi-party transactions, enables backtracking food provenance in seconds rather than days, makes verifying food safety and quality compliance more manageable, and improves data protection. The basis of the blockchain technology utilized in the food supply chain is a distributed ledger that holds information on every transaction and event that occurs in the chain. Data blocks that are encrypted, timestamped, and connected chronologically make up the ledger. A batch of transactions verified using the pre-defined consensus protocol is stored in each block.

The overarching purpose of this paper is to develop a decision-making framework for blockchain technology evaluation and selection of an optimal blockchain platform tailored to the unique needs of the UAE food supply chain by conducting a comprehensive analysis of the unique requirements, regulatory framework, and technological considerations specific to the UAE.

2 LITERATURE REVIEW

This chapter examines various aspects of blockchain technology and its potential applications, particularly in the food supply chain industry.

2.1 Components of the Blockchain Technology

In terms of technical structure, a blockchain contains a distributed ledger with a series of data blocks linked together by cryptographic algorithms. Each block contains information about all transactions for a particular batch. A block comprises a header and body, as shown in Figure 1 below. The header contains information that connects to other blocks. Moreover, information relating to the verification of transactions, the block's timestamp, and the previous block's hash value are contained in the block header.

On the other hand, the block body carries all transaction information in the blockchain [5]. A blockchain operation is initiated when a node records new information and broadcasts it to the entire network. Consequently, the nodes that receive this information conduct verification processes and store them in a block. If all blocks reach a consensus on the transaction's validity, a new block is added to the blockchain, and all nodes are updated with the information [6]. Transaction information is added to the blockchain when all blocks verify the information is correct. In addition to the consensus mechanism, blockchain technology is enabled by cryptography, which is comprised of a series of hash functions and public keys that ensure the security, authenticity, integrity, and immutability of the data contained in the distributed ledger. Moreover, blockchains are facilitated by smart contracts, which are digital promises that are automatically execute when certain conditions are met, thereby enhancing the efficiency and reliability of blockchain operations [5].

2.2 Applications of Blockchain Technology

Blockchain technology has been applied in various fields due to its unique decentralization, immutability, and security advantages. One of the earliest and most successful applications of blockchain technology was in developing and operating cryptocurrencies, which are forms of digital or virtual currencies that use cryptography to achieve security functions. These currencies are operated decentralized without requiring a central bank's mediating role [6]. The success of blockchain technology has motivated its application in other fields.

In healthcare, blockchain technologies are used to preserve, exchange, and manage health records for efficient decision-making [7]. In the education sector, blockchain technology offers immense benefits and potential applications in performing tasks such as resource sharing, administration and management, facilitating online l earning and testing, college

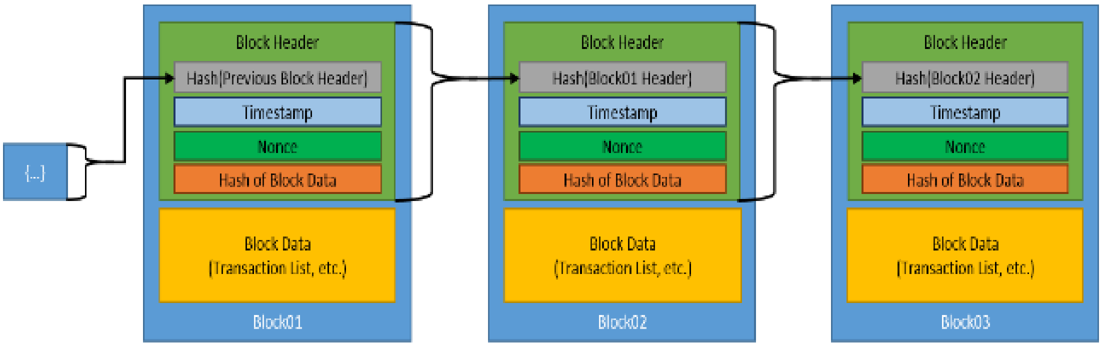

Figure 1: Structure of the blockchain network [5].

crowdfunding, verification and authentication of education records, and data storage and management [8]. In agriculture and food production, blockchain technology may be applied to monitor the origin of food products to build consumer confidence [9]. The technology also offers opportunities for managing food supply chains, management transactions among stakeholders, the transmission of agricultural data, management of agricultural insurance, land registration, and smart farming, among others [9]. Blockchain technology has also been found to be significant in the military and modern warfare. According to Jadav [10], blockchain technology may be adopted in modern warfare to acquire data in critical missions, reconnaissance, and intelligent management of battlefield operations. The immutable nature of blockchain technology allows the military to share susceptible data securely with minimal risk of disclosure to intruders and enemies [10]. The United Arab Emirates has also demonstrated the potential application of blockchain technology in providing government services [11]. Thus, blockchain technology offers immense opportunities for application in diverse fields.

In the UAE, Eletter [12] have reported the utilization of blockchain technology in supply chain management by the retailer Carrefour. Carrefour UAE employed the IBM Food Trust to manage its food traceability by collaborating with food industry players along the value chain. The initiative not only helped to boost trust in the food supply chain but also led to improved efficiency, reduced supply chain risks, and low implementation costs. Eletter [12] demonstrated that the implementation of a full blockchain platform for Carrefour would help the UAE retailer to achieve greater collaboration, enhanced control of food quality, improved transparency, and efficient flow of goods and services. The blockchain platform could also help in real-time platform for negotiation and agreements execution, showcasing the practical benefits of blockchain technology in supply chain management.

2.3 Types of Blockchain Platforms

Several types of blockchain platforms exist, which include public, private, and consortium blockchains (Meng et al., 2021). Of these, public blockchains are are open, decentralized networks with participants that do not require a central entity authority to set it up. They differ from private blockchains, which are centralized networks in terms of authority access, requiring operational authorization, whereby prequalified parties are the only ones authorized to operate the networks [13].

In turn, the participants on a public blockchain can be anonymous and invite other members into the network, while those in a private one must be clearly stated, and only internal participants can manage the network. In turn, the advantage of public blockchains over private ones is the increased visibility of transactions because of the accessible data access to all network users. However, private blockchains have the advantage of increased security because the financially essential data is only sharable and visible within the internal system. In addition, private blockchains are faster than public ones because of the single controlled consensus, increasing transaction rates [13]. The consortium blockchain combines a public and private blockchain. Individuals or groups manage the system's accessibility in a consortium-comprising user and scheduling nodes. This arrangement leads to a fast transactional speed and a high transmission operating efficiency. Figure 2 provides an overview of different types of blockchain platforms.

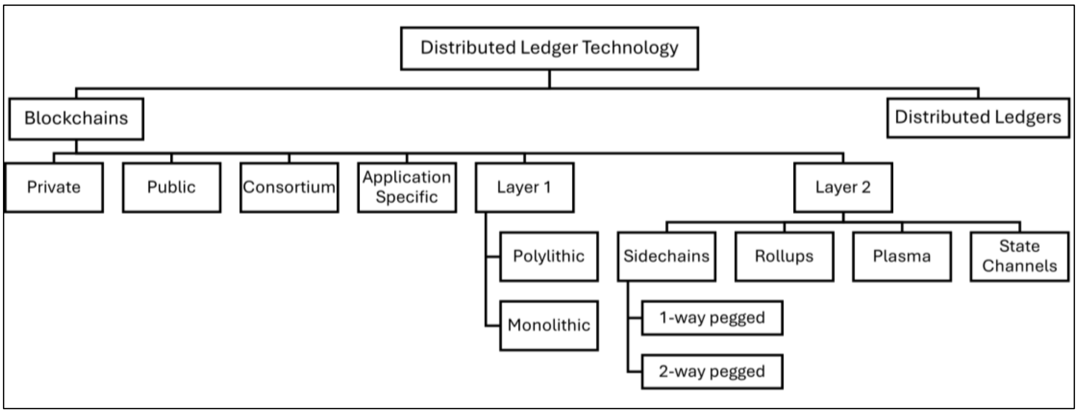

Figure 2: Blockchain platforms types [4].

2.4 Blockchain Technology in the Food Supply Chain

Blockchain technology has been adopted and implemented by several industry players in the food supply chain. In Australia, for instance, a commodity management platform service provider AgriDigital has implemented a blockchain service that verifies and assures agricultural products for consumer benefit [14]. In China, Techrock provides a platform that allows consumers of infant formula to authenticate the product quality and traceability, while the Fiji technology company TraSeable Solutions has developed a blockchain platform for tracing tuna processing (Rodgerson & Parry, 2020). In the United States, Walmart has partnered with IBM to develop a platform incorporating suppliers and distributors to trace the origin of various food products to ensure that they meet quality standards [15]. The fast-moving consumer goods provider Unilever has also implemented a blockchain technology solution that allows the company to manage its tea business. Through the blockchain framework, Unilever monitors all transactions along the supply chain to maintain quality standards [15]. These case studies demonstrate that the UAE could benefit from implementing similar technological solutions.

3 METHODOLOGY

This section outlines the methodology employed for the research, detailing each stage of applying the fuzzy analytical hierarchy process.

3.1 Fuzzy Analytical Hierarchy Process

Multi-criteria decision-making frameworks are useful in decision-making in environments that are characterized by complexities and uncertainties. These frameworks allow the analysis of critical factors based on multiple dimensions. In the present study, a fuzzy analytic hierarchy process (AHP) was used to analyze the evaluation and selection criteria for blockchain platforms in the UAE’s food supply chain industry. The process adopted in this study involved the following key steps:

3.1.1 Identification of the Selection Criteria

The first step in the fuzzy AHP process will be identifying the relevant criteria for evaluating blockchain platforms. This study's criteria identified from the literature include technological factors, platform security, organizational factors, regulatory issues, and developer support. Data was collected from the panel of experts to determine the factors that they deemed important in the case study.

3.1.2 Criteria Weighting

The second step involved assigning weights to the criteria identified in the previous step. The weights were assigned based on the relative importance that the experts assigned to each criterion. The experts were assigned to make pairwise evaluations of the factors and their impacts on each other. Consequently, the criteria were ranked hierarchically based on their assigned weights.

3.1.3 Calculating the Fuzzy Weights

The third step involved computing the relative significance of the weights of the criterion established in the previous steps. During this phase, experts were asked to assign scores to the criteria using linguistic terms, as shown in the Table 1.

Table 1: Comparative scale used to assess the importance of criteria and their corresponding fuzzy numbers.

Linguistic terms	Fuzzy scale
Equally important (EI)	[1.00, 1.00, 1.00]
Weakly important (WI)	[2.00, 3.00, 4.00]
Fairly important (FI)	[4.00, 5.00, 6.00]
Strongly important (SI)	[6.00, 7.00, 8.00]
Absolutely important (AI)	[9.00, 9.00, 9.00]

3.1.4 Normalizing the Scores

Next, the scores of criterion performance were normalized through mathematical transformation. This involved replacing linguistic scales with corresponding numerical values, ensuring data consistency, and establishing a common scale for subsequent analysis. The final list of categories and sub-categories used in this evaluation is presented in Table 2

3.1.5 Aggregating the Normalized Scores

In the fifth step, the normalized scores were normalized by multiplying the scores with the corresponding weights. This process culminated in deriving aggregate scores that were used to compare the criterion from the most to least important. For a criterion j whose fuzzy performance score is $\tilde{a}_{ij}$ and its weight is $\tilde{\omega}_i$, the fuzzy weight $\tilde{u}_i$ is obtained using the following equation:

$$\tilde{u}_i = \sum_{j-1}^{n} \tilde{\omega}_i \tilde{a}_{ij} .$$

Table 2: Final list of categories and sub-categories of blockchain evaluation criteria.

Category	Sub-category	Sub-category code
Technical factors (C1)	Interoperability	C11
	Scalability	C12
	Usability	C13
	Consensus mechanism	C14
	Network performance	C15
Cost (C2)	Initial cost of equipment	C21
	Transaction fees	C22
	Maintenance costs	C23
	Personnel costs	C24
Security factors (C3)	Data security concerns	C31
	User Privacy	C32
	Cybersecurity	C33
Legal and regulatory issues (C4)	Local regulatory framework	C41
	International regulatory framework	C42
	Jurisdictional issues	C43
	Smart contracts	C44
	Antitrust law	C45

3.1.6 Validating the Results

The final step in the fuzzy AHP involves the validation of the results. In this phase, the results of the analysis are validated through comparison with expert opinions. The results were also inspected to ensure their feasibility and consistency with those established in literature.

4 RESULT AND DISCUSION

This chapter discusses the analysis's findings, including the identification of key selection criteria. Interviews were conducted with 15 experts in the UAE's food supply chain.

4.1 Fuzzy AHP Analysis

An initial analysis of the four categories was conducted to determine the hierarchy of the evaluation criteria based on the experts' opinions. As shown in Table 3, technical factors received the most significant weight, with an average score of 0.438. The second-ranked criteria were legal and regulatory issues, with a mean score of 0.205. The third most important selection criterion was the security factors, with an average score of 0.181. Lastly, cost factors were ranked fourth with a score of 0.177. The experts stated that technical factors were the most important in selecting blockchain platforms. A more detailed breakdown of the factors is presented in Tables 4 - Table 7.

Table 3: Main criteria fuzzy evaluation and decision matrix.

	C1	C2	C3	C4	Weight	Rank
C1	(1,1,1)	(3,4,5)	(1,2,3)	(4,5,6)	0.438	1
C2	(0.2, 0.25, 0.33)	(1,1,1)	(0.25, 0.33, 0.5)	(0.33, 0.5,1)	0.177	4
C3	(2,3,4)	(0.25, 0.33, 0.5)	(1,1,1)	(0.33, 0.5,1)	0.181	3
C4	(1,2,3)	(0.33, 0.5,1)	(1,2,3)	(1,1,1)	0.205	2

Table 4: Pairwise comparison and decision matrix for the technological factors sub-criterion.

	C11	C12	C13	C14	C15	W	R
C11	(1,1,1)	(2,3,4)	(0.25, 0.33, 0.5)	(0.33, 0.5, 1)	(1,2,3)	0.268 904	2
C12	(0.25, 0.33, 0.5)	(1,1,1)	(0.25, 0.5,1)	(1,2,3)	(0.2, 0.25, 0.33)	0.162 166	5
C13	(2,3,4)	(0.25, 0.33, 0.5)	(1,1,1)	(0.5, 1,2)	(2,3,4)	0.328 961	1
C14	(1,2,3)	(0.33, 0.5,1)	(1,2,3)	(1,1,1)	(0.33, 0.5,1)	0.239 969	4
C15	(0.33, 0.5,1)	(0.2, 0.25, 0.33)	(3,4,5)	(0.33, 0.5, 1)	(1,1,1)	0.25	3

Table 5: Pairwise comparison and decision matrix for the cost factors sub-criterion.

	C21	C22	C23	C24	W	R
C21	(1,1,1)	(0.33, 0.5,1)	(0.2, 0.25, 0.33)	(0.33, 0.5,1)	0.164967	3
C22	(1,2,3)	(1,1,1)	(0.33, 0.5,1)	(0.2, 0.25, 0.33)	0.257428	2
C23	(0.12, 0.2, 0.25)	(0.2, 0.25, 0.33)	(1,1,1)	(0.33, 0.5,1)	0.137916	4
C24	(0.25, 0.5,1)	(0.33, 0.5,1)	(1,2,3)	(1,1,1)	0.43969	1

Table 6: Pairwise comparison and decision matrix for the security factors sub-criterion.

	C31	C32	C33	W	R
C31	(1,1,1)	(0.25,0.33,0.5)	(0.2,0.25,0.33)	0.109558	3
C32	(2,3,4)	(1,1,1)	(1,2,3)	0.405771	2
C33	(4,5,6)	(0.5,1,2)	(1,1,1)	0.484671	1

Table 7: Pairwise comparison and decision matrix for the regulatory issues sub-criterion.

	C41	C42	C43	C44	C45	W	R
C41	(1,1,1)	(2,3,4)	(0.25, 0.33, 0.5)	(0.33, 0.5,1)	(0.33, 0.5,1)	0.241489	3
C42	(2,3,4)	(1,1,1)	(0.2, 0.25, 0.33)	(1,2,3)	(0.2, 0.25, 0.33)	0.28217	2
C43	(1,2,3)	(0.25, 0.33, 0.5)	(1,1,1)	(0.5,1,2)	(1,2,3)	0.282458	1
C44	(0.2, 0.25, 0.33)	(0.33, 0.5,1)	(1,2,3)	(1,1,1)	(0.33, 0.5,1)	0.193883	4
C45	(0.33, 0.5,1)	(0.2, 0.25, 0.33)	(1,2,3)	(0.25, 0.33, 0.5)	(1,1,1)	0.183064	5

4.2 Ranking of Evaluation Criteria

The final weights criteria were normalized using the scores W = (0.438, 0.177, 0.181, 0.205). As a result, a final weight ranking was obtained for all the 17 sub-criteria. Technical/technological factors emerged as the most critical evaluation criteria for adopting blockchain technology in the UAE's food supply chain industry, as it had the first four top-ranked sub-criteria. Platform usability emerged as the top-ranked factor for blockchain evaluation with a weighted score of 0.125, as shown in Table 8 below. The second and third most relevant factors were interoperability and network performance, and the fourth most important sub-criteria is consensus mechanism. Overall, technical factors occupied the first four positions in the evaluation criteria. The fifth and sixth-ranked positions were the security factors of cybersecurity and user privacy respectively. Furthermore, to round up the top ten positions were personal costs, transaction, scalability, and jurisdictional issues. The Table 8 below shows the ranking of all the 17 criteria used to evaluate blockchain platforms in the UAE's food supply chain.

Table 8: Final weight ranking of blockchain selection criteria.

Category	Weight	Sub-criteria	Weight	Finalized weight	Global ranking
Technical factors (C1)	0.438	C11	0.268904	0.102184	2
		C12	0.162166	0.061623	9
		C13	0.328961	0.125005	1
		C14	0.239969	0.091188	4
		C15	0.25	0.095000	3
Cost (C2)	0.177	C21	0.164967	0.044902	13
		C22	0.257428	0.070068	8
		C23	0.137916	0.037539	16
		C24	0.43969	0.070491	7
Security factors (C3)	0.181	C31	0.109558	0.019940	17
		C32	0.405771	0.073850	6
		C33	0.484671	0.088210	5
Legal and regulatory issues (C4)	0.205	C41	0.241489	0.051920	12
		C42	0.28217	0.060667	11
		C43	0.282458	0.060728	10
		C44	0.193883	0.041685	14
		C45	0.183064	0.039359	15

4.3 Discussion

This study has formulated a strategic decision-making framework for evaluating and selecting blockchain platforms in the UAE's food supply chain. The findings show that technical and technological factors are the most essential evaluation criteria. System usability, interoperability, network performance, consensus mechanism, and cybersecurity were identified as the most critical evaluation factors for blockchain adoption in the UAE's food supply chain. These findings are consistent with earlier studies that show that technical issues are key factors in blockchain adoption in the food supply chain. For example, a study by Fernandez-Vazquez [16] revealed that technical factors such as decentralization, security, and system resiliency were the priority factors for blockchain adoption in the supply chain management sector. In India [17], have reported technical factors such as traceability, availability of real-time information, and presence of immutable databases as the most important factors in blockchain adoption. On their part, Okorie [18] have reported technical issues such as consensus mechanisms, processing power, scalability, and data infrastructure as critical barriers to blockchain use in the food supply chain. Therefore, developing an effective framework for blockchain technology in the UAE must start with establishing the relevant technological infrastructure.

Cost factors also emerged as key selection factors for blockchain evaluation in the UAE's food supply chain industry. The major cost drivers were identified as personnel costs and transaction fees. Implementing blockchain technology involves significant investment in technology adoption, knowledge management, and technology deployment [19]. Therefore, availability of funds is a critical determinant of the attractiveness of the technology for individual firms. Investigations by Okorie [18] have revealed that the cost of building a blockchain platform is an important priority factor because of the need for firms to acquire new infrastructure, incur development costs, and maintain the systems' operations. Therefore, funds availability could be an important factor in the platform selection in the UAE.

Legal and regulatory factors were also identified as essential criteria for blockchain selection. However, these factors were ranked behind technological, security, and cost factors. This observation could be because the experts interviewed in this study viewed the platform from a technical and economic perspective. Nevertheless, legal and regulatory issues are important in blockchain technology. Public blockchains, for instance, present confidentiality challenges that may have far-reaching legal consequences [20]. Further, the blockchain platforms operate in a nascent and still-evolving legal and regulatory framework. Therefore, their operational environment is unpredictable as more laws and regulations are enacted in different jurisdictions. According to Katopodi [21], blockchains also present antitrust law challenges, which are yet to be addressed by existing legal frameworks.

5 CONCLUSIONS

In conclusion, this paper explores blockchain technology's potential to transform UAE's food supply chain management, addressing food security challenges exacerbated by global dependencies and climate change. By leveraging the Fuzzy Analytical Hierarchy Process (AHP), the study developed a robust decision-making framework that prioritizes technical feasibility, security, cost-effectiveness, and regulatory compliance in selecting optimal blockchain platforms. Key findings emphasize the critical role of technical factors like platform usability, interoperability, and consensus mechanisms in enhancing supply chain transparency and efficiency. Cost considerations are also pivotal, underscoring the importance of financial viability in blockchain adoption. While legal and regulatory aspects are considered, their lower prioritization reflects the evolving nature of blockchain governance frameworks in food supply contexts. Practical implications include blockchain's potential to mitigate supply chain risks, enhance traceability, and strengthen consumer confidence in food safety and quality. Theoretical contributions extend to advancing blockchain's applicability in complex supply chain environments and offering a structured approach for decision-makers navigating technological adoption. Future research could explore implementation challenges, scalability issues, and validate the framework's applicability across diverse industries and global contexts, promoting resilience and sustainability in food systems worldwide.

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