Blockchain in Healthcare from a Neutrosophic Analysis

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Abstract

According to experts, the blockchain is very suitable for supply chains, as it streamlines processes and reduces their complexity. Both the pharmaceutical and health sectors can take advantage of their potential since, having different intermediaries, processes can become inefficient on many occasions. Blockchain contributes to bringing order and automation. The pharmaceutical sector has been one of the ones that have obtained the most advantages from this technology. Getting a drug out of the box is a long and expensive process that can take a long time between studies and clinical trials and all the regulations. However, if it is possible to gather all the information needed to complete the process of bringing a new drug to light so that it is available immediately and with all the safety guarantees and improve its management, speed up the process. Therefore, blockchain is the most appropriate technology, although the ability to government bodies to recognize the network's benefits is hampered. This study is focused on determining the level of integration of Blockchain technology in the health sector, and the level of acceptance and contradiction in the adoption of the new technology in the community through the application of the neutrosophic Iadov method.

Keywords: Neutrosophy; Blockchain; Healthcare

1. Introduction

When talking about blockchain, it is common for the concepts of bitcoin and cryptocurrencies to come to mind. While it is true that cryptocurrencies use blockchain networks to carry out secure transactions, this technology has applications in many other fields such as smart contracts, voting systems, cloud storage, digital identities, or the health sector [1]. For example, the blockchain network in the health sector has multiple applications and its use is already generating a great impact, increasing the level of reliability and security of the shared information (data on patients or medicines)[2, 3].

The chain of blocks or blockchain is a technology that allows to record transactions or exchange data securely. In a blockchain network, a single, consensual and unalterable record is made and it is distributed

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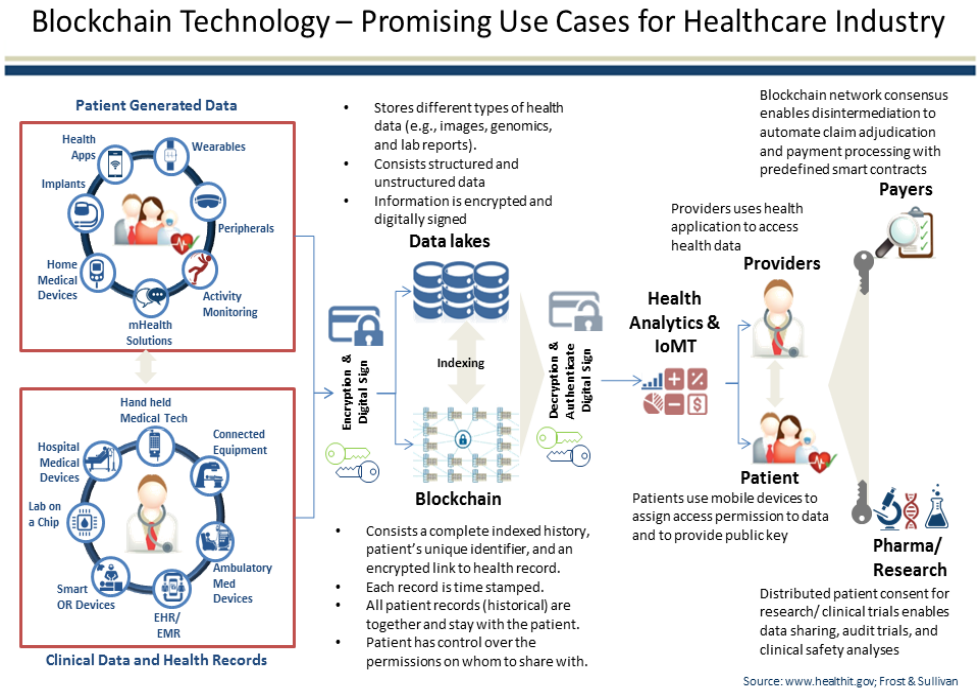
in all the nodes that belong to the network. This way, even if some of the nodes fail, the information about the exchange is always available as it is not centralized [4]. Furthermore, in the blockchain, smart contracts are used to verify if a transaction or block comes from the correct user, without the need for a third party to intervene to carry out such verification (as is the case with money transactions where a bank intervenes for its verification) [5].A blockchain network is made up of many nodes that function as an accounting record where all the operations carried out in it are recorded. Each block in the chain has a specific and unalterable place within it since it contains information from the previous block. The complete chain is stored in each node that belongs to the network so that there are simultaneously a large number of exact copies, guaranteeing that it is always available and that it cannot be altered by third parties [5]. The nodes through which the blocks travel are linked and encrypted to increase the level of protection and privacy of the data.Blockchain technology has applications in different areas, although its main use today is in cryptocurrencies such as bitcoin or Ethereum [1].



Figuer 1: Blockchain technology applications in the health sector. Source: Forbes [6]

If we talk about the health sector, the blockchain network allows us to face the main current challenges, such as counterfeit medicines, medical data segmentation, poor administration and management, and the security of the critical data stored. The main applications that can be made of blockchain in the health sector to generate value are:

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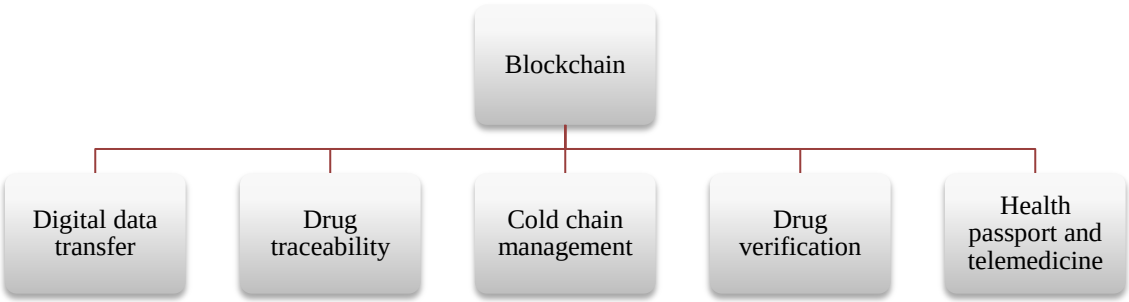

Figure 2: Applications to the health sector in the blockchain network [7].

Digital data transfer

Blockchain networks use very sophisticated encryption that allows data transfer in a completely secure way. This high level of security guarantees the privacy and integrity of the data and perfectly meets the needs of the health sector, where patients' personal information is handled. With the blockchain network, the clinical data of patients and their history can be shared safely, facilitating their access from any device, anywhere, and at any time, without their integrity or privacy being compromised. For the use of eHealth mobile applications and data exchange between medical devices (Internet of Things, IoT), blockchain networks offer the ideal framework to guarantee a secure transfer of information [8].

Drug traceability

One of the main concerns of doctors and pharmacists is in the traceability of medicines, that is, in knowing all the steps that a medicine or drug has followed through the supply chain, from its manufacture to its arrival at the patient [9]. The blockchain network is presented as a fast and secure way to be able to reliably control the traceability of medicines, allowing laboratories, pharmacies, doctors, and health authorities to have access to the route of the medicine accurately and reliably (the medicines will have an immutable timestamp throughout the supply chain) [10].

Cold chain management

Breaking the cold chain has catastrophic consequences in the health sector, where faulty storage can compromise medicines, such as vaccines that require a specific temperature for their conservation [11]. In the case of Pfizer's recent Covid-19 vaccine, its need to be stored at minus 70 degrees before administering is critical for it to have optimal results. Pfizer has been betting since 2017 on the creation of a system with blockchain technology to comply with the security law of the drug supply chain [4].

Drug verification

The pharmaceutical industry can use the blockchain network to store information about drugs and medicines. In this way, they guarantee that these data cannot be altered, avoiding possible falsifications. With the verification of drugs with blockchains, many drugs that are fraudulently introduced will be eliminated from the market as there is no adequate control system that allows these counterfeits. The result is more excellent safety for the health of the patient and an increase in the security for pharmaceutical companies by eliminating the false medicines that cause them losses from the market [12].

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Health passport and telemedicine

Health passports have come to the fore to meet current mobility challenges. In this type of digital documents, there is sensitive information that must be protected so that it cannot fall into the hands of unauthorized persons [13]. Companies such as Samsung have opted for blockchain technology to create health passports and thus be able to promote sectors that are blocked by mobility limitations imposed by health criteria (such as tourism or aviation). The blockchain network allows the secure exchange of information thanks to decentralization, distributing the record of transactions or exchanges in the different nodes that make up the blockchain [14].

The health sector is one of the great beneficiaries of applying this new technology that enhances to a new level the privacy and integrity of the exchanged data. The quality of medical services will be improved thanks to this new ecosystem and business model. The blockchain network allows the decentralization of health information, facilitating its access under safe conditions (efficiency, transparency, and trust) to the different actors that intervene in health processes (doctors, patients, health personnel, pharmaceutical companies, and service providers) [6]. This study aims to determine the level of integration of Blockchain technology in the health sector and the level of acceptance and contradiction in adopting the blockchain in the community.

2. Definitions

To apply the neutrosophic Iadov technique, experts must rely on a linguistic evaluation system that shows the expert's opinion [15]. This system and its neutrosophic and numerical equivalents are shown in Tables 1 and 2 [15] [16].

Table 1: Evaluation system for experts. Linguistic terms are associated with their neutrosophic evaluation and a score value.

Linguistic term	SVNN	Scale
Clearly satisfied	(1,0,0)	3
More satisfied than dissatisfied	(1, 0.35, 0.35)	23
Undefined	I	1.5
More dissatisfied than satisfied	(0.35, 0.35, 1)	1
Clearly dissatisfied	(0; 0; 1)	0
Contradictory	(1,0,1)	2

The term I in neutrosophy is interpreted as a unit of indeterminacy[17]. Another component of the method is the Iadov Logical Table, which assigns numerical values to three closed questions that are applied to the experts. If necessary, open questions can be applied to the surveys [18].

Table 2: Derivation of the Iadov Logic table

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QUESTION 1	Yes			I don't know			No		
QUESTION 2	Yes	I don't know	No	Yes	I don't know	No	Yes	I don't know	No
QUESTION 3									
It is a consolidated research process	1	2	6	2	2	6	6	6	6
It is a partially consolidated research process	2	3	3	2	3	3	6	3	6
It does not matter to me	3	3	3	3	3	3	3	3	3
It is a less established research process than it claims to be	6	3	6	3	4	4	3	4	4
It is an unconsolidated research process	6	6	6	6	4	4	6	4	5
I do not know what to say	2	3	6	3	3	3	6	3	4

To survey the level of satisfaction of the experts, the neutrosophic Iadov technique was used. This technique is based on the use of single value neutrosophic sets (SVNS) associated with linguistic variables or its ability to increase the interpretability in the recommendation models and the use of indeterminacy [19] [20]. The definition of SVNS is as follows:

Let X be a universe of discourse. An SVNS A over X is an object of the form.

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$$A = \{[x, u_a(x), r_a(x), v_a(x)] : \in X\}\, dA = \{[x, u_a(x), r_a(x), v_a(x)] : \in X\} d \quad (1)$$

Where: $u_a(x): X \to [0, 1], r_a(x): X \to [0, 1]\ y\ v_a(x): X \to [0, 1]$

With $0 \leq u_a(X), r_a(X), v_a(X) \leq 3, \forall x \in X$

For convenience, a Single Value Neutrosophic Number (SVNN) will be expressed as $A = (a, b, c), where\ a, b, c \in [0,1]\ and\ satisfies\ 0 \leq a + b + c \leq 3$.

Aggregation operators are used to find a single SVNS set that describes several sets simultaneously. One of these operators is the neutrosophic weighted average (WA), which is defined as follows[18]. Be $\{A_1, A_2, \dots, A_n\} \in SVNS\ (x), where\ A_j = (a_j, b_j, c_j)(j = 1, 2, \dots, n)$, The Neutrosophic Weighted Average Operator (WA) is calculated:

$$WA\ (A_1, A_2, \dots, A_n) = \sum_{i=1}^{n} [w_j, A_i] \quad (2)$$

Where: $WA\ (w_1, w_2, \dots, w_n) = \sum_{i=1}^{n} [w_j, A_i]\ is\ the\ vector\ A_j\ (j = 1,2, \dots, n)\ such\ that\ w_n \in [0,1]\ y\ \sum w_j = 1$

A scoring function is generally used to de-neutrosophicate this set so that a single value is obtained [21]. Let A = (a, b, c), the scoring function S of an SVNS, based on the indeterminate degree of membership and the false membership degree, is defined by the following equation:

S (A) = 2 + abc (3)

For using an SVNS to measure individual satisfaction, this value must be associated with a linguistic variable [15]. Therefore, the scales shown in Table 2 were specified, and the corresponding score was calculated using (3). A process was developed for cases in which the evaluation corresponds to indeterminacy (not defined) (I).

$$\lambda([a_1, a_2]) = \frac{a_1 + a_2}{2} \quad (4)$$

To calculate the Global Satisfaction Index of Respondents (GSI), the aggregation operator WA (2) was used, taking into account the score values and that all respondents have the same weight, therefore:

$$w_i = \frac{1}{n} \quad (5)$$

The instrument designed for the application of the survey was a questionnaire with five questions, of which three are closed (1, 3, and 5) and two are open (2 and 4). The three closed questions were related through the "Iadov logical table", which is presented in Table 3 [19] [22]. The algorithm used for the application of the neutrosophic Iadov technique is then the following:

1. Once the questionnaire has been applied, the corresponding value (from 1 to 6) is found in the Iadov logical table of three entries for the satisfaction classification of the surveyed experts [22].
2. The linguistic variable, the SVNS, and the score according to table 2 correspond to this value.
3. The score value of each respondent is used to calculate the Group Satisfaction Index (GSI) from the aggregation of all scores using the aggregation operator formula WA (2).
4. The GSI is interpreted from the location of the value in the graph of figure 3.

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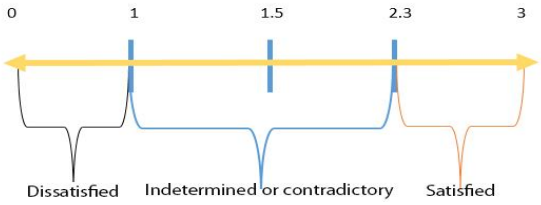

Figure 3: Scale to determine the level of satisfaction according to the scores used

The two open questions allowed to complete the assessment of the students' level of satisfaction with the applied methodology. For the development of the Iadov method, the following questions were applied:

1. Do you think that the integration of blockchain technology will revolutionize health outcomes? (question 1 of the questionnaire)
2. Do you think that blockchain technology should be developed to reach and specify the new guidelines to be achieved in the field of health? (question 4 of the questionnaire)
3. What is your opinion about blockchain technology in the healthcare sector? (question 5 of the questionnaire)
4. How do you think the health field could develop this new technology? (question 2 of the questionnaire)
5. What do you think of blockchain technology and its applications? (question 3 of the questionnaire)

3. Results

For the development and modeling of the neutrosophic method, three groups were established:

Group 1	**Group 2**	**Group number 3**
Private university health experts	Experts from medical research centers	Experts from centers for the development of the healthcare industry

From the application of the survey to the three groups of experts, the results were obtained in terms of the individual satisfaction levels shown in Figure 4.

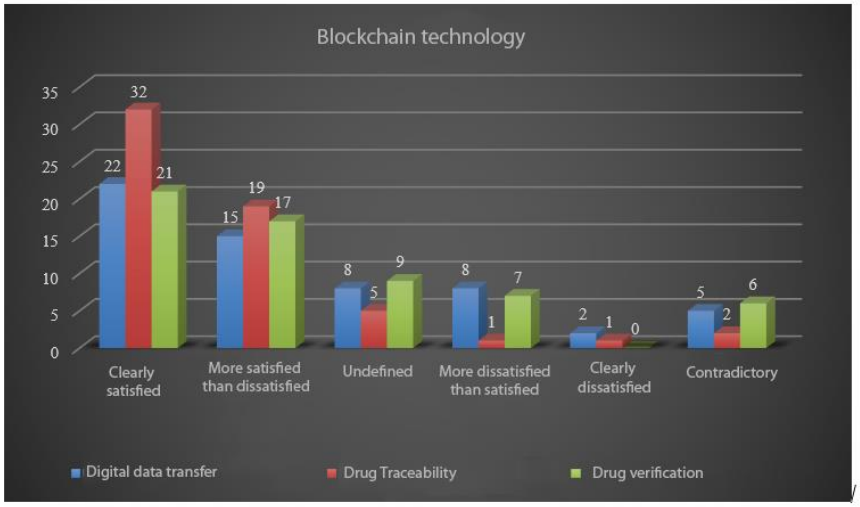

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Figure 4: Individual satisfaction levels by group

Positive satisfaction levels can be seen in the SI sciences, with a predominance of drug traceability in the three groups. However, experts are observed with dissatisfaction, especially in digital data transfer. In digital data transfers and drug verification, indeterminate and contradictory positions were also found, albeit scarce. Some experts are still rejecting the change that blockchain technology leads, as it is considered a decentralized network, and one of the most important issues in context is the privacy of each patient's data.

Table 3: Calculation of the Group Satisfaction Index (GSI) of the Digital Data Transfer group

Linguistic term	**SVNN**	**Punctuation (S)**	**Frequency (F)**	**F * S**	**(F * S) / n**
Clearly satisfied	(1,0,0)	3	22	66	1.10
More satisfied than dissatisfied	(1, 0.35, 0.35)	23	15	34.5	0.58
Undefined	I	1.5	8	12	0.20
More dissatisfied than satisfied	(0.35, 0.35, 1)	1	8	8	0.13
Clearly dissatisfied	(0; 0; 1)	0	2	0	0.00
Contradictory	(1,0,1)	2	5	10	0.17
		Group Satisfaction Index			**2.18**

Linguistic term	**SVNN**	**Punctuation (S)**	**Frequency (F)**	**F * S**	**(F * S) / n**
Clearly satisfied	(1,0,0)	3	32	96	1.60
More satisfied than dissatisfied	(1, 0.35, 0.35)	2.5	19	47.5	0.79
Undefined	I	1.5	5	7.5	0.13
More dissatisfied than satisfied	(0.35, 0.35, 1)	1	1	1	0.02
Clearly dissatisfied	(0; 0; 1)	0	1	0	0.00
Contradictory	(1,0,1)	2	2	4	0.07
		Group Satisfaction Index			**2.6**

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					0

Table 4: Calculation of the Group Satisfaction Index (GSI) of the drug Traceability group

Linguistic term	**SVNN**	**Punctuation (S)**	**Frequency (F)**	**F * S**	**(F * S) / n**
Clearly satisfied	(1,0,0)	3	21	63	1.05
More satisfied than dissatisfied	(1, 0.35, 0.35)	2.5	17	42.5	0.71
Undefined	I	1.5	9	13.5	0.23
More dissatisfied than satisfied	(0.35, 0.35, 1)	1	7	7	0.12
Clearly dissatisfied	(0; 0; 1)	0	0	0	0.00
Contradictory	(1,0,1)	2	6	12	0.20
		Group Satisfaction Index			**2.30**

Table 5: Calculation of the Group Satisfaction Index (GSI) of the Drug Verification group

4. Discussion

Of the three groups, only the GSI of the Drug Traceability group is greater than 2.60, which is why it is considered that the experts agree on the integration of blockchain technology in the health field as a consolidated investigation process of the SI. Considering one of the biggest problems for the health system and the patient, determining the location of the drug at a regional, country, and planet level. For the Groups of Digital Data Transfer and Verification of Medicines, there is a level of indeterminacy or contradiction among experts on the interrelation and integration of blockchain technology in the health sector. Experts say that since it is a young technology, it should be taken into account that several governing bodies would demonstrate a reaction to change.

These results were obtained from the satisfaction of the experts by the *Drug traceability* with the Iadov technique, they were reaffirmed with the experts' answers to the open questions. Among the most frequent opinions stand out the contradictions of the experts on the *Digital data transfer* in the integration the development of health, although the results of projects in the field of health that operate on the blockchain network. Therefore, they can help the reflection of current researchers and serve as a guide for improving their research strategies by providing elements that define the contradictions and indeterminacies of the experts to reach the desired consensus.

It should focus on both experts and health governing bodies that should not have financial limitations to investigate new and interesting technologies. All signs point to a decentralized medical future [23]. *According to a BIS research report, by 2025, the healthcare industry can save up to $ 100 billion per year*

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in costs related to data breaches, IT costs, operational costs, support functions and personnel costs, fraud related to counterfeiting, and insurance fraud if they incorporate blockchain technology [8].

The report also states that:

"The use of blockchain to solve the most widespread problem in health information systems related to interoperability and non-standardization has created data silos in the industry."[8]

The indeterminacy and contradiction among the experts reflect that for the human being to adapt to new things is not always easy, much less when it comes to disruptive technologies, which tend to change the pre-established schemes of how things are supposed to work. That is why even more effort is needed to achieve the acceptance of technologies like these [24].

5. Conclusions

From the results obtained, it is concluded that:

- Blockchain technology has the potential to prevent alterations to health data, while the distributed nature of this technology allows medical teams to have real-time access to vital patient information, thus improving diagnosis and care provided.
- Blockchain still has a long way to go to be implemented in the healthcare world. It is still a relatively new technology that requires very powerful computers, so the current health system will have difficulty adapting to the required speed.
- The neutrosophic IADOV technique allows experts to represent indeterminacy as part of their knowledge and of complementary evaluations based on linguistic terms shown in the questionnaire. The neutrosophic method provides great value for the study of satisfaction - dissatisfaction of experts when evaluating the applications of blockchain technology in the field of health. The use of the neutrosophic IADOV visualizes the levels of indeterminacy in the acceptance of new technology in the health sector since large companies are reluctant to incorporate new technologies in the development of the health industry. Nevertheless, a deeper study of the results of health projects on the blockchain network would allow a broader integration in the health sector and its adoption
- Various sectors are adopting blockchain technology and the way blockchain, it looks like the future of the healthcare industry is decentralized. Blockchain technology is expected to provide the horizontal innovation push this industry desperately needs.

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