Methods of medical data management based on blockchain technologies

Tetiana Hovorushchenko1 · Artem Moskalenko2 · Vitaliy Osyadlyi1

Received: 10 February 2022 / Accepted: 4 May 2022 / Published online: 24 May 2022
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2022

Abstract
The healthcare sector in Ukraine has long been in need of change, and many opportunities of blockchain technology can help it lead the transformation of this sector and ensure compliance with the requirements of the efficiency, safety, novelty, and economic benefits. State-of-the-art on known decisions on the use of blockchain technologies in the information technology for medical data management showed that, despite a large number of different solutions, effective methods and solutions for medical data management based on blockchain technologies are currently lacking. Therefore, improving the efficiency of medical data management by developing methods of medical data management based on blockchain technologies is currently an urgent problem. The paper developed a method for assessing the sufficiency of medical data, which provides: the ability to analyze a variety of medical data for their sufficiency; the ability to quantify the sufficiency of medical data; in case of insufficiency of the medical data, formation of recommendations on supplementing the medical data to be able to upload them to the "Block Data" section of the blockchain block. The paper developed a method of performing transactions on medical data, which consists of the stages of entering information into the blockchain and obtaining information from the blockchain. The developed method of performing transactions on medical data provides the ability to decide on the addition of transactions and medical data from the patient to the blockchain; the ability to decide on the issuance of data from the blockchain on request from a doctor.

Keywords Blockchain technology · Medical data · Blockchain transaction · Sufficiency of medical data

1 Introduction
The introduction of the latest competitive information technologies in all spheres of human activity to automate processes, reduce the share of physical labor, and minimize the impact of the human factor is the main strategic goal of the information society in Ukraine [1–4].

Even before the COVID-19 pandemic, the health and natural sciences sectors had serious problems with interoperability, confidentiality, and traceability of supply chains. Another serious problem is the lack of coordinated interaction between closed electronic medical record systems, which are offered by more than 700 providers.

In the context of the pandemic, health and natural science organizations have faced new challenges, including adapting supply chains to deliver remedies and rapidly developing treatments, tests, and vaccines. They are currently actively implementing consent management and medical data security tools to resume work as soon as possible after the restrictions are lifted.

Today, medical information technology must meet four requirements: efficiency, safety, novelty, and economic benefits [5]. The healthcare sector in Ukraine has long been in need of change, and many opportunities of blockchain tech-
nology can help it lead the transformation of this sector and ensure compliance with these four requirements.

Blockchain is one way of distributed storage. This technology can be used to record and track any type of information: from medical records to elections [6]. The main difference between blockchain and standard databases is decentralization. That is, first, this process is not monitored by any regulator or organization. And second, the information is not focused on servers in one place, but distributed in a huge network of computers around the world [7].

Blockchain is literally interpreted as a chain of blocks. Each of these blocks digitally records one or another piece of information. Any user can view this information, but cannot change it [8]. Each new transaction, regardless of its size, is converted into a new hash cluster. It consists of a unique set of symbols and numbers created by a certain algorithm. The new block always refers to the previous one, thus creating a strict sequence [9]. Each block is associated with the previous and next blocks. Blocks form a chain of data as a resource moves from one place to another or changes owners. The blocks confirm the exact time and order of transactions. In addition, the blocks are inextricably linked to each other, which eliminates the possibility of changing the block or inserting between the other two blocks [10].

Blockchain has already proven its effectiveness in health and natural science, helping to build trust and optimize cooperation. Moreover, this technology will continue to play a leading role in solving even more complex problems [11].

Therefore, improving the efficiency of medical data management by developing methods of medical data management based on blockchain technologies is currently an urgent problem.

2 State-of-the-art

We will conduct state-of-the-art on known decisions on the use of blockchain technologies in the construction of information technology for medical data management.

Usually, medical data are considered only those data, which were obtained by measuring the characteristics of the patient. The number of patient characteristics is considerable (and it does not matter whether it is a sick or healthy person).

Most medical data are characterized by the following features: vagueness; inconsistency of terminology; a large number of qualitative features that subjectively assess the patient’s condition; lack of uniform algorithms for describing the patient’s condition; lack of uniform algorithms for describing diagnostic and therapeutic processes; insufficient level of standardization of medical documentation; the significant variety of medical data.

Medical data, as a rule, are uncertain. Reliability is an important characteristic of healthcare systems. In reliability engineering, such systems are considered complex, inhomogeneous, and uncertain, and require special mathematical representations. The reliability analysis based on uncertain data is represented in [12–14]. New methods to construct a structure function based on initial uncertain data are proposed in [12]. Fuzzy decision trees are used in this method to transform initial uncertain data about a real system into an exact-defined system structure function. Incomplete data are analyzed in [13] using fuzzy decision trees, where input and output attributes are interpreted as component states and values of the structure function, respectively. In the paper [14], a method for structure function construction is proposed based on incomplete and uncertain data in human reliability analysis. The proposed method application is considered for healthcare to evaluate medical error. This method is developed using a fuzzy decision tree, which allows all possible component states to be classified into classes of system performance levels.

Blockchain can transform healthcare enterprises and improve service quality by enabling new ecosystems and new business models to evolve. Healthcare information stored in the blockchain can change the way clinical information is stored, as well as how information is shared in the organization, with healthcare partners, payers, and, most importantly, patients. Blockchain decentralizes medical information, increasing the availability, efficiency, transparency, and credibility of data, but also requires careful planning to maximize the benefits it brings [15].

Separate accounting systems can lead to patient consent and medical histories that are incomplete, inconsistent, or ambiguous. Blockchain records can be used to provide complete longitudinal health records for individuals, giving all patients more control over their own information through confirmed consent. Thanks to the blockchain, each patient record reflects the most well-known medical facts—from genomic data to diagnostic medical imaging—and can be reliably transmitted when needed, without the need for a central administrator [16, 17].

Clinical trial management generates vast amounts of data, requiring healthcare administrators to keep reliable and consistent records for peer review and regulatory compliance. Blockchain tools, combined with electronic data collection, can automatically aggregate, replicate, and distribute clinical data among researchers and practitioners with greater revision, tracking, and control compared to complex and conventional systems [18].

It is difficult to estimate the cost of medical care. Accounting for the real costs of all aspects of health care can be frustrating for both providers and patients. Outcome-based blockchain contracts link clinical outcomes to costs. Service providers from pharmacies to hospitals can offer consumers medical care using a cost model instead of a service fee and reduce the complexity of records [19].

*Springer*
Currently, there is a rapid development of information systems and network technologies of health care facilities, and cyber-physical medical systems. However, the data used in these systems and technologies may be at risk of leakage, falsification, and forgery during their transmission, storage, and exchange [20].

Medical care has become an integral part of people’s lives. There is currently a sharp increase in medical data (such as medical records). Accuracy and completeness of medical data are some of the most important requirements for both patients and physicians. Protecting the confidentiality and secure storage of medical data are crucial issues in the provision of medical services. The safe storage and completeness of personal medical records have long been a concern for mankind. If medical data are stolen, falsified, or deleted, it can delay the progress of treatment and even endanger the patient’s life [21].

Electronic medical records are a convenient tool for storing and analyzing medical data. The exchange of electronic records and cards between different healthcare organizations is of great positive importance for research on disease and epidemic/prevention, improves health care, minimizes emergency response times, and more accurately monitors critical medical events. However, electronic medical records contain a large amount of confidential information, so it is still very difficult to exchange medical information between different medical institutions, although the exchange of data between different medical institutions is already a trend in medicine and health services. The exchange of large amounts of information between different healthcare organizations is difficult in terms of security, privacy, and network load, especially for large-scale healthcare systems. Leakage of data in electronic medical records can lead to a breach of confidentiality of patient data (e.g., health status, diagnosis, etc.) [22–24].

The advent of blockchain technology provides a new idea to solve this problem. As a hash chain with the characteristics of decentralization, verification, and immutability, blockchain technology can be used to securely store personal medical data. Blockchain technology is decentralized, secure, reliable, collaborative, and counterfeit protecting, so it is suitable for protecting and sharing medical data. Blockchain, as a new technology, is widely used to address the efficiency and security of medical data exchange. Blockchain is safe to use, because it encrypts and verifies medical data in the event of a hack or leak. Due to such features, blockchain technology today receives huge benefits for medical data [25].

With the help of the blockchain, users can store important medical data, the authenticity of which can be verified if there is a suspicion of forgery. In addition, cryptographic algorithms can be used to ensure the confidentiality of medical data (for example, an attacker will not be able to read the text if he stole data) [26].

As a rule, most of the data in electronic medical records remain unchanged after their download into the system. Thus, the blockchain can potentially be used to facilitate the exchange of medical data. Various medical organizations and individuals (such as doctors, hospitals, medical laboratories, and insurance companies) can access electronic medical records stored in the blockchain with a higher level of trust. Blockchain solutions offer effective approaches to the reliable management of medical data when confidential patient data are stored and processed. Of course, for the successful implementation of blockchain technology in medical data management, it is important to obtain the consent of physicians and patients. To date, many institutional and industrial institutions have recognized the importance of technology for the health sector, as well as formulated basic ideas, concepts, and key uses [27].

An overview of all existing projects, systems, and technologies for the use of blockchain technology in health care the authors conducted in [28].

In addition, [21] presents the concept of healthcare verification using blockchain and artificial intelligence, as well as a cloud architecture of intelligent agents based on convolutional neural networks to increase medical data, which verifies medical data using artificial intelligence algorithms in multidimensional arrays; after verification, the data are placed in a blockchain block, then in smart contracts and distributed separately using consensus algorithms.

The paper [22] presents the architecture of the system, where the blockchain consortium is presented as an intermediate software with a certain level of trust, and each medical institution acts as a member of the platform.

The following architecture of the system based on the blockchain consists of three levels—the level of data acquisition, the level of data storage, and the level of data exchange [23].

The authors of [24] present a blockchain-based access control architecture for medical data. To ensure that policies and exchange permissions are publicly available in the blockchain, and to save blockchain resources, these two key parameters are stored in the blockchain. Other medical data are still stored on the medical institution’s server, and the medical institution’s server is responsible for access control authentication. After the user submits an access request, the data security management module will analyze the access request, assign roles, analyze tasks, and request access to medical data.

For increasing the efficiency and security of the exchange of electronic medical records between medical information control systems, a single and compatible approach will promote correct data management—for example, the scheme of sharing electronic medical records based on hybrid...
blockchain architecture [25]. All members of the consortium are bound together by a set of rules and pre-defined smart contracts. Only authorized organizations can access sensitive parts of electronic medical records to make a medical diagnosis and make treatment plans.

The DynamiChain network service based on blockchain and big data for the healthcare industry is presented in [26]. The proposed medical blockchain network specialized in processing large health review data, which consists of health tests, blood tests, and functional test data sets. Three organizations—data providers, data users, and a hospital—form a consortium at DynamiChain. Basically, data providers can set their own dynamic consent rules. Hospitals can keep records of medical data transfers and manage the transfer of general health data. Data users can compare health review data hashes and read review data accordingly. All three organizations join the consortium through one channel. Organizations install their own peer device in their data center. Additional participation in the consortium can be established using the configuration block stored in the order service.

The detailed workflow of the SPChain blockchain network is presented in [27]. Every organization (such as patients and healthcare facilities) in SPChain has a blockchain account. The system consists of stages of setting up, registering, downloading, tagging, sharing, and searching.

A study of the use of blockchain technology in healthcare has shown that currently almost all of the described projects are prototypes that are under development. Most of these prototypes are in the alpha testing phase, which does not allow us to see the finished product. However, many projects are open source and open to new entrants.

State-of-the-art on known decisions on the use of blockchain technologies in the construction of information technology for medical data management showed that, despite a large number of different solutions, effective methods and solutions for medical data management based on blockchain technologies are currently lacking. Therefore, it is necessary to develop effective methods of medical data management based on blockchain technologies, which is the purpose of this study.

3 Methods of medical data management based on blockchain technologies

In the process of managing medical data using blockchain technologies, medical data will be located in blocks of the blockchain. Therefore, first, consider the structure of the blockchain block. Given that the header of the blockchain block contains the date and time, version, metadata, digital signatures of the parties, its own encrypted code, the hash of the previous block, we present such a block as follows (Fig. 1).

Given the peculiarities of blockchain construction, the sufficiency of medical data should be assessed before entering them in the "Block Data" section of the blockchain block. Given the papers [3, 4], the main condition for this is to understand what are the mandatory elements to be presented in these data, because the sufficiency of medical data will mean the presence of all necessary information elements.

Given that the data of block D is a set of records: $D = \{d_1, d_2, ..., d_k\}$, and the individual record in the set of medical data is perceived as a system of three elements (type, time, and quality) $d_i = <dtp_i, dtm_i, dq_i>$, then the available set of medical data, which are planned to be entered in the blockchain block, can be represented as a matrix

$$D_{av} = \begin{bmatrix} dtp_{1av} & dtm_{1av} & dq_{1av} \\ dtp_{2av} & dtm_{2av} & dq_{2av} \\ \vdots & \vdots & \vdots \\ dtp_{nav} & dtm_{nav} & dq_{nav} \end{bmatrix}$$  \hspace{1cm} (3)
Fig. 1 Blockchain block structure

where $dtp_i$ is the data type (data type can be dynamic—for example, blood test, or static—genome, fingerprints); $dtm_i$ is the time of data, date when these data were received; $dq_i$ is the data quality, which takes into account the "shelf life" of information or analysis—the higher it is, the more valuable the information; for example, the result of a cholesterol test is valid for six months, and a genetic test—a lifetime; $i = 1..k$; $k$ is the number of records in the set of medical data that are being prepared for entry in the blockchain block. The elements $dtp_i, dtm_i, dq_i$ may be absent if the medical data in the set are insufficient.

Given that all the elements of medical data listed in the matrix are mandatory in terms of adequacy of medical data, the rules for determining the sufficiency of medical data are as follows:

1. if in the $i$th data record of the set $D_{av}$ there is information about the data type (available element $dtp_i$), then: $sdtp = sdtp + 1$ and $b[i, 1] = 1$; otherwise, $b[i, 1] = 0$.
2. if in the $i$th data record of the set $D_{av}$ there is information about the time of the data (available element $dtm_i$), then: $sdtm = sdtm + 1$ and $b[i, 2] = 1$; otherwise, $b[i, 2] = 0$.
3. if in the $i$th data record of the set $D_{av}$ there is information about the quality of the data (available element $dq_i$), then: $sdq = sdq + 1$ and $b[i, 3] = 1$; otherwise, $b[i, 3] = 0$.

Matrix $B$ has the following generalized view (Table 1).

| $B$ | 1 (Data type $dtp$) | 2 (Data time $dtm$) | 3 (Data quality $dq$) |
|-----|-------------------|--------------------|---------------------|
| 1   | 0 (in the absence of such an element in the 1st record) or 1 (in the presence of such an element) | 0 (in the absence of such an element in the 1st record) or 1 (in the presence of such an element) | 0 (in the absence of such an element in the 1st record) or 1 (in the presence of such an element) |
| 2   | 0 or 1            | 0 or 1             | 0 or 1              |
| $i$ | 0 or 1            | 0 or 1             | 0 or 1              |
| $k$ | 0 or 1            | 0 or 1             | 0 or 1              |

Given the peculiarities of the formation of the matrix $B$ (Table 1), the rules for the formation of recommendations for supplementing the set of medical data are as follows:

1. if $b[i, 1] = 0$, the user is recommended to supplement the $i$th data record of the block with information about the data type.
2. if $b[i, 2] = 0$, the user is recommended to supplement the $i$th data record of the block with information about the data time.
3. if $b[i, 3] = 0$, the user is recommended to supplement the $i$th data record of the block with information about data quality.

Then, the method of assessing the sufficiency of medical data consists of the following steps:

1. Analysis of a set of medical data $D_{av}$ before entering them in the section "Data of the block" of the blockchain block using each of the developed rules for determining the sufficiency of medical data and counting the counters $sdtp, sdtm, sdq$.
2. Calculation of quantitative assessment of the sufficiency of medical data by the formula

$$sfmd = \frac{1}{3} \left( \frac{sdtp}{k} + \frac{sdtm}{k} + \frac{sdq}{k} \right). \quad (4)$$
3. If $sdtp = k$ and $sdtm = k$ and $sdq = k$ and $sfmd = 1$, then a decision is made on the sufficiency of medical data in the $D_{av}$ set (because all elements of the medical data set are mandatory in terms of medical data sufficiency and are available in the medical data set, which are being prepared for entry in the blockchain block) and entering the data of the $D_{av}$ set in the section "Block data" of the blockchain block.

4. If $sdtp < k$ or $sdtm < k$ or $sdq < k$ or $sfmd < 1$, then a decision is made on the insufficiency of medical data in the $D_{av}$ set; such a set of medical data needs to be supplemented before entering these data in the "Data of the
block” section of the blockchain block; the user is provided with recommendations for supplementing the set of medical data—according to the rules for the formation of recommendations for supplementing the set of medical data—as a guide on what information should be added to the set of medical data to be uploaded to the blockchain block section; supplement to the set of medical data take place; return to step 1 of the Method takes place.

The developed method of assessing the sufficiency of medical data provides the ability to analyze a set of medical data for their sufficiency; the ability to quantify the sufficiency of medical data in the set, formation of recommendations on supplementing the set of medical data—as a guide, what information should be added to the set of medical data to be able to upload them to the section “Data block” blockchain.

Now, consider the features of transactions in working with medical data.

The medical ecosystem provides four groups of users: users (patients)—patients themselves or authorized third parties (medical centers, for example) who upload medical data to the system; validators—check the quality and authenticity of data uploaded by users; clients (doctors)—study patient data, compile health reports; pharmaceutical and research companies that can access depersonalized user data.

The process of performing transactions on medical data (entering information into the blockchain and obtaining information from the blockchain) is presented in the form of a diagram—Fig. 3.

Then, the method of performing transactions on medical data consists of the following steps:

Stage I—entering information into the blockchain:

1. Uploading data by users (patients) to the cloud environment
2. Anonymization (deletion of patient ID) of data
3. Data encryption by symmetric encryption
4. Sending keys to custodians via direct authenticated communication channels
5. Generation of service transaction (with the public key, data type information, and reference to data in the cloud environment), which informs other participants in the ecosystem about uploading data to the cloud
6. Deciding on the possibility of adding medical data to the blockchain using the consensus algorithm (the block is compared with each instance of the registry; if all instances of the registry match, the transaction is approved)
7. Validation of information by validators
8. Generation of service transaction (with data hashes and validation results)
9. If the data is verified, the information is recorded in the blockchain, and patient information becomes available to other participants, otherwise, the user is denied entry of information to the blockchain

Stage II—obtaining information from the blockchain:

10. If the doctor needs certain data for research or diagnosis, then he generates a request to the validators
11. Adding a validator request to the blockchain
12. Custodian notifications by the validators that cryptographic keys need to be sent to the doctor to decrypt cloud data
13. Obtaining data—if permission is obtained from validators and custodians

Therefore, the method of performing transactions on medical data has been developed, which consists of the stages of entering information into the blockchain and obtaining information from the blockchain. The developed method of performing transactions on medical data provides the ability to decide on the addition of transactions and medical data from the patient to the blockchain; the ability to decide on the issuance of data from the blockchain on request from a doctor.

Based on the analysis of architectures of known medical data management systems based on blockchain technologies, let us develop the architecture of medical data management system based on developed methods of assessing the sufficiency of medical data (medical data sufficiency assessment unit), and performing transactions on medical data (unit of the performing transactions on medical data). The architecture of the medical data management system is presented in Fig. 4.

The presented medical data management system is not now realized; now only its architecture is developed. Further research of the authors will be aimed at the realization and implementation of such a system, as well as the validation and verification of the proposed medical data management system after its realization and implementation, which will be the goal of another study, another paper.

4 Results and discussion

Let us conduct experiments on medical data management based on blockchain technologies using the developed method of assessing the sufficiency of medical data. For the experiment, let us evaluate the sufficiency of the set of medical records of outpatients of family medicine outpatient clinics, which are planned before the entry of the data block of the blockchain block.
Let us analyze this set of data using each of the developed rules to determine the sufficiency of medical data and count the counters $sdtp$, $sdtm$, $sdq$.

The considered set of medical data consists of ten records, and in the first record, there is no element "data time"; in the second record, there are no elements "data type" and "data quality"; in the third record, there are no elements "data time" and "data quality"; in the fourth record, there is no element "data type"; in the fifth record, there are all three elements; in the sixth record, there is no element "data quality"; in the seventh record, there are all three elements; in the eighth record, there are no elements "data type", "time data"; in the ninth record, there are all three elements; and in the tenth record, there is no element "data time", so the matrix B has the following form—Table 2.

Counters $sdtp$, $sdtm$, $sdq$ in this case have the following values: $sdtp = 7$, $sdtm = 6$, $sdq = 7$. Next, let us calculate the quantitative assessment of the sufficiency of medical data, given that the set of medical records of outpatients of family medicine outpatient clinic, which are planned to enter the
data block of the blockchain block, consists of 10 records, i.e., $k = 10$

\[
sfm = \frac{1}{3} \cdot \left( \frac{sdtp}{k} + \frac{sdtm}{k} + \frac{sdq}{k} \right)
\]

\[
= \frac{1}{3} \cdot \left( \frac{7}{10} + \frac{6}{10} + \frac{7}{10} \right) = 0.67.
\]

Since $sdtp < k$ and $sdtm < k$ and $sdq < k$ and $sfmd < 1$, then: a decision is made on the insufficiency of medical data in the set of $D_{av}$ medical records of outpatients of family medicine outpatient clinic. Therefore, the considered set of medical data needs to be supplemented before entering these data in the section "Data of the block" of the blockchain block.

The user is provided with recommendations for supplementing the set of medical data—according to the rules for the formation of recommendations for supplementing the set of medical data—as a guide on what information to add to the $D_{av}$ medical data set to be uploaded to the blockchain block section. For the considered set of data of medical records of outpatients of family medicine outpatient, clinic recommen-
Table 2 Matrix $B$ for the set of data of medical records of outpatients of family medicine outpatient clinics

| 1 (Data type $dtp$) | 2 (Data time $dtm$) | 3 (Data quality $dq$) |
|---------------------|---------------------|------------------------|
| 1                   | 1                   | 0                      |
| 2                   | 0                   | 1                      |
| 3                   | 1                   | 0                      |
| 4                   | 0                   | 1                      |
| 5                   | 1                   | 1                      |
| 6                   | 1                   | 1                      |
| 7                   | 1                   | 1                      |
| 8                   | 0                   | 0                      |
| 9                   | 1                   | 1                      |
| 10                  | 1                   | 0                      |

Table 3 Matrix $B$ for the supplemented set of data of medical records of outpatients of family medicine outpatient clinics

| 1 (Data type $dtp$) | 2 (Data time $dtm$) | 3 (Data quality $dq$) |
|---------------------|---------------------|------------------------|
| 1                   | 1                   | 0                      |
| 2                   | 1                   | 1                      |
| 3                   | 1                   | 0                      |
| 4                   | 1                   | 1                      |
| 5                   | 1                   | 1                      |
| 6                   | 1                   | 1                      |
| 7                   | 1                   | 1                      |
| 8                   | 1                   | 1                      |
| 9                   | 1                   | 1                      |
| 10                  | 1                   | 1                      |

Dations are as follows: to supplement the 1st record with the element "data time", to supplement the 2nd record with elements "data type" and "data quality", to supplement the 3rd record with elements "time data" and "data quality", add the 4th record with the element "data type", add the 6th record with the elements "data type" and "data time", add the 8th record with the elements "data type" and "data time", add the 10th record element "data time".

If the medical institution is still interested in uploading its data to the blockchain unit, it completes the medical data set $D_{av}$, then returns to step 1 of the method of assessing the sufficiency of medical data, i.e., analyzes the updated medical data set. For the experiment, the considered set of medical data was supplemented, after which this set of data were reanalyzed using each of the developed rules for determining the sufficiency of medical data and were counted counters $sdtp$, $sdtm$, $sdq$.

After supplementing the medical data, in the first record, there is no element "data time"; in the second record, there is no element "data quality"; in the third record, there is no element "data quality"; in all other records, there are all three elements, so matrix $B$ has the following form—Table 3.

Counters $sdtp$, $sdtm$, $sdq$ in this case have the following values: $sdtp = 10$, $sdtm = 9$, $sdq = 8$. Next, let us calculate the quantitative assessment of the sufficiency of medical data

$$sfmd = \frac{1}{3} \cdot \left( \frac{sdtp}{k} + \frac{sdtm}{k} + \frac{sdq}{k} \right)$$

$$= \frac{1}{3} \cdot \left( \frac{10}{10} + \frac{9}{10} + \frac{8}{10} \right) = 0.9.$$

Currently $sdtp = k$, but $sdtm < k$ and $sdq < k$ and $sfmd < 1$, so again the decision is made about the insufficiency of medical data in the set of $D_{av}$: medical records of outpatients of family medicine outpatient clinic. Therefore, the considered set of medical data again needs to be supplemented before entering these data in the section "Data of the block" of the blockchain block.

The user is provided with recommendations for supplementing the set of medical data—in accordance with the rules for the formation of recommendations for supplementing the set of medical data $D_{av}$. For the considered revised set of data of medical cards of outpatients of family medicine outpatient clinic, the recommendations are as follows: to supplement the 1st record with the element "data time", to supplement the 2nd record with the element "data time", to supplement the 3rd record with the element "data quality", and to supplement the 4th record with the element "data quality".

The medical institution, having analyzed the obtained conclusions and recommendations, decided to upload a set of data from the medical records of outpatients of the family medicine outpatient clinic to the blockchain without further supplementing.

5 Conclusions

The conducted state-of-the-art on known decisions on the use of blockchain technologies in the construction of information technology for medical data management showed that, despite a large number of different solutions, effective methods and solutions for medical data management based on blockchain technologies are currently lacking. Thus, improving the efficiency of medical data management by developing methods of medical data management based on blockchain technologies is currently an urgent problem.

The paper developed a method for assessing the sufficiency of medical data, which provides: the ability to analyze a variety of medical data for their sufficiency; the ability to quantify the sufficiency of medical data; in case of insufficiency of medical data in the set, formation of recommendations on supplementing the set of medical data—as a guide, what information should be added to the set of med-
The paper also conducted experiments on medical data management based on blockchain technologies using the developed method—experiments on assessing the sufficiency of medical data, which confirmed the viability and veracity of the developed method.

Further research of the authors will be aimed at the realization and implementation of such a system, as well as the validation and verification of the proposed medical data management system after its realization and implementation.

Acknowledgements The authors would like to thank the Armed Forces of Ukraine for providing security to perform this work. This work has become possible only because of the resilience and courage of the Ukrainian Army.

Funding The National Research Foundation of Ukraine funded this research under the project ”Neural network models, methods and tools for high-speed IoT data processing in information systems of the critical information management system after its realization and implementation.

References

1. Cresswell K, Majeed A, Bates D, Sheikh A (2012) Computerised decision support systems for healthcare professionals: an interpretative review. J Innov Health Inform 20(2):115–128. https://doi.org/10.14236/jhi.v2012.32
2. Drozd J, Drozd A, Al-dhabi M (2015) A resource approach to on-line testing of computing circuits. In: Paper presented at the IEEE East-West design & test symposium, Batumi, Georgia, 26–29 September 2015, pp 276–281. https://doi.org/10.1109/EWDTS.2015.7493122
3. Hovorushchenko T (2018) Information technology for assurance of veracity of quality information in the software requirements specification. Adv Intell Syst Comput 689:166–185. https://doi.org/10.1007/978-3-319-70581-1_12
4. Hovorushchenko T, Herts A, Hnatchuk Y (2019) Concept of intelligent decision support system in the legal regulation of the surrogate motherhood. In: CEUR-WS, vol 2488, pp 57–68
5. Collen M, Ball M (2015) Medical informatics: past and future. History of medical informatics in the United States, pp 725–748. https://doi.org/10.1007/978-1-4471-6732-7_18
6. Zheng Z, Xie S, Dai H, Chen X, Wang H (2018) Blockchain challenges and opportunities: a survey. Int J Web Grid Serv 14(4):352–375. https://doi.org/10.1504/IWWS.2018.095647
7. Zeng Y, Zhang Y (2019) Review of research on blockchain application development method. J Phys Conf Ser 1187:052005. https://doi.org/10.1088/1742-6596/1187/5/052005
8. Xu Z, Zou C (2021) What can blockchain do and cannot do? China Econ J 14(1):4–25. https://doi.org/10.1080/17538963.2020.1748968
9. Pal O, Alam B, Thakur V, Singh S (2021) Key management for blockchain technology. ICT Express 7(1):76–80. https://doi.org/10.1016/j.ictex.2019.08.002
10. Li W, He M, Sang H (2021) An overview of blockchain technology: applications, challenges and future trends. In: Paper presented at the IEEE international conference on electronics information and emergency communication, Beijing, China, 18–20 June 2021, pp 31–39. https://doi.org/10.1109/ICEIECS.2019.9463842
11. Kuo T, Rojas H, Ohno-Machado L (2019) Comparison of blockchain platforms: a systematic review and healthcare examples. J Am Med Inform Assoc 26(5):462–478. https://doi.org/10.1093/jamia/ocy185
12. Zaitseva E, Levashenko V (2016) Construction of a reliability structure function based on uncertain data. IEEE Trans Reliab 65(4):1710–1723. https://doi.org/10.1109/TR.2016.2578948
13. Levashenko V, Zaitseva E, Kvassay M, Deserno T (2016) Reliability estimation of healthcare systems using fuzzy decision trees. In: Paper presented at the Federated Conference on Computer Science and Information Systems, Lviv, Ukraine, 23–25 September 2016, pp 331–340. https://doi.org/10.15439/2016F150
14. Zaitseva E, Levashenko V, Rabcan J, Krak E (2020) Application of the structure function in the evaluation of the human factor in healthcare. Symmetry 12(1):93. https://doi.org/10.3390/sym12010093
15. (2018) Transform healthcare outcomes with the simplicity of IBM Blockchain. https://www.ibm.com/downloads/cas/DQPLDP8N
16. Syed T, Alzahrani A, Jan S, Siddiqui M, Nadeem A, Alghamdi T (2019) A comparative analysis of blockchain architecture and its applications: problems and recommendations. IEEE Access 7:176838–176869. https://doi.org/10.1109/ACCESS.2019.2957660
17. Zheng Z, Xie S, Dai H, Chen X, Wang H (2017) An overview of blockchain technology: architecture, consensus, and future trends. In: Paper presented at the IEEE international congress on big data, Honolulu, Hawaii, 25–30 June 2017, pp 557–564. https://doi.org/10.1109/BigDataCongress.2017.85
18. Li X, Jiang P, Chen T, Luo X, Wen Q (2017) A survey on the security of blockchain systems. Future Gener Comput Syst Int J 74:841–853. https://doi.org/10.1016/j.future.2017.08.020
19. Alexander C, Wang L (2019) Cybersecurity, information assurance, and big data based on blockchain. In: Paper presented at the IEEE Southeast conference, Huntsville, USA, 11–14 April 2019
20. Westphal E, Seitz H (2021) Digital and decentralized management and information development method. J Phys Conf Ser 1187:052005. https://doi.org/10.1088/1742-6596/1187/5/052005
21. Kim S, Huh J (2020) Artificial neural network blockchain techniques for healthcare system: focusing on the personal health records. Electronics 9(5):763. https://doi.org/10.3390/electronics9050763
22. Chen Y, Meng L, Zhou H, Xue G (2021) A blockchain-based medical data sharing mechanism with attribute-based access control and privacy protection. Wirel Commun Mobile Comput 2021:6685762. https://doi.org/10.1155/2021/6685762
23. Zhang L, Peng M, Wang W, Su Y, Cui S, Kim S (2021) Secure and efficient data storage and sharing scheme based on double
24. Chen F, Huang J, Wang C, Tang Y, Huang C, Xie D, Wang T, Zhao C (2021) Data access control based on blockchain in medical cyber physical systems. Secur Commun Netw 2021:3395537. https://doi.org/10.1155/2021/3395537

25. Cao Y, Sun Y, Min J (2020) Hybrid blockchain-based privacy-preserving electronic medical records sharing scheme across medical information control system. Meas Control 53(7–8):1286–1299. https://doi.org/10.1177/0020294020926636

26. Kim T, Lee S, Chang D, Koo J, Kim T, Yoon K, Choi I (2021) DynamiChain: development of medical blockchain ecosystem based on dynamic consent system. Appl Sci Basel 11(4):1612. https://doi.org/10.3390/app11041612

27. Zou R, Lv X, Zhao J (2021) SPChain: blockchain-based medical data sharing and privacy-preserving eHealth system. Inf Process Manag 58(4):102604. https://doi.org/10.1016/j.ipm.2021.102604

28. Hovorushchenko T, Hnatchuk Y, Herts A, Moskalenko A, Osyadyi V (2021) Theoretical and applied principles of information technology for supporting medical decision-making taking into account the legal basis. In: CEUR-WS, vol 3038, pp 172–181

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.