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RESEARCH ARTICLE

Investigation of Digital Calibration Certificate - Digital Test Report Sharing in Metrology Network

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ABSTRACT
With the development of technology, digitalization studies have begun in metrology applications, and digital certificates in accordance with the ISO 17025 standard have started to be produced. There is a need for a platform where digital calibration certificates (DCC) / digital test report (DTR) produced today and to be created in the future are shared. In this study, the topics that digital calibration certificates / digital test report must include according to the ISO 17025 standard are explained, and information is given about the Blockchain structure, which is currently widely used in the financial field. The Blockchain platform suggested for use as a digital calibration certificates / digital test report sharing platform for metrological needs is given in this publication. Suggestions on how to run the process for using Blockchain in digital calibration certificates / digital test report sharing are also given in this study.

Keywords: Blockchain, Digital calibration certificate, Digital test report, Local metrology network, Wide metrology network

1. Introduction

Technological changes have become mandatory in the manufacturing equipment, measurement devices and service provider systems in the age of Industry 4.0. The fact that production and measurement devices are constantly communicating and that all communication data is digital has made digital transformation mandatory in all sectors. There are significant changes in measurement devices and output of the measurement devices such as measurement results and measurement report by the Industry 4.0 evolution. Digital transformation is one of the most essential topics that came from technological change in metrology nowadays. In particular, the digitization of metrological outputs and the sharing of these outputs in digital networks are new important research topics.

Many scientists and researchers are studying to adapt measuring devices to the digital world [1-5]. In the digital transformation of measuring devices, studies continue to not only create digital copies of the devices on the computer but also make simulations in the computer environment by providing communication between digital device models and real devices. Along with these studies, real devices are also identified in the digital environment.

Identifying measuring devices in the digital format can be under two steps. The first is the digitalization of the product identification data, and the second is the digitalization of the calibration certificates or test reports.

Product identification data of a measurement device is the data such as manufacturer, brand, model number, and serial number. Nowadays, manufacturers give these with a barcode or data matrix. Digital transformations of measuring devices such as electricity, gas, and water meters that people use daily have begun to be made with legal regulations to protect consumer rights. However, this digital transformation has not been defined as the internationally accepted format of machine-readable Digital Test Report (DTR) has yet to be completed. While measuring devices such as electricity, gas, and water meters directly affect people's quality of life, digital transformations of measurement devices used in production indirectly affect people's quality of life.

Calibration certificates and test reports are important documents that provide information about the measurement device's current status. For these documents to be reliable and acceptable to everyone, the National Metrology Institute (NMI) and Designated Institute (DI) recognized by the Bureau of Weights and Measures (BIPM) or calibration and testing laboratories approved by accreditation authorities should be created. The measurement method, the special conditions in the measurements, the environmental conditions, the person who performed the measurement, and the laboratory information are given together with the measurement results and uncertainties in the certificates and reports currently. The abovementioned information is defined in detail in the ISO/IEC 17025 standard [6]. Project studies continue to transfer calibration certificates and test reports to digital media. These projects aimed to create a machine-readable certificate that can be output when necessary. For this purpose the working group led by Physikalisch-Technische Bundesanstalt (PTB, National Metrology Institute of Germany) created the machine-readable Digital Calibration Certificate (DCC) format. For DCC to become widespread, PTB shares its study outputs via its web page (www.ptb.de/dcc/).

When the digital transformation of the measuring devices used in production is completed, and a digital calibration and test report is created, it will be necessary to share the device definition and current device data in the digital platform. These sharing studies are the newest research topics nowadays. Digital data sharing needs to be considered comprehensively, from doing it in regional networks to doing it in global networks. We can think of regional networks where digital data of measuring devices are shared regionally, such as accreditation authorities of countries, associations of calibration and test laboratories in countries, and country quality infrastructure. When we generalize about the world, we can also call the BIPM network, of which Regional Metrology Organizations (RMO) are members, a global network.

In this study, the non-digital and digital data contents of the measurement devices are given and especially the calibration certificate as process output by measuring devices are detailed, and some predictions for Blockchain are given on how to share digital outputs in regional networks. The features of the Blockchain general structure suitable for sharing digital calibration certificates or digital test reports are stated, and the application of digital device output data into the Blockchain is detailed in this study.

This study proposes a new concept for DCC sharing in Blockchain. DCCs and DTRs must be produced to have application results. DCCs/DTRs are in the production phase, and these digital documents are not shared on platforms such as Blockchain now. Sharing examples on Blockchain will only be possible after DCC DTRs are produced. Therefore, this study only contains a concept proposal and does not include application results.

2. Digital Data Contents of Measurement Devices

The ISO/IEC 17025 standard is a reference document that sets out the rules that must be followed by all institutions and organizations that provide calibration and testing services [6]. In article 7.8 of the ISO/IEC 17025 document, the content of the calibration certificate is clearly defined. The digital data contents of measuring devices are also detailed in the digital calibration certificate portal by PTB [1, 7, 8, 9, 10]. Measurements are usually presented to the customer in a report (for example, a test report (TR), a calibration certificate (CC), or a report of sampling) to be provided accurately, clearly, concisely, and objectively. All drafted reports should contain as a technical record all the information necessary to interpret the results and all required information by the method used. Report detail can be separated into four topics as given below.

- Administrative Data
- Conditions Data
- Result of Measurements Data
- Comments

Test reports or calibration certificate should include at least the information in Table 1 according to the above separation as ISO standard requirements. In Table 1, the ADD data type represents administrative data, the CON data type represents environmental conditions data, the ROM data represents the measurement results, and the COM data type represents special situations that are taken into consideration when making measurements.

After creating the calibration certificate or test report, it is an acceptable of the current device information, and it cannot be changed at any time. If there is a typo or wrong information on the created certificate or report, a new certificate or report is created with a new number. In this new document, the reason for the new document creation can be given, and this new document is acceptable of the current device information.

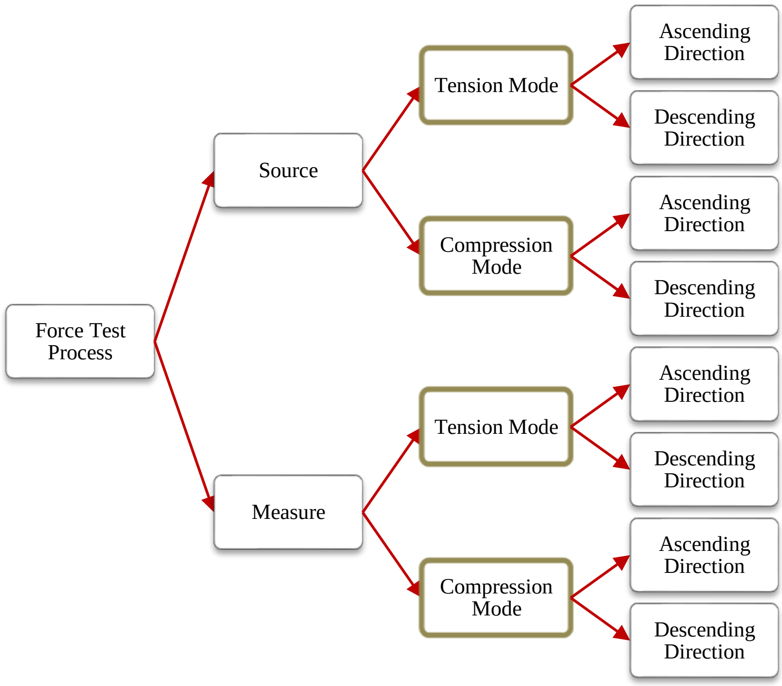
CCs/TRs are human-readable formats that can be converted into forms such as PDFs and shared in digital environments. Documents converted to PDF in human-readable form are large in size and require large memory storage. DCCs/DRTs are machine-readable formats that are smaller in size compared to CCs/TRs and are easier to distribute and share digitally.

Table 1. Digital Certificate Information and Types

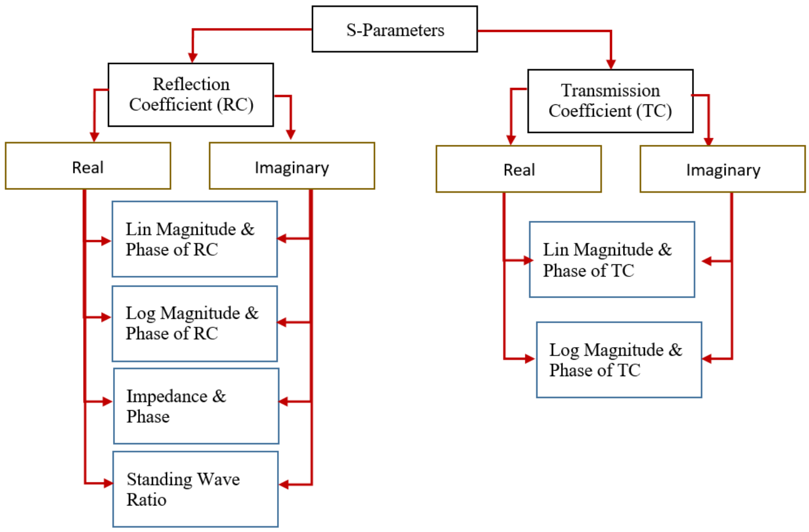
Name in ISO/IEC 17025 Standard	Data Type	Name in ISO/IEC 17025 Standard	Data Type
Document Title	ADD	Date of The Performance	CON
Laboratory's Name and Address	ADD	To Be Used Method	CON
Document Number	ADD	Special Conditions	CON
Location of The Performance	ADD	Environmental Conditions	CON
Identification Of Device Under Test	ADD	Used Software	CON
Persons	ADD	Measuring Equipment Description	CON
External Providers	ADD	The Statement to the Effect That the Results	COM
Measurement Results	ROM	Adjustment or Repairment	COM
Additions To, Deviations	ROM	Statement of Conformity	COM
Measurement Uncertainty	ROM	Opinions and Interpretations	COM

Together with the DCC, it is developing a new method for exchanging measurement data and certificate values between digital systems. The studies for DCC creation aimed at creating machine-readable report with the calibration data contained in the calibration process, instrument specifications, measurement conditions and accreditation scopes. This process is defined as taxonomy. Taxonomy is a basic concept a classification of all kinds of things. Taxonomy in DCC metrology explains the structure of DCC.

A measurement taxonomy database is intended to be a working reference database of measurement categories or type definitions. It will describe the broad parameters of each measurement without specific knowledge of the measurement technique or special equipment used. Taxonomy is necessary because a unit of measure can be an extremely ambiguous value [11, 12]. For example, a 90 ° angle measurement can easily be misinterpreted without knowing the measurement type. Is it a physical angle? Maybe an electric phase? Perhaps the rotation angle of a force transducer? This misunderstanding problem aims to be solved by providing certain information about the data beyond the simple unit of measure with taxonomy. Some taxonomy examples are given in Figure 1. The force measurement in tests are given in Figure 1(a). The applied force is classified in Figure 1(a), according to the force direction and application type such as compression/tension and ascending/descending. S parameter measurement in the calibration process is given in Figure 1(b). The real and imaginary components of vector reflection coefficient and vector transmission coefficients are essential measured quantities for s parameter measurement in RF metrology. All of the other measurement units are derived by real and imaginary component are given in Figure 1(b). Studies on the taxonomy of measurement quantities have been carried out by BIPM and since 2021, the digitalization studies of these taxonomies have started to be published on the BIPM website [13]. Since both the certificates on which the measurement values are printed are digitalized and the measurement quantities are defined digitally, in the following process, it is important to share the certificates and reports that will be produced digitally in digital environments such as Blockchain.



(a)



(b)

Figure 1. (a) The Force Measurement Taxonomy Diagram, (b) The RF Scattering Parameter Measurement Taxonomy Diagram

3. The Blockchain Structures and Data Sharing in the Blockchain

When we look at the history of digital transformation of IT systems, we first encounter electro-mechanical system transformations before the 1960s. Central data storage systems (Mainframe) were developed in the 1960s, and in 1975 and later, personal computers (PC, laptop, handheld computers) took their place in the markets. While Central and Distributed systems were developed in the 1980s, Decentralized systems (web3, p2p, ownership in digital assets, Blockchain-based trust) were developed in 2000 and beyond [14, 15].

The Blockchain systems are a technological innovation that has shown itself in crypto money systems today but has much more usage areas. It is a disruptive yet transformative technology, as it eliminates the need for intermediaries, trusted, and third parties in terms of trust. The Blockchain is a reliable network that stores records of transactions between peers in a secure and tamper-proof way.

The Blockchain technology is built on six fundamental principles. These are; decentralization consensus, a trustable system, immutability, tramper-resistant, transparency, highly accusable, and security [16].

In digital data storage systems, a digital data registry that is not centrally controlled and stored centrally, managed by peer nodes (Peer-to-Peer Nodes), copies of which can be updated by consensus and multiplexed in different locations is called "Distributed Ledger Technology (DLT)". DLT refers to a decentralized technological infrastructure that is not dependent on specific centres, where encrypted and fragmented data can be accessed, verified and updated in multiple areas on the network. The DLT structure is shown in Figure 2 [17]. A distributed ledger technology (DLT) is a technology that facilitates an expanding, historically chronologically ordered list of cryptographically signed, irreversible transaction records shared by all participants in a network. Any participant with the right access rights can track a transaction event belonging to any actor in the network at any point in its history. The technology stores transactions in a decentralized manner. Value exchange transactions are conducted between directly connected peers and verified through consensus using algorithms across the network.

Blockchain is the most well-known and used DLT where transactions are recorded with an immutable cryptographic signature called a hash. A Blockchain is a type of ledger in which value exchange transactions (in the form of cryptocurrencies, tokens, or information) are sequentially grouped into blocks. Each block contains a signature based on the exact content (data string) of that block. The next block also contains this signature, linking all previous blocks back to the first block. In the Blockchain, the transaction orders are kept as blocks, the order and content of the blocks are cryptographically sealed, and consensus algorithms provide trust between the nodes. Blockchain and block structures are shown in Figure 3. Integration (Bridge, Hub, and Sidechain) can provide the connection between the two Blockchain platforms.

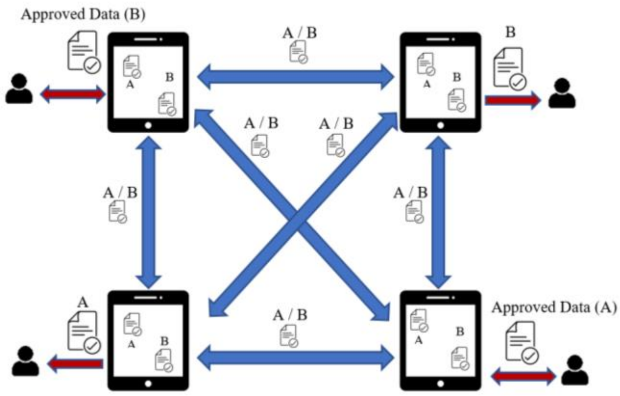


Figure 2. The Data Sharing in a DLT Structures

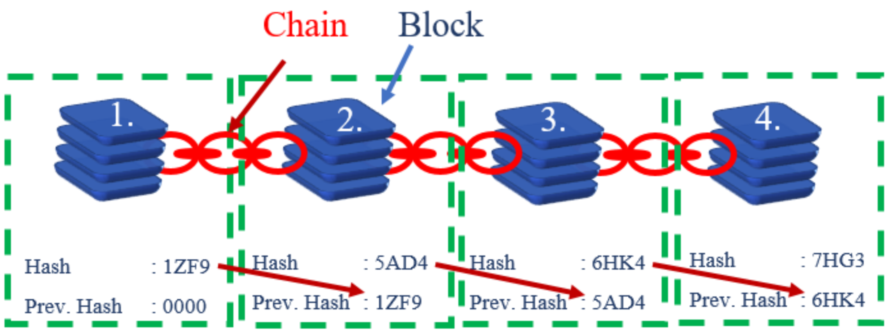


Figure 3. A DLT in Blockchain Structure and a Block Structure

Each block to be added to the Blockchain must be associated with the previous block's hash. More than 50% of Blockchain validators should permit the change of previous block data. Because previous blocks are encrypted and stored, replacing previous blocks takes a lot of time. This characteristic renders Blockchain highly resilient to adversarial attacks. Since the data in the Blockchain is not stored at a single point but is backed up at many points, it is possible to access the backup from the other in case one of the data is lost.

There are many types of Blockchain. The four most widely used Blockchain are listed below [15]:

- Private Blockchain
- Public Blockchain
- Permissioned Blockchain
- Consortium Blockchain

Private Blockchain is more centralized than Public Blockchain and Public Blockchain is more secure. Although it is not the owner of the Permissioned Blockchain, it is necessary to provide an insider invitation or predetermined special conditions to enter the chain. Consortium Blockchain is a Blockchain managed by a particular group or person [18, 19]. In order to obtain permission to upload or change data on the Blockchain, a smart contract must be signed with the Blockchain administration. Thus, unauthorized use is eliminated.

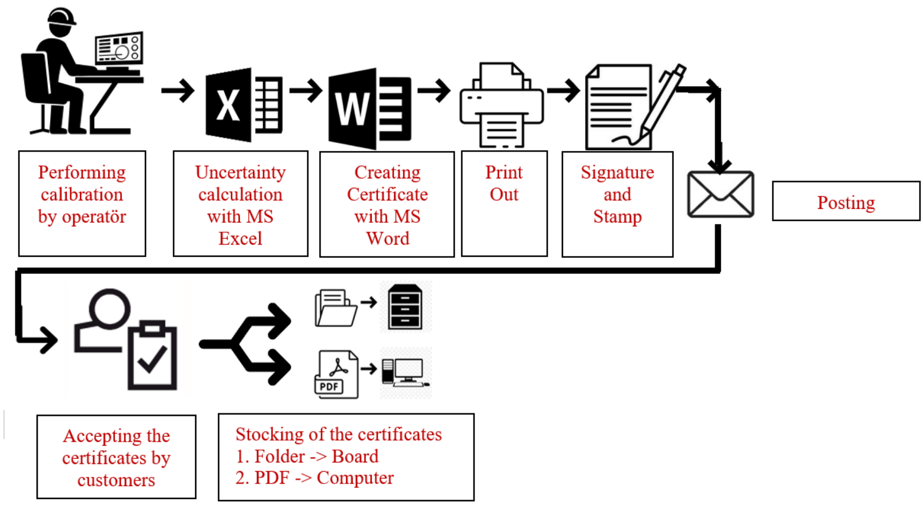
Blockchain applications can be seen to have used in the finance sector, digital identities, decentralized autonomous organization, Metaverse, defence industry, supply/logistics chain management companies, health services and additive manufacturing [12, 20, 21].

As for the general building blocks of the Blockchain, it can be thought that it will be used to store and access reliable DCC/DTR. Blockchain is one of the digital data sharing systems. It is possible that any group or network can create a new digital sharing system for their purpose. The features of the digital data sharing of the Blockchain can be applicable to the DCC/DTR sharing.

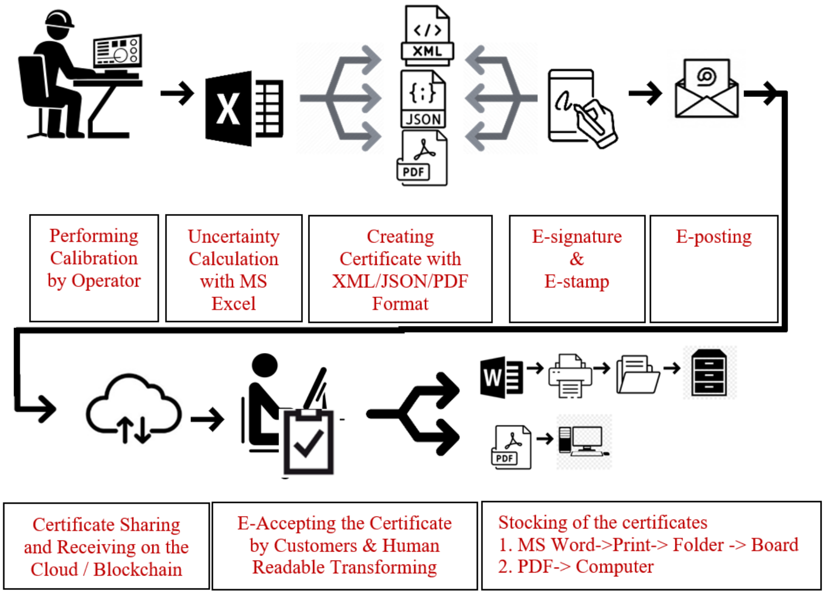
3. Sharing of DCCs/DTRs on Blockchain

The calibration certificate and testing report preparation processes are expressed in Figure 4. Figure 4 contains the currently CC/TR preparation flow and the new DCC/DTR preparation flow. When creating a CC/TR, it is usually an MS Excel application to calculate the uncertainty and MS Word or MS Excel applications are used to create a CC/TR. CC/TR is printed out and signed by an authorized person. Signed CC/TR is transferred to customers by post or hand in. Customers accepts the CC/TR and keep it in the relevant file by the customer (Figure 4.a). The preparation process for CC and TR predominantly relies on paper, leading to an inefficient depletion of global resources. The adoption of DCC and DTR will contribute to environmental sustainability. While DCC/DTR producing, operator usually uses MS Excel applications. Afterward, depending on the density of the data, it is converted into PDF, XML, or Jason formats and approved by Electronic-signature. Electronic-signatures provide non-repudiation, integrity, and authentication at the DCC/DTR application. It is transferred to the cloud data by the laboratory using Blockchain to be transmitted to the customer. The transferred information is received by the customer via Blockchain and transferred to their own systems. Afterward, they are kept in the relevant file by the customer (Figure 4.b).

Blockchain has started to be used in many metrological applications for calibration and testing processes [1, 22, 23]. Accredited calibration and testing laboratories, NMIs, and manufacturer calibration and testing laboratories need to prepare DCC/DTR.



(a)



(b)

Figure 4. (a) Currently calibration certificate creation and sharing process (b) Digital calibration certificate creation and sharing process

DCCs/DTRs must be created as both machine-readable and human-readable. The DCCs/DTRs created are desired to be easily accessible by accreditation bodies, auditors, certificate holders, and certificate producers. The new CC/TR must be created either by the laboratory that created the previous CC/TR or by another laboratory with the same competence. The new CC/TR, which an unauthorized laboratory will create, metrological means breaking the measuring device from the metrological traceability chain. CCs/TRs of measuring devices created in specific periods are considered the history of the measuring device and their accessibility by authorities when necessary, which is defined in the ISO/IEC 17025 standard.

The process from creating the CC/TR to its access must be valid within the DCC/DTR. Therefore, the Blockchain structure is suitable for DCC/DTR to be stored and accessed securely in the digital environment. Blockchain, where information that is important worldwide, such as financial data, is stored securely, is also suitable for storing DCC/DTRs, which are valuable for measurement devices.

Hardcopy CC/TR can be easily copied and modified using high-tech printers and copy systems. Although encrypted DCCs/DTRs will prevent their contents from being altered in any digital medium, they can be decrypted and changed. In the Blockchain, the original digital data is kept on several servers, and if one of its copies is altered, it will not be approved, and the change will not be allowed if it differs from the copies on other servers. Due to the decentralized nature of the Blockchain, DCC/DTR can only be modified or copied by the right people. The DCC/DTR stored on the Blockchain will also be protected against hacker attacks. With the addition of accreditation bodies, accreditation auditors, device owners, and CC/TR generators to the definition of persons or legal entities authorized to access data in the Blockchain, DCCs/DTRs can be easily and securely accessed. It will be possible to securely access DCC/DTR data stored in the Blockchain with e-signature.

Storing DCC/DTRs within the Blockchain network will eliminate the need for both the DCC/DTR creator and those who use or have access to them to use separate storage space. However, for the sustainability (eternity, et al.) of DCC/DTR storage on Blockchain, the Blockchain requires a small fee for storing each DCC/DTR [22]. Customers and DCC/DTR's creators need to be aware of this fee. This fee can be used for the sustainability of the Blockchain system and the new storage area of the DCC/DTR.

Consortium Blockchain is a suitable structure for the sharing of DCC/DTRs.

To implement these predictions, we can summarize the sharing process of DCC/DTR on Blockchain as follows.

- Creation of the certificate as DCC/DTR
- Connecting the certificate creator to the Blockchain with a smart contract
- Uploading DCC/DTR to Blockchain and spreading its copies to DLT
- Making DCC/DTR access influences
- Updating DCC/DTR when revision is required or creating new DCC/DTR when due
- For sustainability, the DCC/DTR creator pays for the Blockchain structure at specific periods.

The sharing of DCC/DTR on the Blockchain platform is shown in Figure 5. Red numbers are used to show the flow of DCC in Figure 6. In this sharing process, a DCC created by one user is sent to the Blockchain network (1). DCC is transferred to the process pool (2). DCC is controlled, and it is added as a new block (3). DCC was added as a new block (4), which is checked by the concessions mechanism and added to the Blockchain (5). Then, DCC is transferred to the Blockchain network for sharing (6). Through this process, a new DCC is approved and shared in the Blockchain network.

A visual depicting DCCs of a measuring device stored in the Blockchain is shown in Figure 6. Since the calibration certificate created in each calibration period is saved by linking to the hash of the previous calibration certificate, it will be easier to access the history of the device and the calibration data at the same time. It will also be possible to analyze data about the evolution of the device over time using DCC blocks.

Blockchain is ready and is currently used as a sharing system around the world. In this study, methods were proposed for the use of Blockchain as DCC/DTR in the field of metrology. However, the main organizations in this sector, such as BIPM, EURAMET, or the country's accreditation bodies, can create a similar data-sharing system specific to their own purposes.

The first studies to establish DCC in Türkiye are continuing at TÜBİTAK UME. Software for DCC production is being developed. The PTB-based XML file output of the software's possible DCC output types is given in Figure 7. Since the finalized XML files have not been created yet, their testing on the Blockchain network has not started.

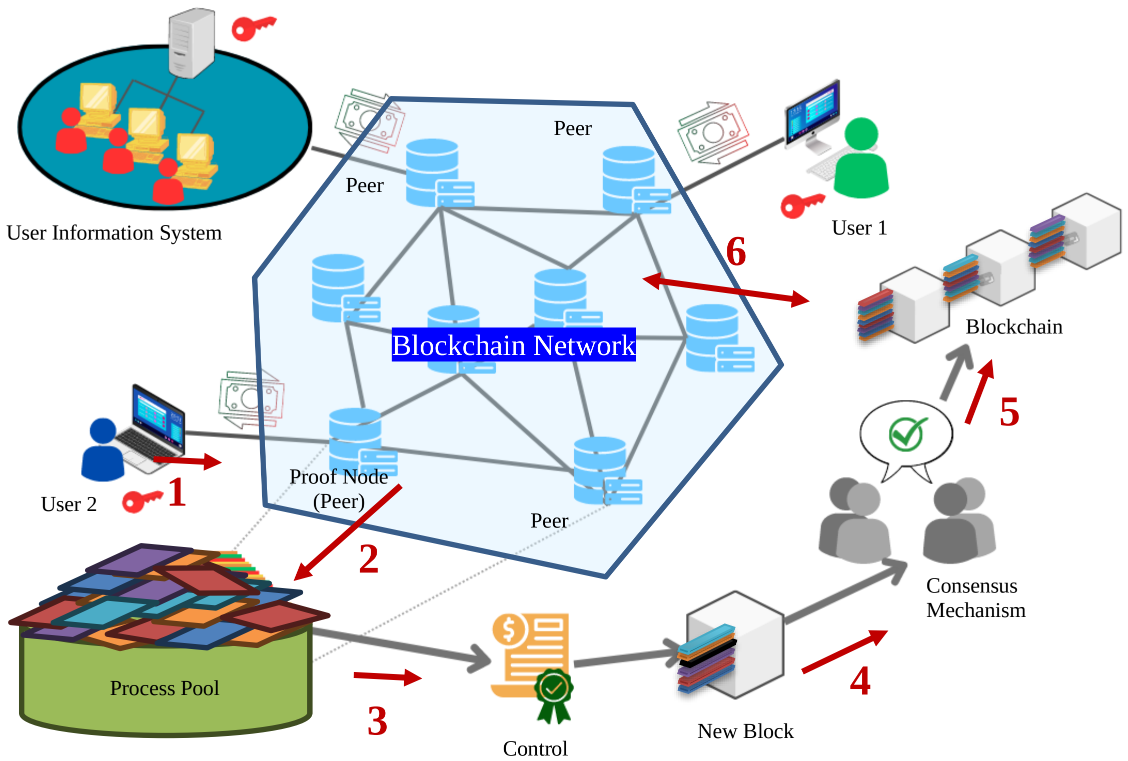


Figure 5. Sharing of DCC/DTR on the Blockchain Platform

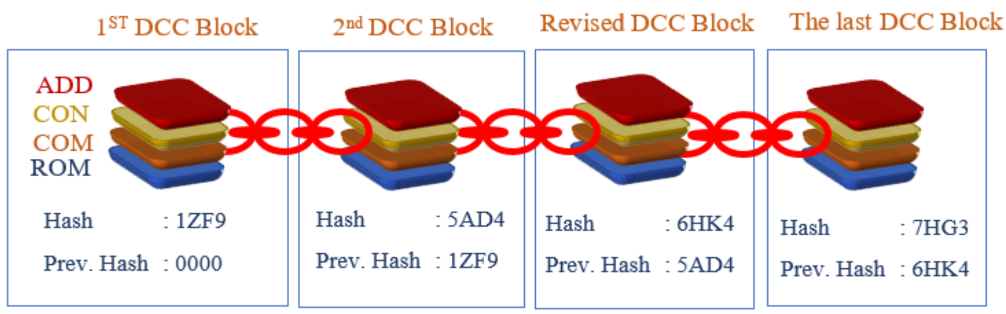


Figure 6. DCCs of a Measurement Device in the Blockchain

```xml
▼<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema"
xmlns:dcc="https://ptb.de/dcc" xmlns:si="https://ptb.de/si"
xmlns:ds="http://www.w3.org/2000/09/xmldsig#" version="3.2.1"
targetNamespace="https://ptb.de/dcc" elementFormDefault="qualified">
  <xs:import namespace="https://ptb.de/si"
  schemaLocation="https://ptb.de/si/v2.1.0/SI_Format.xsd"/>
  <xs:import namespace="http://www.w3.org/2000/09/xmldsig#"
  schemaLocation="https://www.ptb.de/dcc/d-sig/xmldsig-core-schema.xsd"/>
 ▶<xs:annotation>
  ...
  </xs:annotation>
  <xs:element name="digitalCalibrationCertificate"
  type="dcc:digitalCalibrationCertificateType"/>
 ▶<xs:complexType name="digitalCalibrationCertificateType">
  ...
  </xs:complexType>
 ▶<xs:complexType name="administrativeDataType">
  ...
  </xs:complexType>
 ▶<xs:complexType name="softwareListType">
  ...
  </xs:complexType>
 ▶<xs:complexType name="softwareType">
  ...
  </xs:complexType>
 ▶<xs:complexType name="refTypeDefinitionListType">
  ...
  </xs:complexType>
 ▶<xs:complexType name="refTypeDefinitionType">
  ...
  </xs:complexType>
 ▶<xs:complexType name="measuringEquipmentListType">
  ...
  </xs:complexType>
 ▶<xs:complexType name="measuringEquipmentType">
  ...
  </xs:complexType>
 ▶<xs:complexType name="measuringEquipmentQuantityListType">
  ...
  </xs:complexType>
 ▶<xs:complexType name="primitiveQuantityType">
  ...
```

Figure 7. DCC Example in XML Format

5. Discussion and Conclusions

Blockchain, as it is known, has a structure that can be used for DCC/DTR, storage, and sharing purposes. The features of the Blockchain given below can be preferable criteria for why it is useable for sharing the DCC/DTR.

- Digital data on the Blockchain can be changed by only an authorized person
- Digital data on the Blockchain is globally accessible, ensuring transparency and availability.
- Digital data on the Blockchain can be used for the traceability of the validated and confirmed data
- In order to a part of the Blockchain digital data creator, a person / company should sign a contract and accept all the terms and conditions of the Blockchain structure.
- Blockchain's decentralized DLT structure ensures original data remains intact within the network, allowing correction if any digital data is mistakenly altered. .

DCCs/DTRs can be shared locally with storage space on the Blockchain to be created within the country or within an accreditation body. With the Blockchain structure to be created under the umbrella of BIPM or EURAMET, it will be possible to share DCCs/DTRs widely on a global scale within or outside the region. In this way, a worldwide structure will be created and DCCs/DTRs stored with Blockchain will be kept transparent, reliable, and encrypted, and they will be protected against adversarial attacks.

The necessity of charging a small fee per certificate for the sustainability of the Blockchain to be established for the purpose of storing DCC/DTR is also an important issue for customers. It is possible for metrology networks such as BIPM, EURAMET or the country's accreditation bodies to create a special digital data-sharing system for their own purposes. However Blockchain is ready and is currently used as a sharing system in the world. In this study, the necessary structure, requirements, and process steps of DCC/DTR sharing with the Blockchain are discussed in detail. This study has been prepared to guide future studies on sharing DCC/DTRs within the Blockchain structure.

Blockchain is an option to share DCC/DTR, but the other emerging technologies can be another option for the DCC/DTR sharing. When all metrological partners such as NMIs, DIs, calibration laboratories or test laboratories prepare the DCCs/DTRs, an optimum solution will be found in their sharing in the future.

References

[1] S. M. Wilson, "Blockchains and Legal Metrology: applications and possibilities," *OIML Bulletin Volume LXII*, Number 3, July 2021.

[2] H. ElBouanani, C. Barakat, W. Dabbous, T. Turletti, "Passive delay measurement for fidelity monitoring of distributed network emulation," *Computer Communications*, Volume 195, pp. 40-48, 2022. ISSN 0140-3664, https://doi.org/10.1016/j.comcom.2022.07.004.

[3] M. Vlaeyen, H. Haitjema, W. Dewulf, "Digital Twin of an Optical Measurement," *System Sensors* 21, 6638, 2021. https://doi.org/10.3390/s21196638.

[4] O. Baer, C. Giusca, R. Kumme, A. Prato, J. Sander, D. Mirian, F. Hauschild, "Digital Twin concept of a force measuring device based on the finite element method," *ACTA IMEKO*, Volume 12, Number 1, pp 1 – 5, March 2023. ISSN: 2221-870X.

[5] D. Schnürer, F. Hammelmüller, J.H. Holl, W. Kunze, "Offline digital twin synchronization using measurement data and machine learning methods," *Materials Today: Proceedings*, Volume 62, Part 5, pp. 2416-2420, 2022. ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2022.02.566.

[6] ISO/IEC 17025, 2017. General requirements for the competence of testing and calibration laboratories. [Online] https://www.iso.org/standard/66912.html [Accessed: 27-Febraury-2024].

[7] Digital Calibration Certificate, [Online] https://www.ptb.de/dcc/ [Accessed: 27-Febraury-2024].

[8] Physikalisch-Technische Bundesanstalt (PTB). DCC Schema Version 3.1.0, DCC Version 3.1.0. [Online] https://www.ptb.de/dcc/v3.1.0/dcc.xsd [Accessed: 13-April-2022].

[9] Release and Gitlab Repository of DCC Schema/DCC/xsd-dcc, GitLab. [Online] https://gitlab.com/ptb/dcc/xsd-dcc [Accessed: 19-April-2022].

[10] S. Hackel, S. Schönhals, L. Doering, T. Engel, R. Baumfalk, "The Digital Calibration Certificate (DCC) for an End-to-End Digital Quality Infrastructure for Industry 4.0.," *MPDI Sci* 5, 11, 2023. https://doi.org/10.3390/sci5010011.

[11] The BIPM Key Comparison Database, Classification of Services in Electricity and Magnetism. Version No 9 (dated 04 June 2020). [Online] https://www.bipm.org/en/cipm-mra/cipm-mra-documents/service-categories [Accessed: 27-Febraury-2024].

[12] M. S. Nikoo, M.C. Kaya, M.L. Schwartz and H. Oguztuzun, "An MII-Aware SoA Editor for the Industrial Internet of Things," *II Workshop on Metrology for Industry 4.0 and IoT* (MetroInd4.0&IoT), Naples, Italy, pp. 213-218, 2019. doi: 10.1109/METROI4.2019.8792903.

[13] The BIPM, Developing the SI Digital Framework as the anchor of trust for metrology in the digital era [Online] https://www.bipm.org/en/digital-transformation [Accessed 30 July 2024]

[14] Z. Zheng, S. Xie, H.N. Dai, X. Chen, H. Wang, "An overview of Blockchain technology: architecture, consensus, and future Trends," *IEEE 6th International Congress on Big Data*, pp. 557-564, Las Angles, USA, December 2019.

[15] M. Niranjanamurthy, B. N. Nithya, and S. Jagannatha, "Analysis of Blockchain technology: pros, cons and SWOT," *Cluster Comput 22* (Suppl 6), 14743–14757, 2019. https://doi.org/10.1007/s10586-018-2387-5.

[16] B. Lui, "Overview of the Basic Principles of Blockchain," *2021 International Conference on Intelligent Computing, Automation and Applications* (ICAA), Nanjing, China, pp. 588-593, 2021. doi: 10.1109/ICAA53760.2021.00108.

[17] H. Natarajan, S. Krause, H. Gradstein, "Distributed Ledger Technology and Blockchain," *FinTech Note*;No. 1.© World Bank, Washington, DC, USA, 2017. http://hdl.handle.net/10986/29053

[18] B. C. Ghosh, T. Bhartia, S. K. Addya and S. Chakraborty, "Leveraging Public-Private Blockchain Interoperability for Closed Consortium Interfacing," *IEEE INFOCOM 2021 - IEEE Conference on Computer Communications*, Vancouver, BC, Canada, pp. 1-10, 2021. doi: 10.1109/INFOCOM42981.2021.9488683.

[19] N. Elisa, L. Yang, H. Li, F. Chao, and N. Naik, "Consortium blockchain for security and privacy-preserving in e-government systems," *In Proceedings of the 19th International Conference on Electronic Business*, pp. 99- 107, Newcastle upon Tyne, UK, 8-12 December 2019.

[20] D. Özdemir, T. Çobanoğlu, T.F. Cihan, S. Dörterler, R. Uyar, "Eğitimde Blok Zincir Uygulamaları," *14. International Congress of Educational Research,* Çanakkale, Turkiye, pp. 222-233, 27 - 30 October 2021.

[21] A. Ekin, and D. Ünay, "Blockchain applications in healthcare," *26th Signal Processing and Communications Applications Conference (SIU)*, Izmir, Turkey, pp. 1-4, 2018. doi: 10.1109/SIU.2018.8404275.

[22] N. Takegawa, N. Furuichi, "Traceability Management System Using Blockchain Technology and Cost Estimation in the Metrology Field," *MPDI Sensors*, 23, 1673i 2023. https:// doi.org/10.3390/s23031673.

[23] A. Softic, U. N. Zaimovic, and S. Lemes, "Blockchain-based Metrological Traceability," *Proceedings of the 32nd DAAAM International Symposium*, Vienna, Austria, pp. 0522-0526, 2021. B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-33-4, ISSN 1726-9679. doi: 10.2507/32nd.daaam.proceedings.

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