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Proposal for a Blockchain-Based Model for Data Management in Maritime Education and Sector Stakeholder Institutions

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ABSTRACT
Blockchain technology is increasingly proving to be an innovative solution in numerous spheres of the economy, including education, and by extension, institutions involved in Maritime Education and Training (MET). As MET institutions face increasing challenges, such as managing and maintaining large databases, extensive record-keeping, and exchanging and processing information, the application of this technology is emerging as a response to these challenges. In addition to the fact that it would lead to the digitalisation of documents, the application of the technology would, above all, improve the security and reliability of documentation. Owing to its decentralised, transparent and immutable nature, blockchain technology offers a comprehensive framework for overcoming these challenges within MET institutions. The objective of this paper is to propose a model for the application of blockchain technology in MET institutions in order to address the lack of a unified, secure and transparent data system shared by all stakeholders involved in maritime education and training. This paper provides a comprehensive review of the literature on the application of blockchain technology in the maritime industry, highlighting its potential for improving data management and operational efficiency. Furthermore, the paper proposes the implementation of blockchain technology, focusing on the creation of an integrated database that would be used by various users, including MET institutions, state administration (ministries, port authorities), seafarer training centres, maritime agencies, medical institutions and seafarers themselves. Moreover, the paper offers detailed recommendations and guidelines for implementing the hybrid model in MET institutions, with a special emphasis on its role in automating administrative processes through smart contracts, enhancing transparency, and improving overall document security.

KEYWORDS
MET institutions; education and training seafarers; blockchain technology; smart contracts.

1. INTRODUCTION

All participants in the maritime industry chain are connected both by the activities they perform and by the information shared between them. MET institutions are the foundation for the creation of a competent seafarer, but only in conjunction with the maritime industry do they form a complete whole. So, in addition to MET institutions, state administration, line ministries, port authorities, maritime agencies, seafarer training centres, medical institutions, etc., also participate in the process of creating a competent seafarer.

Systematisation of data and information from all participants in an appropriate database, in which all their data would be stored and which they would all use for their own needs, would certainly contribute to the quality of the entire process. In their day-to-day work, all these institutions are connected, but they are lacking, at least in Montenegro, a unique, integrated database.

In recent decades, blockchain technology has found its application in all spheres of the economy, including the maritime industry. There are numerous branches within the maritime industry where scientific research on this topic can be found. On the one hand, the positive impacts of the exchange of information through blockchain technology in the maritime transport sector, as well as the challenges and obstacles to the successful exchange of information, viewed through the three aspects of sustainability (economic, environmental and social) are being discussed [1-2]. On the other hand, the application of blockchain technology can be observed in the promotion of maritime sustainability and the optimisation of maritime supply chain management, all through improved traceability, advancement of smart delivery with automated processes and encouragement of collaboration among stakeholders [3]. The application of blockchain technology in the maritime shipping industry offers many opportunities for developing and launching future blockchain solutions within this industry, both in ports and in maritime transport [4-7]. Also, the application of blockchain technologies to supply chains, i.e. across all participants in maritime transport, whether it applies to complete logistics on land or on board, would be great support in terms of data organisation. Scientific research has been conducted on the main challenges and success factors of the application of blockchain technology in the Singaporean maritime industry using surveys and various analytical methods. High implementation costs and a lack of legal certainty have been identified as the main challenges, while the key success factors include sufficient capital, employee training and support from regulatory authorities [8]. Also, blockchain technology has found its application in the digitalisation of important documentation on board, such as bills of lading, as it ensures the authenticity of documents without the need for a centralised database [9]. Blockchain technology and artificial intelligence find their role in the development of smart cities, emphasising security challenges and the possibilities for their convergence in order to build sustainable digital ecosystems [10-11]. The potential of blockchain technology is also analysed in terms of reducing pollution in the maritime industry, highlighting its role in improving environmental efficiency through supply chain optimisation, increasing data transparency and reducing operating costs. It is also underlined that examples of successful blockchain applications in other sectors can promote the readiness of the maritime industry to adopt this technology [12-13].

As previously mentioned, blockchain technology has found its wide application beyond cryptocurrencies, not only in the maritime industry, but in other industries as well [14]. Furthermore, the economic and technical aspects of blockchain technology have been analysed, highlighting its role in the financial sector, smart contracts and decentralised organisations. Obstacles to its widespread adoption, including regulatory and technical challenges, as well as its potential for innovation in economic management and the provision of financial services in unstable and underdeveloped markets, have also been identified [15]. An example from the hotel industry can serve to illustrate how blockchain technology can facilitate international business, reduce costs and increase the quality of business by minimising the possibility of abuse and intermediary fees [16]. The application of blockchain technology in supply chains in international postal traffic highlights its advantages in information security, cost reduction and improvement of service quality. The implementation of blockchain enables data transparency, facilitates tracking of shipments and increases the efficiency of the entire system [17]. The potential of blockchain technology is also reflected in the improvement of capital markets, especially in the context of reducing costs, accelerating transactions and increasing data security. Also, although blockchain is not yet widely adopted in capital markets, it can bring competitive advantages to less developed markets through more efficient record-keeping and reduced intermediary costs [18].

This paper focuses on the potential of blockchain technology to be applied in institutions involved in maritime education and training, primarily higher education institutions, where it has found its application as well [19-20]. Also, quality control, as well as prescribed standards that monitor all activities, are essential in these institutions [21-22].

Although a broad spectrum of research has been conducted on blockchain applications across various industries – from maritime logistics and port operations to hospitality and general education – there remains a lack of focused studies that examine how blockchain technology can be applied specifically within MET institutions. Most existing studies emphasise sector-specific efficiencies or general benefits, but do not address the cross-institutional coordination, quality assurance or administrative processes in the context of maritime education. This paper seeks to bridge that gap by proposing a tailored model for blockchain integration in MET institutions, with particular attention to stakeholder collaboration, data verification and regulatory compliance.

The main scientific contributions of this paper are:

— A proposal for an education and training quality control system based on blockchain technology, which would be used in MET institutions, with resources available to all other participants in the chain of creating a competent seafarer.

— The application of this system provides simple data verification for all authorised users with a high level of protection of documents against falsification.
— Administrative processes, such as document validation and issuance, can be significantly sped up, making all work activities more efficient using smart contracts.
— The integration of blockchain technology with existing databases enables greater interoperability, better data organisation, and the improvement of education and training quality.

The main research objective of this paper is to examine how blockchain technology can be implemented in MET institutions in order to improve interoperability, automate administrative processes and ensure secure and efficient data exchange among all key stakeholders in the maritime education system. In addition to MET institutions, other stakeholders from the maritime sector are also involved. The paper addresses the existing lack of a centralised and reliable data infrastructure in Montenegro and proposes a hybrid model to overcome this problem.

The structure of the paper, by chapters, is as follows.

The introduction briefly outlines the characteristics of the topic and provides an overview of the majority of the reviewed literature. The second chapter lists some of the fundamental characteristics of the technology, with an emphasis on smart contracts, which form the basis of blockchain technology, while the third chapter focuses on a proposal for the application of blockchain technology at a MET institution, namely the Faculty of Maritime Studies Kotor. The conclusion highlights the advantages of the joint use of available resources that would benefit all participants and suggests further directions for implementing the proposed solution.

2. CHARACTERISTICS OF BLOCKCHAIN TECHNOLOGY

Blockchain technology was first mentioned in literature in a paper describing its basic concept as part of a system for decentralised digital currency, Bitcoin. This paper lays the foundation for using blockchain as a distributed database (ledger) in which transactions are recorded in a secure and immutable manner [23].

Although the application of blockchain technology was then widely considered as connected to Bitcoin, the idea of such databases, i.e. cryptographically secured chains of data, also existed in earlier research in the field of computer science and cryptography.

Looking at the name itself, the compound "blockchain" is composed of the words "block" and "chain", denoting a chain of blocks. Blockchain technology groups transactions into blocks, which are linked into chains via cryptography, or more precisely, the hash function, in such a way that it is impossible to change the content of one block without changing the content of all subsequent blocks. This is a particularly significant feature of the technology because it ensures the immutability of the entered data. Blockchain functions as a decentralised system, which means that there is no central server or anything similar that users connect to. Instead, all users are connected in a peer-to-peer network, and each user represents a node in the network. Each block must contain a digital signature of the previous block, as this regulates the order and guarantees that a new block can join the chain only if it starts where the previous one ended. *Figure 1* illustrates how blocks connect in blockchain technology.

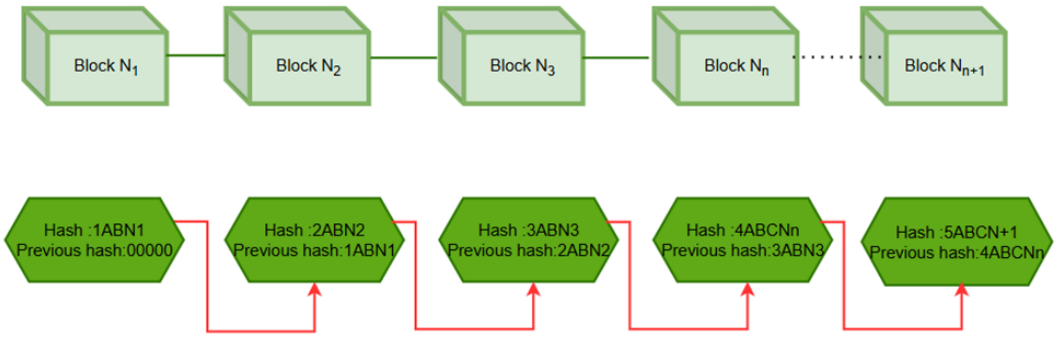

Figure 1 – Connecting blocks in blockchain technology

Another important feature of blockchain technology is transparency, which ensures a high level of reliability, meaning that all transactions are publicly available and cannot be changed once they have been recorded. Owing to cryptographic methods, data stored on a blockchain are protected against unauthorised access. Each block in the chain is protected and linked to the previous one, which makes the system resistant to manipulation and guarantees security. Additionally, blockchain stores a copy of each previous transaction

on every account on which the blockchain software is installed, which further strengthens the security. One of the main features of blockchain technology is the use of smart contracts, which enable the automation of many aspects of business [24]. The reliability of data is ensured by its immutability, meaning that information once entered cannot be changed without adhering to the rules and authorisations in the network. Another important feature of blockchain technology, on which special emphasis is put in this paper, is the facilitated exchange of information between different databases and systems.

Building on these fundamental properties, this paper also highlights smart contracts as a central element of blockchain technology with high relevance to MET institutions. Smart contracts are executable codes or scripts built into blockchains which are triggered when certain conditions are met. Their central role is the automatic execution, control or documentation of legally relevant events and actions in accordance with the terms of the contract. The automatic execution of predefined conditions in code, without the need for additional interventions, is the main feature of smart contracts. Recording data on blockchains ensures security and resistance to changes or falsification. Automation also enables a significant reduction in costs and time, as there is no need for intermediaries in the processes. All terms of the contract are available to all participants and cannot be changed without the consent of all parties; therefore, transparency is another important characteristic of smart contracts [25-26].

The topic of this paper is the application of blockchain technology in institutions involved in maritime education and training, and smart contracts, which are an inseparable part of this technology, could help in the complete digitalisation of the process of training and education of seafarers. *Figure 2* shows a diagram in which the Faculty of Maritime Studies Kotor, which is involved in both education (teaching process) and training (seafarer training centre) of seafarers, is taken as an example of a MET institution using blockchain technology. The process begins at the Faculty of Maritime Studies Kotor, which is the central educational institution in this system. The faculty is responsible for providing education and training to seafarers as well as for managing data related to their academic results and certificates. A digitised database, which is in accordance with blockchain technology, is a centralised or decentralised database into which the data generated by the faculty (on diplomas, certificates, grades, training, etc.) are entered and are completely digitised. This database allows efficient access to data and data management in real time, thus eliminating manual processes and increasing the reliability of information. The data from the database used at the Faculty of Maritime Studies Kotor, both for education and training, need to be cleaned and structured in order to be recorded on a blockchain. Transferring a database from the traditional existing system to blockchain technology entails specific steps because these technologies differ significantly. For example, these databases are centralised, whereas blockchain technology ones are decentralised. Defining the rules for how data enter the blockchain and being the key component of blockchain technology, smart contracts automate the process of validating and issuing diplomas and certificates. When a student or trainee fulfils all necessary conditions (e.g. passes exams, completes their studies or training), the smart contract automatically creates a digital version of the diploma or certificate. The output of smart contracts is a digital version of documents (diplomas and certificates). These documents are secure, immutable and verified via blockchain, which means that they cannot be forged or changed without authorisation. The end users of this system are students and seafarers. They receive their diplomas and certificates in digital form, which they can use in their further professional careers, e.g. to apply for jobs, without the need for paper documentation. These documents are easily accessible and verifiable globally, significantly facilitating the verification process for employers and institutions.

Figure 2 – Overview of the use of smart contracts in the MET institution

3. APPLICATION OF BLOCKCHAIN TECHNOLOGY IN QUALITY CONTROL OF EDUCATION AND TRAINING IN MET INSTITUTIONS

Quality control of education is a process that must be continuously implemented in educational institutions. Monitoring and measuring various parameters, indicators, risk and opportunity management are just some of the elements which increase the efficiency of an educational institution. The application of blockchain technology in this area can certainly make a great contribution to education and training, not only by increasing

work efficiency through the measurement and monitoring of the aforementioned elements, but also by significantly improving the quality and integrity of maritime education and training. On the other hand, the application of this technology by all other participants in the creation of a competent seafarer would result in a large database, which would simplify the work of everyone involved in the process.

The practical application of blockchain technology could greatly encourage the continuation of digitalisation in Montenegro in the field of maritime education and training, enabling more efficient cooperation between key entities in these processes. Blockchain technology provides a decentralised database, where each entity, such as educational institutions, port authorities, seafarers training centres, maritime agencies and health institutions, functions as a node in the network. This ensures that all data are up to date, available in real time, and resistant to unauthorised changes [27].

Figure 3 shows an overview of all the participants involved in creating a competent seafarer, with an emphasis on MET institutions and their connection with other participants in this process. All participants are interconnected, and data are exchanged in both directions. For example, a MET institution that issues a diploma to a graduate student or a certificate to a candidate who has completed a training course could "offer" these resources to interested entities. The entity can be any participant, such as maritime agencies, seafarer training centres, medical institutions and state administration bodies.

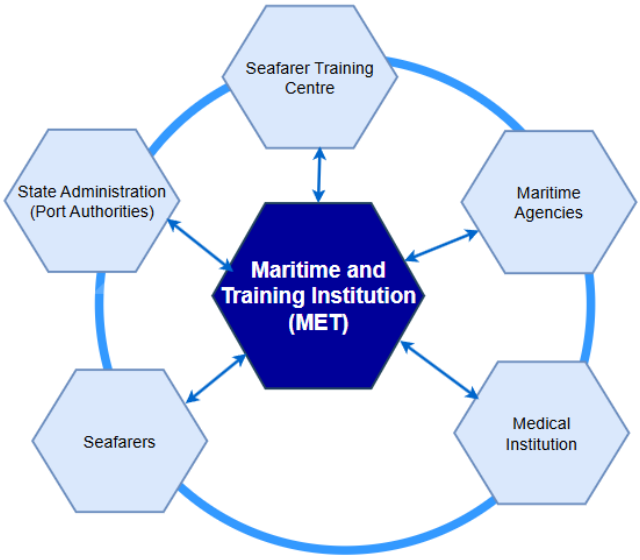

Figure 3 – Participants in the chain of creating a competent seafarer

As previously mentioned, smart contracts can automate the processes of issuing certificates, diplomas, medical certificates and other documents. For example, when a healthcare institution issues a medical certificate, the information is automatically updated on the blockchain and becomes available to all relevant entities, reducing the need for manual verification and administration. Blockchain also allows access control and restrictions on access to information. Seafarers, for example, can have access to relevant education and health data, while other data remain private.

It should be emphasised that blockchain technology provides data security and transparency as well as a high level of protection against fraud or unauthorised manipulation, with access strictly controlled by authorisations. Another important feature of blockchain technology is its ability to integrate with existing IT systems and support various data standards. This is especially useful because different institutions (for example, educational institutions, government administration, maritime agencies) use different types of data (sometimes numerical and sometimes narrative).

Both numerical (for example, percentages, grades, averages) and narrative data (for example, various reports, certificates, documents, legal acts) can be efficiently recorded and processed on a blockchain via smart contracts, enabling the analysis of statistical information directly within the system.

Data access can be adjusted to users, allowing different groups, such as officials, researchers, regulatory bodies and educational institutions, to access specific aspects of data in accordance with their needs and authorisations. When processing narrative responses, special attention is paid to the protection of participants' privacy, with the application of blockchain technology to securely store data and ensure anonymity or protection of personal information in accordance with legal regulations.

This approach enables efficient and secure data management, improving maritime education and training processes in Montenegro.

3.1 Application of blockchain: A case study of the Faculty of Maritime Studies Kotor

Educational institutions in Montenegro, including MET institutions, operate in an environment digitised to a certain extent, but the existing information resources need to be improved and integrated in order to improve work processes. The application of blockchain technology would substantially contribute to the quality and integrity of data both in MET institutions themselves and in the entire sphere of maritime education and training.

How are we currently obtaining data by means of which we track students from the moment of enrolment to the moment of graduation, and candidates who attend training courses at the Seafarers Training Centre and what is currently available to us in terms of digitised data?

The Faculty of Maritime Studies Kotor, one of the institutions involved in maritime education and training, utilises the software provided by the Centre of Information Systems (CIS) for data digitalisation during student education, which is used by all units of the University of Montenegro. The data are now managed using the aforementioned software, which is connected to the E-index portal. It should be noted that, at the University of Montenegro, including the Faculty of Maritime Studies Kotor, the enrolment of new students and the signing of Study Contracts have been carried out electronically via the portal in recent years, which is a big step forward in data digitalisation. This is a relational database based on the Oracle database manager, which can enable a hybrid solution.

Figure 4 shows a part of the resources of the aforementioned software used by all faculties at the University of Montenegro, including the Faculty of Maritime Studies Kotor. It contains all data about a student, starting from personal data (name and surname, personal identification number, unique student code, address, phone number, etc.), to their important academic records from enrolment up until the day of graduation.

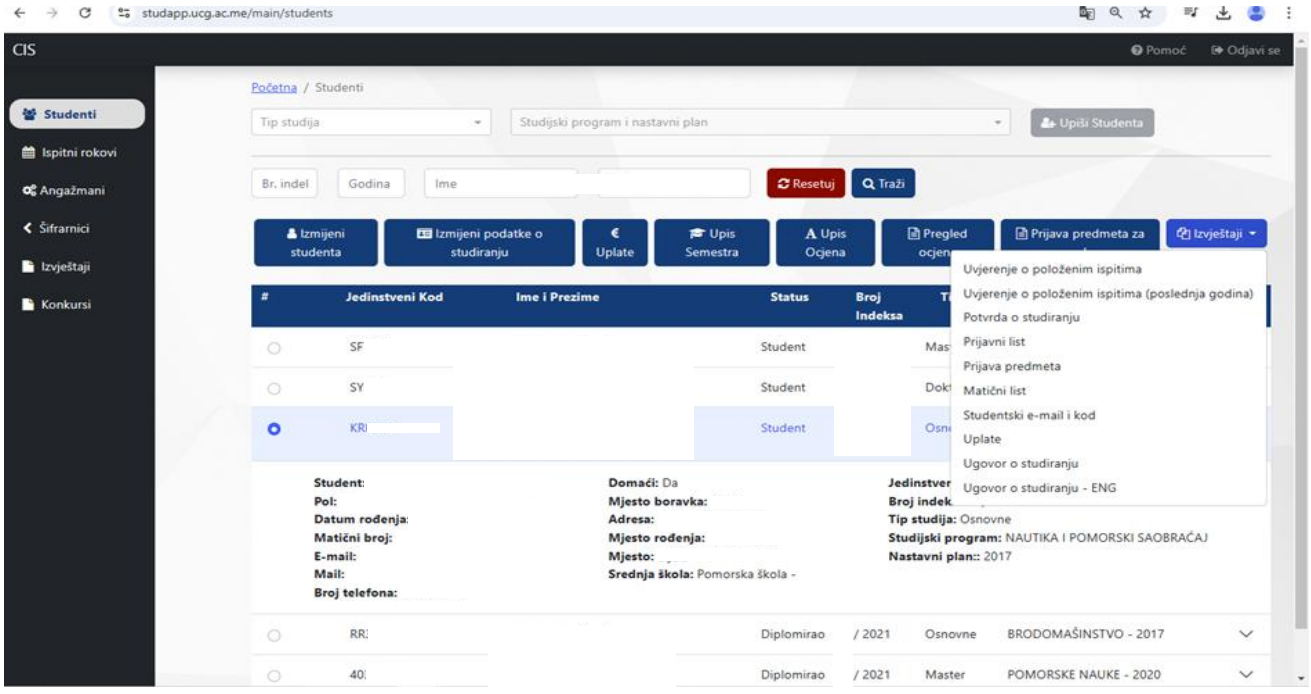

Figure 4 – Overview from the CIS database of enrolled students
Source: CIS software, University of Montenegro

All certificates that a student may need, such as various certificates, study contracts, etc., can be obtained from the database, on the Reports tab.

In *Figure 5*, the Reports tab shows the resources which can be downloaded from the database upon a student's graduation. Currently, all this documentation is kept electronically, but eventually, the user/student receives it in paper form.

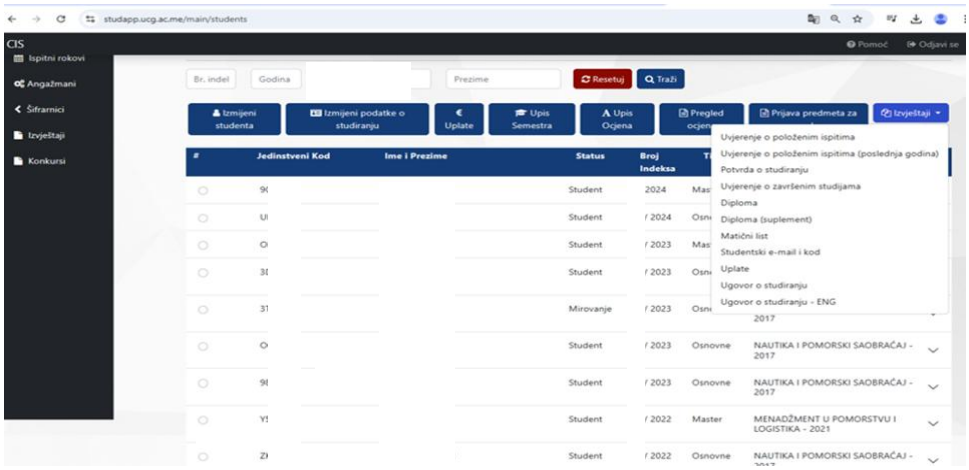

Figure 5 – Overview from the CIS database of graduate students
Source: CIS software, University of Montenegro

The Maritime Information System implemented by the Ministry of Maritime Affairs (at the time of the system implementation, the Ministry of Capital Investments) is used for seafarer training at all seafarer training centres. Each seafarer training centre keeps records of candidates undergoing training in this way. Seafarer training centres do not have access to each other, and only the Ministry of Maritime Affairs (Port Authorities) has access to everything. *Figure 6* shows a selection of options provided by the aforementioned software, which are used by seafarer training centres in Montenegro. There is an overview of candidates who have submitted a Request for a training course, candidates who are waiting for a training course, candidates who are currently on a training course, Training courses which have been completed and Reports.

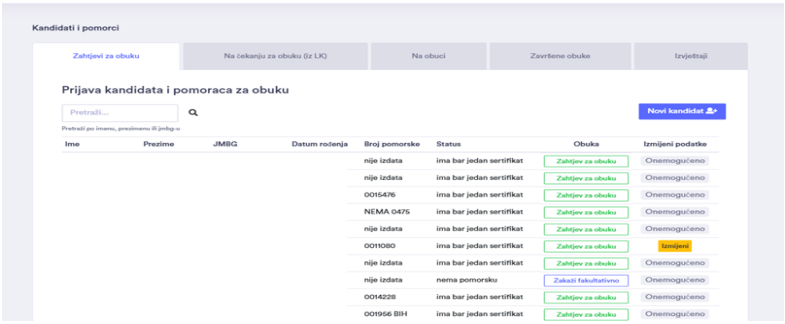

Figure 6 – Overview of resources on the Maritime Information System
Source: Maritime Information System software, Ministry of Maritime Affairs

In *Figure 7*, the Reports tab allows tracking of the courses completed by candidates.

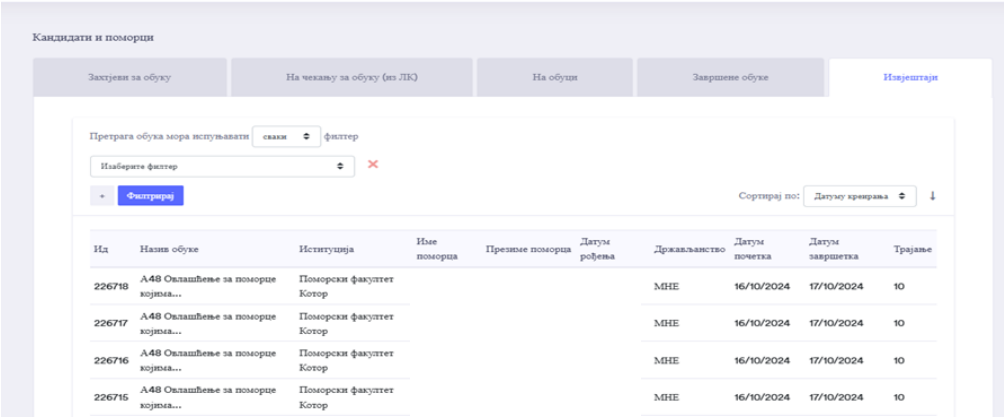

Figure 7 – Overview of the Maritime Information System Training Report
Source: Maritime Information System software, Ministry of Maritime Affairs

A common aspect in keeping various records, diploma confirmations, and certificates related to education and training, which are monitored by the aforementioned software, is that "hard copy" versions are still used as output documents, i.e. it is still necessary for the documentation to be printed and signed by the responsible person.

What would be the most efficient and optimal approach for obtaining these data in an easier way using blockchain technology in the future?

Offering organisation of various types of data, blockchain technology could be the optimal solution for securely monitoring, recording, storing and exchanging data in the future. With the help of smart contracts, the longevity of documents would be ensured, and by digitalising these documents, their immutability and the possibility of easier access would eliminate the need for physical documents and reduce the possibility of forgery. Thus, automating data through smart contracts would reduce administrative burden, speed up document issuance and facilitate data verification, both internally and externally.

As previously mentioned, institutions involved in education and training already have databases developed within them, both for education and training, and although they are currently not fully digitised, it is extremely important to use the resources of the existing ones. Existing databases can provide good informational support as they already contain key information about educational processes, trainings, students and their achievements, as well as data on issued certificates, diplomas, etc. However, the data need to be identified and organised and the quality of information assessed to ensure that only relevant and accurate data are selected for recording on a blockchain. It is important to note that all of these actions are done gradually, and instead of a complete and sudden transition to the new system, existing databases can be integrated into blockchains in phases. For example, data on certificates and diplomas can be entered first, while other data can be transferred gradually. The transition to blockchain is an opportunity to digitise missing data and unify different formats to ensure their consistency and readiness for integration. Employees who already manage the existing databases can undergo training to be able to work with the blockchain platform, which would further facilitate the transition process.

In addition to facilitating the transition, the use of existing databases would reduce the costs and time required to implement blockchain technology. Instead of building a completely new system from scratch, upgrading existing resources would be a rational and sustainable approach, allowing the institution to gradually transition to a modern, decentralised and efficient data management system.

Information systems in Montenegro have been operating successfully in healthcare, education and public administration for a while now; therefore, it is expected that an appropriate information system for seafarers based on blockchain technology can be implemented without any problems. In most cases, an electronic ID card is considered the key to a digital society. In Montenegro, electronic ID cards have been issued since June 2020. This document contains a digital signature, which allows the signing of electronic documents, and a digital certificate, which proves identity in online spaces.

In order to use the resources of existing databases for the education and training of seafarers, this paper will propose a hybrid model of blockchain technology.

3.2 Overview of data for the application of blockchain technology

Data which are important and are the basis of blockchain, and which could be sourced from the existing database used within the software at the Faculty of Maritime Studies Kotor, are the following:

Basic identification data

— Name and surname
— Date of birth
— JMBG (Unique Master Citizen Number)
— Index number (student ID)

Education data

— Enrolment data: date of enrolment, faculty/major/level of study
— Academic status: current status (active, paused, finished, etc.)
— Courses and grades: detailed record of all subjects passed and grades achieved
— Diplomas and certificates: information about completed educational programs, diplomas and certificates
— Attendance at lectures and exercises: record of attendance as proof of educational activities

Training data

— Practical training: information on completed practical training, including duration, location and content of training
— Simulation/computer exercises: record of participation and results in these exercises

Licensing and certification – for students combining sailing and education and training

— Licensing: data on issued licenses/certificates required for working on board a ship, including date of issue and duration of validity
— Medical certificates: information on medical examinations and certificates of medical fitness required for working on board a ship
— Safety and specialist certifications: data on completed safety training

Additional data

— Awards: list of all awards received by the student
— Disciplinary measures: number of disciplinary actions and measures taken (if any)
— Professional development: attendance of additional courses, seminars, student mobility, participation in conferences, panels

Privacy and security

— Consent to provide data: records of consent for data collection and processing
— Security data: cryptographic signatures and hash values for verifying data integrity.

Figure 8 shows an overview of the main blocks of data monitored and measured by the MET institution. This example shows only some of the data that are tracked, such as basic student data, education data and training data. There is a wide range of information that is tracked at a single MET institution for each student, and all of it can be tracked in this way and linked via a unique student ID or a JMBG (UMCN) that will help us integrate the data.

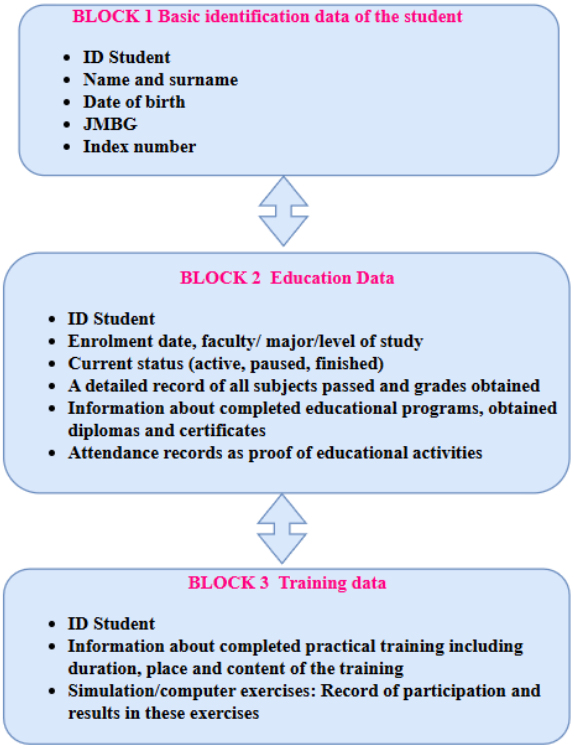

Figure 8 – Example of block structure in MET institution

When integrating these data, it is important to ensure that all data are anonymous where necessary and that they are accessible only to authorised persons, in accordance with data protection regulations.

Such a system would enable comprehensive monitoring and analysis of the quality of education and training, which could significantly improve the efficiency and transparency of educational programs.

Institutions involved in maritime education and training are only one link in the chain of creating a competent seafarer. This paper will mainly focus on the mandatory activities that these institutions carry out (monitoring the teaching process, training at the Seafarers Training Centre). However, we will also look at other entities that participate in this process. For example, seafarer training centres, maritime agencies, companies that employ this staff on shore, seafarers themselves and medical institutions. Each of these entities can have its own specific "blocks" of data that can enable comprehensive monitoring and analysis of data throughout the entire chain.

Integration of different entities, using blockchain technology, could have the following participants with the corresponding data for each of them:

MET institutions

— Student identification data: student ID, name and surname, date of birth, JMBG (UMCN)
— Education data: diplomas, certificates

Seafarers

— Seafarer identification data: JMBG (UMCN)/SID (Seafarer Identity Document), name and surname, date of birth
— Education data: diplomas, certificates
— Rank/position data: Master, Chief Engineer, Officer, Crew
— Seafarer activity data: whether the seafarer is active or currently/no longer sailing

Seafarer training centres

— Training data: details of completed training courses, results, instructors, duration of training
— Certificates: information on issued certificates with dates

Maritime agencies

— Embarkation data: information on employment mediation, embarkation dates, duration of contract
— Ratings and feedback: feedback from employers on seafarer performance

Companies employing seafarers

— Work experience: employment details, position, performance reviews, length of employment
— Career development: information on promotions, additional training organised by the company

Medical facilities

— Health examinations: details of medical examinations, certificates of fitness for work, examination dates
— Specialist examinations: information on additional specialist examinations and treatments, vaccinations.

Each of these entities can create specific data blocks that are linked to the central identifier of the seafarer. In this way, all relevant data can be integrated into a single system. The resources of this database can be used by everyone with certain rights and authorisations, which include both seafarers themselves and the state administration (port authorities, relevant ministries, etc.). By integrating data from different entities into a single blockchain system, it can be ensured that all relevant data on education, training, employment and health of seafarers are monitored in a single and secure manner. This approach allows for comprehensive monitoring of seafarers' competencies, which contributes to better quality education and training, as well as better management of seafarers' careers. An example of a block structure is different participants who could use their own resources (data) for themselves and the data they need from other entities, of course, with rights, privileges and restrictions that would be set from the aspect of information protection both among themselves and among third parties, and vice versa.

Figure 9 shows examples of data, such as candidate tracking at MET institutions, seafarer training centres and maritime agencies, and seafarer tracking within companies which employ them and medical institutions which issue their medical documentation, through "blocks". Data for each candidate would be linked through the database, i.e. through blocks, via a specific code, which could be an ID number, a SID (Seafarer Identity Document) or a JMBG (UMCN). Of course, in order to ensure completely secure data exchange, each participant would have limited and permitted access to the various data they need.

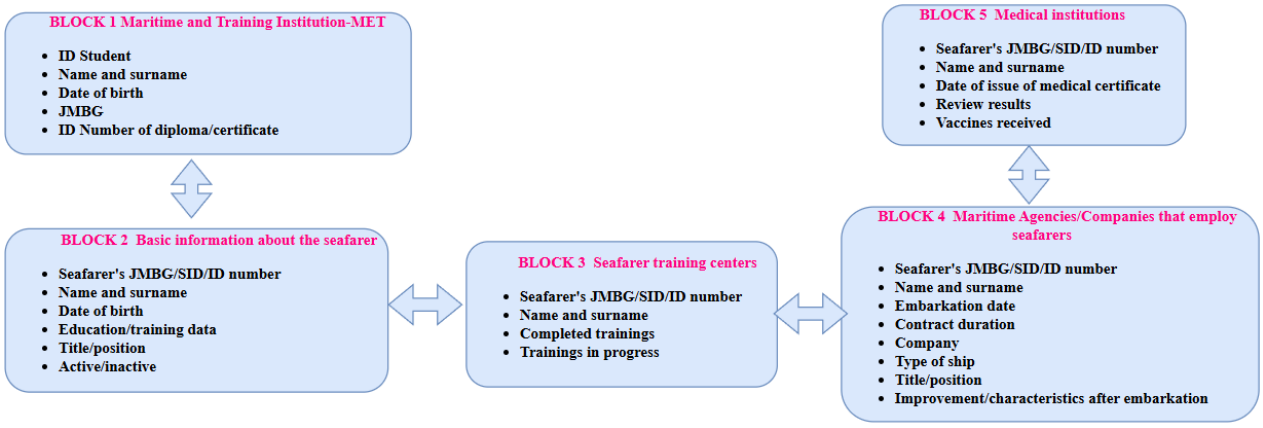

Figure 10 – Example of blocks of different entities in the maritime economy chain

The integration and analysis of data collected from various sources, i.e. from all major participants in the maritime economy chain, using blockchain technology enables comprehensive data monitoring, which leads to the development of seafarer competences.

Figure 10 shows a proposal for the application of blockchain technology, including all participants in the chain of creating a competent seafarer, as well as an overview of important documentation (diplomas, certificates, employment contracts, medical records, etc.), national and international regulations. The state administration (line ministries, port authorities) has feedback with all participants, and their joint work must have the implemented international and national legal regulations as a framework. Also, all participants (MET institutions, seafarer training centres, seafarers, maritime agencies, companies and medical institutions) are interconnected. The documentation they issue via smart contracts would lead to the digitalisation of the complete output documentation, the resources of which would be used by everyone in accordance with their authorisations and needs.

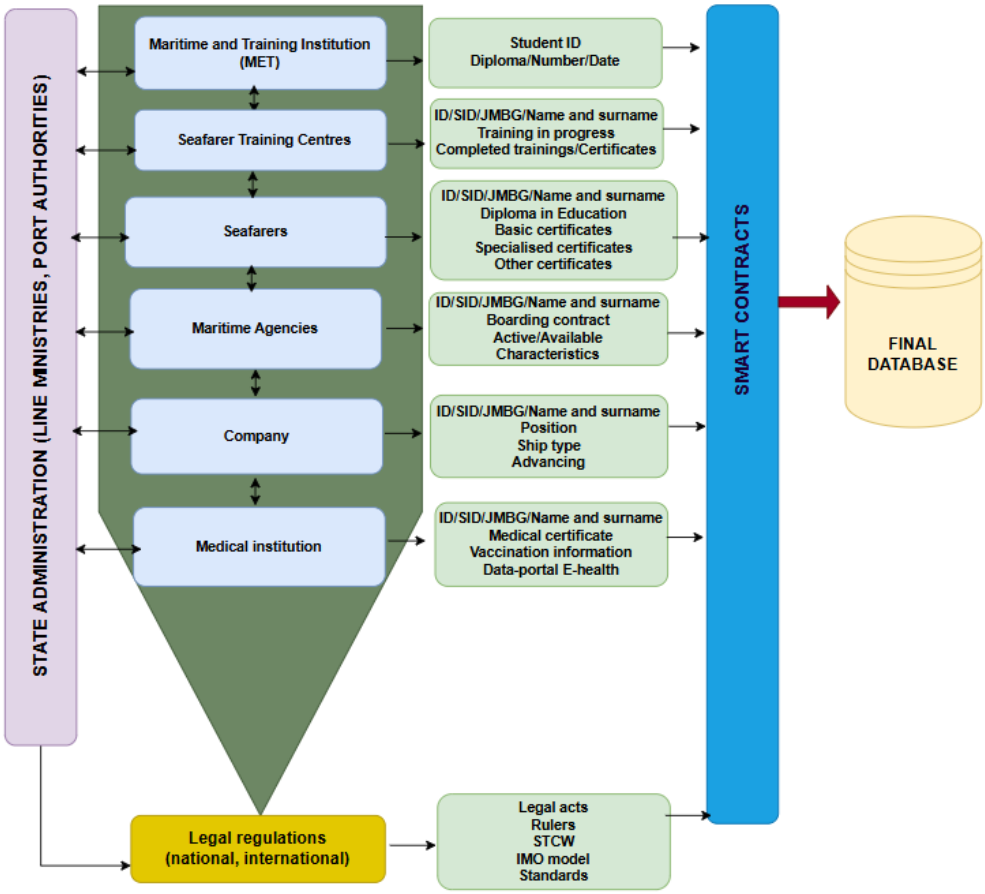

Figure 10 – Proposal for the application of blockchain technology

3.3 Proposal for a hybrid model at the MET institution

Since the Faculty of Maritime Studies Kotor uses software resources from CIS and the Ministry of Maritime Affairs, the transition to blockchain would follow a simple scenario involving a hybrid approach. This approach would entail continued use of the existing database in day-to-day work in the initial phase of the implementation of blockchain technology. In this case, the existing database that stores all data on students and training and the interface remain active without significant changes in everyday processes, and blockchain allows verification of data authenticity without direct access to the existing database. This approach would ensure secure and unchangeable storage of diplomas, certificates and other student documentation without the need for complete data migration. In addition, costs would be lower, and administrative barriers would be lower because institutions would retain their data, and the speed of implementation would be higher because the existing situation would not be changed, only new functionality added. The exchange of necessary information with third parties and with students or seafarers would be facilitated with the help of smart contracts. All activities in which a student participates during their studies or a trainee while undergoing training, such as entering grades, adding training courses and updating any kind of data, would still be done through the existing database and its interface. When a degree or certificate is issued to a student/trainee, important data (such as certificate ID, name, date and course information) are written into a blockchain using smart contracts.

Blockchain enables decentralised and secure exchange of information with external systems without exposing the entire database [28-29]. The link between the existing database and the blockchain is the so-called middleware (script or application)[1], which automatically recognises events such as the issuance of diplomas, certificates, etc. and sends the corresponding information to the blockchain. Third parties (e.g. maritime recruitment agencies, other employers, medical institutions, port authorities, etc.) use the blockchain interface or mobile application to verify and validate certificates based on a unique identifier (e.g. QR code).

The increasing use of blockchain technology in higher education and public sector digitalisation has been highlighted by recent research. For example, the EduCTX initiative in Slovenia illustrates how blockchain may be used in practice to manage academic credits and certificates (https://www.eductx.org/). Additionally, there are companies working on blockchain software engineering and research that enable companies and developers worldwide to create decentralised systems (https://www.nethermind.io). The worldwide trend of incorporating blockchain technologies to increase transparency, security and efficiency in educational and public sector operations is highlighted by these instances. In line with these advancements, our suggested hybrid model provides a viable way for MET organisations to adopt blockchain technology in the larger picture of digital transformation.

The range of digital technologies that influence the calibre of higher education is quite extensive. Blockchain technologies have a lot of promise for facilitating data sharing and customised learning pathways in the learning process. The digitisation of student data via blockchain and the flexibilisation of education can both help make higher education more inclusive and of higher quality. The four primary ways that blockchain promotes sustainability are accountability, transparency, traceability and cybersecurity. Furthermore, the transition to blockchain would be significantly aided by the utilisation of the institution's current data infrastructure and other resources. [30-31].

Figure 11 shows the proposed scenario involving the aforementioned hybrid approach, i.e. the use of data from the existing database as a solution to transition to blockchain technology. Also, the resources offered by such a system could be a good base for external users, who would only use the existing data. Of course, a complete transition to blockchain technology would improve the work of the entire maritime industry in the future. It can be observed from the figure that existing databases and middleware can both send and receive data from the database. Middleware and blockchains can do it as well, because middleware can both push data to the blockchain and pull it back for validation. There is also a two-way connection between the blockchain and smart contracts, because smart contracts can write data to the blockchain and receive confirmations. A one-way connection remains between the blockchain and external users, because external users mostly only verify data and do not write anything back.

[1] Middleware refers to software that acts as a bridge between different applications or services, allowing them to communicate and share data seamlessly.

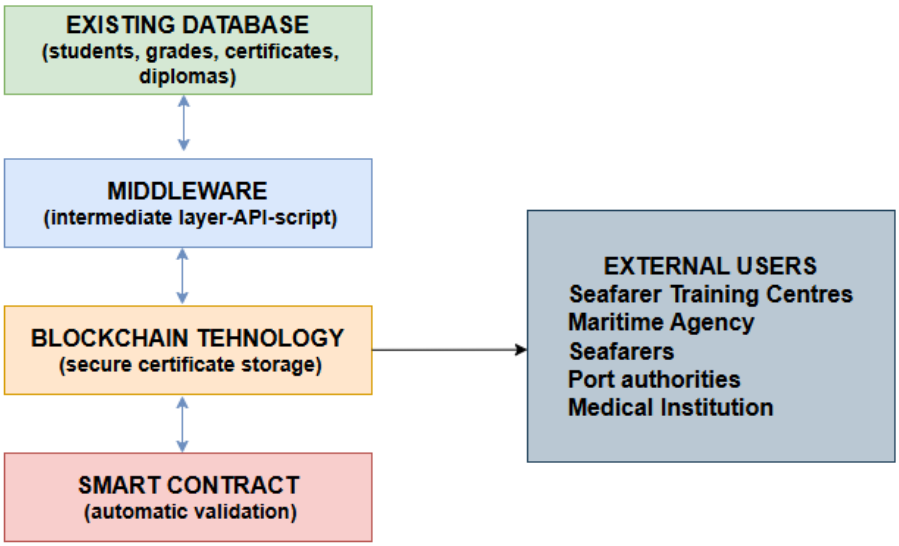

Figure 11 – Hybrid model scenario proposal

The advantages of the proposed solution are reflected in the following facts:

— The gradual integration of blockchain allows the faculty not to change its software immediately.
— Minimal administrative change because blockchain technology adds a layer of security and verification, but does not change existing processes.
— Faster verification of diplomas, as all third parties can verify the data digitally.
— Flexibility and security because sensitive data remain on a private blockchain, while verification data are publicly available.
— This solution allows a safe and gradual transition to blockchain without disrupting current academic processes. The faculty can test the system, for example, with the certificates of one training course or one student, and later extend the use of blockchain technology to the full academic record and all seafarer training courses.

Figure 12 shows a proposed use case diagram of blockchain technology that allows the institution, in this case, the Faculty of Maritime Studies Kotor, to use the existing software while gradually integrating blockchain technology.

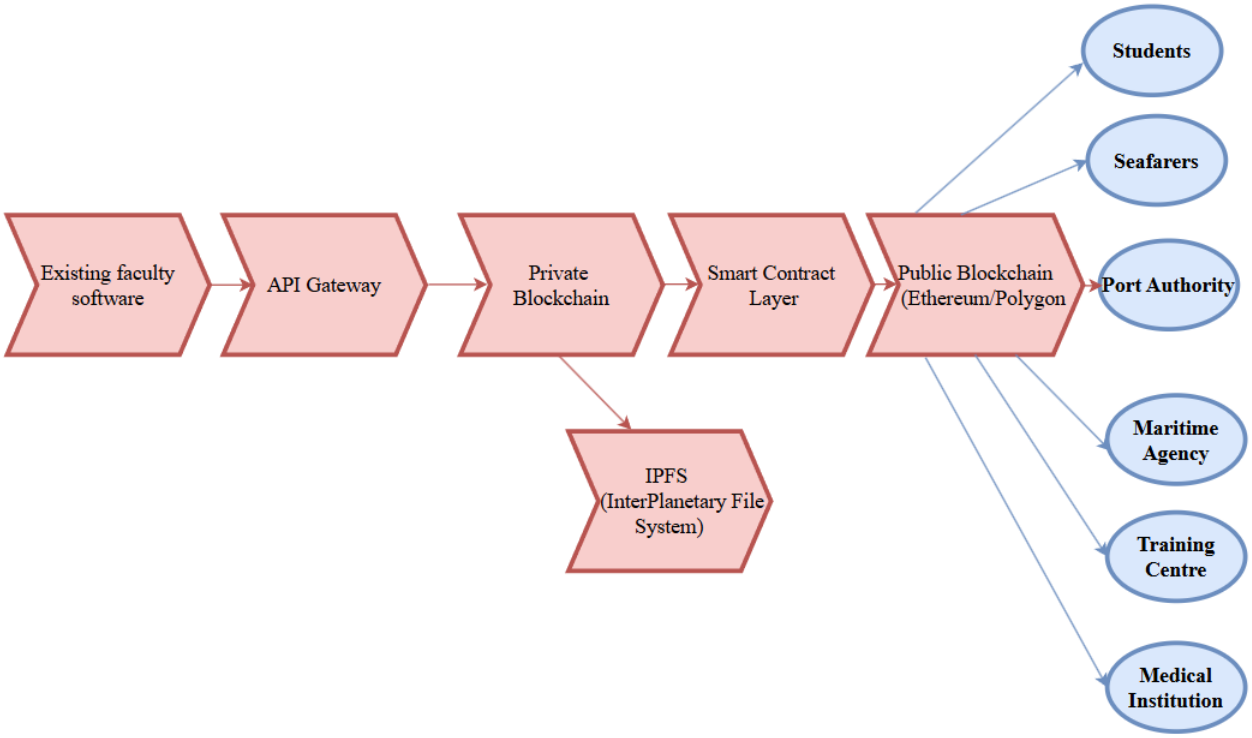

Figure 12 – Suggested use case diagram

In this case, the existing faculty software remains in use for managing academic data, which it sends to the blockchain system through the API Gateway (Application Programming Interface – API)[2]. The API Gateway enables the connection between the faculty software and the blockchain network and converts the data into a format suitable for recording on the blockchain. The faculty uses a private blockchain (e.g. Hyperledger Fabric) to securely store academic data, such as various certificates, diplomas, student records, etc. Afterwards, the Smart Contract Layer automatically generates hash values of diplomas, validates certificates and writes them to the public blockchain. The public blockchain (Ethereum/Polygon) stores hash values of diplomas so that anyone can verify them. IPFS (Inter Planetary File System)[3] allows original documents (diplomas, certificates, medical certificates) to be stored in a decentralised system. The blockchain references these files via cryptographic hash values. The system integrates middleware (software that connects different components of the application), as well as an API Gateway (a tool for managing and directing requests), and utilises IPFS, a decentralised file storage system.

Third parties using the data, students and seafarers, have secure digital access to their diplomas and certificates, while the Port Authority has the ability to quickly check qualifications without the need for physical documents. Maritime agencies can check certificates without contacting the faculty, and seafarer training centres have an overview of the training courses completed by a candidate. Medical institutions also have access to health certificates of students and trainees.

4. CONCLUSION

The introduction of blockchain technology in MET institutions, but also other educational institutions, can bring significant advantages in the field of transparency, security, efficiency and interoperability. The application of blockchain technology can ensure reliable storage, monitoring and validation of data on seafarer education and qualifications, while reducing administrative burden and the possibility of falsifying documents, which was presented as part of the results of this research paper. Automatic verification of various certificates, diplomas and medical documentation, which would significantly speed up the verification process and facilitate cooperation between MET institutions, state administration, recruitment agencies and other interested entities, is provided by this model. The proposed digitalisation model, which uses blockchain technology relying on smart contracts and a decentralised database, will increase the efficiency of all participants in this process.

Despite numerous advantages, there are significant challenges in implementing blockchain technology. High initial integration costs, including specialised equipment, software development and employee training, represent one of the main obstacles. In addition, legal regulations, standards and international conventions in the field of maritime education require strict compliance, which can further complicate the implementation process. Legal aspects such as data protection, e.g. General Data Protection Regulation, GDPR, the legal validity of digital documents, and liability in the execution of smart contracts require careful regulatory assessment. A prerequisite for Montenegro's accession to the EU is the full compliance of the national legislation in the field of data protection with the GDPR. The right to protection of personal data is one of the basic human rights, and the EU will insist on respecting the highest standards of human rights on the road to Montenegro's accession. Interoperability with existing information systems of MET institutions and government bodies can be technically demanding, while resistance to change among staff and institutional structures is a common challenge during the implementation phase. All of this requires a thorough analysis and a gradual approach. For these reasons, the first phase in the realisation of the proposed solution is the adoption of a hybrid model that combines existing databases of MET institutions with blockchain infrastructure, representing an optimal solution for gradual transition without disrupting daily operations.

Furthermore, it should be emphasised that, as part of Montenegro's EU membership application process, adherence to the GDPR will become a legal obligation for government organisations, including MET institutions. This highlights the necessity of making sure that any blockchain-based solution adheres to privacy and data protection rules that comply with EU legislation.

The recommended hybrid model provides a viable option for MET institutions when taking into account the financial and operational hurdles associated with a complete blockchain migration. By preserving current

[2] An API Gateway is a management tool that handles requests, security and routing between clients and backend services in a system architecture.

[3] IPFS is a peer-to-peer distributed file system that allows data to be stored and accessed across a decentralised network, improving speed, security and resilience.

information systems while integrating blockchain components gradually, this strategy lowers upfront expenses and execution hazards. The EduCTX initiative in Slovenia has successfully used a similar model, where educational institutions have implemented a decentralised system for managing academic credits and certificates, proving the viability and cost effectiveness of a hybrid approach in the field of education.

Future research and development should be directed towards further optimisation of blockchain solutions, integration with global maritime standards and regulations, and analysis of the economic viability of implementation on a larger scale. The implementation of all of the above would certainly be of great importance in the future, because the digital transformation of maritime education and training through blockchain technology can significantly improve the quality and integrity of the seafarer education and training system. Uniting all participants in the maritime economy chain in the application of blockchain technology would certainly ensure long-term sustainability and competitiveness in this industry.

The emphasis should absolutely be on performing simulation studies and pilot projects in order to empirically test the suggested hybrid model. These projects would offer tangible knowledge about technical feasibility, system integration and regulatory compliance. Additionally, research on user acceptability and readiness among institutional stakeholders will be essential for a seamless implementation. Ultimately, the actual advantages of implementing blockchain technology in MET institutions will be demonstrated by quantitative analysis of improvements in administrative efficiency, such as faster processing times and fewer mistakes.

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