Arbeidsnotat
Working Paper

2020:6

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Blockchain technology for electronic health records : challenges & opportunities

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Molde University College
Specialized University in Logistics

Molde, Norway 2020

ISSN 1894-4078

ISBN 978-82-7962-300-7 (trykt) ISBN 978-82-7962-301-4 (elektronisk)

1 Introduction and motivation

Healthcare systems

A healthcare system can be described as the collection of services, institutions and legislation that contributes towards providing diagnostic, treatment, rehabilitation and care for patients that suffer from acute or chronic illness or injuries. This definition is not limited to those who are directly involved with patients but includes suppliers of goods and services such as drugs, medical technology, research and innovation. This healthcare systems have gradually evolved into increasingly complex network structures of institutions delivering highly specialised services. The revenue in the healthcare industry in the USA in 2019 was closed to USD 2500 billion, making it clear that this industry has developed into considerable size in terms of revenue and the number of players.

Ownership and governance of healthcare systems can be public, private, or what is probably most common, a healthcare system consisting of a combination of public and private actors. Regardless of the chosen model for ownership and governance, the operation of healthcare systems is heavily regulated to ensure adherence to strict requirements concerning patient safety and quality care. Information about the patient's clinical situation and treatment history is highly sensitive information that must be protected from unauthorised access and alteration. This information is currently stored in traditional electronic databases and commonly named an electronic patient journal or an electronic health record (EHR). One consequence of the development towards increasingly clinical specialisation is an increase in the number of actors and institutions in the healthcare system network. Furthermore, it implies that the patients' journey or pathway through this increasingly complex network traverses through an increasing number of institutions or actors. Hence, this journey must be made as efficient as possible while at the same time ensuring compliance with legislation and ensuring patients safety and quality treatment.

These journeys or pathways might be described as the results of a decentralized business process, meaning that the actual path a patient traverse from the first contact with the health care system until the end of treatment, in general, cannot be known in advance. This is somewhat similar to how routers on the Internet routes data packages by making routing decisions based on available information. One obvious distinction between these two is that

the healthcare system routes patients and not data packages. Furthermore, the information the healthcare system uses for its next-step decisions is much more unstructured and complex than in the routing of data packets.

Requirements of Information systems supporting contemporary healthcare systems

Information systems handling EHR-data must then support decentralized storage and operation to allow for the fact that the different actors need to own and control the data they have created and are responsible for according to legislation that often places strict restrictions on to whom data might be shared. Control over their own data is not at least important for the patients. Furthermore, data must be safe since the consequences in case this information should fall into the wrong hands potentially will be very harmful to the patient. Finally, because time often is of importance in the treatment of patients, information must be distributed quickly to those who need it without unnecessary time lost to reconcile the different siloed EHR systems stored at different actors and organizations.

To sum up, there is a need for a system providing a complete coherent view of the information necessary to fulfil the information requirements. Such a system should represent an agreed-upon "single source of truth". A system fulfilling these requirements could also constitute an important foundation for use of advanced analytics and machine learning to create new knowledge based on historical data describing complete patient journeys.

Limitations of current healthcare information systems

Existing systems often lack sufficient support for cooperation between actors even when the actors belong to the same organisation. When considering the important inter-organisational data sharing capabilities, the situation is even more challenging. Inter-organisational collaboration might be exemplified by collaboration between the different levels of the healthcare system. Figure 1 below shows a generic model for collaboration and types of collaboration in the healthcare sector (The Norwegian Directorate of eHealth, 2019).

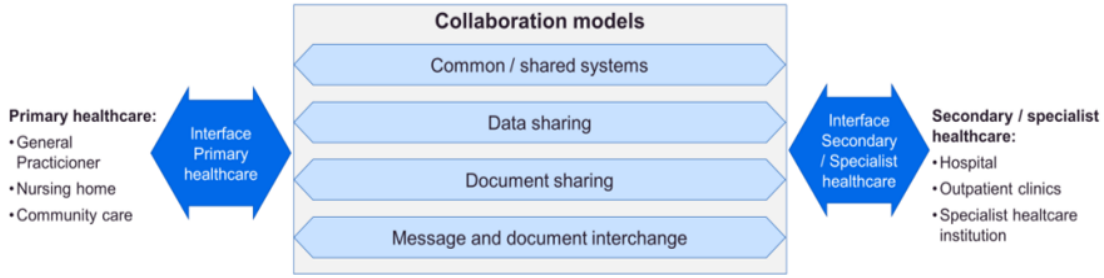

Figure 1: A generic model for collaboration and types of collaboration in the healthcare sector (The Norwegian Directorate of eHealth, 2019)

Blockchain technology

Blockchain was conceptualized by Satoshi Nakamoto in 2008. It works by storing the information in electronic ledgers that are distributed in a decentralized manner on all the nodes that are part of the network. It offers consensus mechanisms, digital signatures, and hash chains while storing the information in their ledgers. Due to this blockchain provides services such as traceability, security and so on as shown in Figure 2 below.

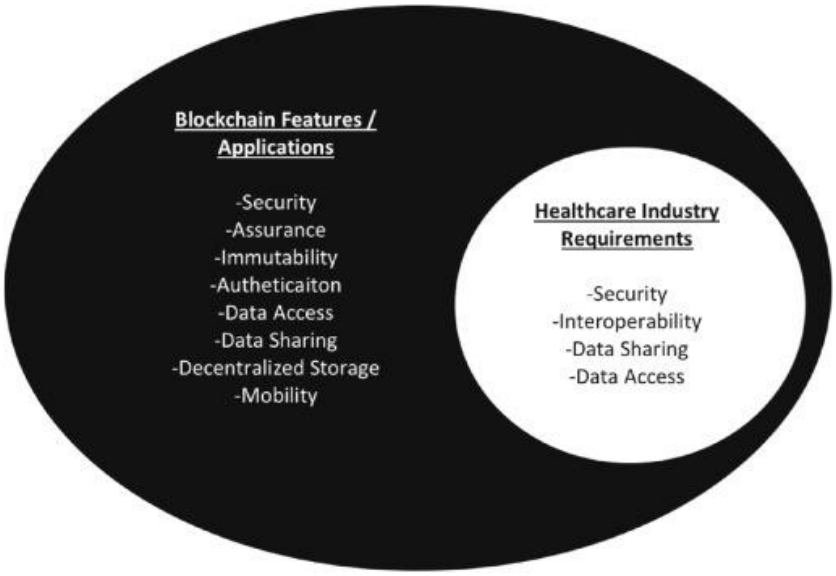

Figure 2: How Blockchain meets Healthcare Requirements. (McGhin, Choo et al. 2019)

The role of BCT in contributing to improved healthcare information systems

There is also research taking place that aims to understand if blockchain technology is the solution that could solve problems in the supply chain. The research focuses on exploring the challenges and opportunities present in the adoption of the blockchain technology for electronic health records of patients. Distributed complete ledger provides the foundation for process-level analytics. Based on the arguments above, the following two research questions are framed for this research:

RQ1: *What are the challenges in adoption of blockchain technology for electronic health records of patients?*

RQ2: *What are the opportunities in the adoption of blockchain technology for electronic health records of patients?*

There have been many literature reviews conducted in the blockchain application in healthcare applications but not many works on the healthcare supply chain applications. So, for this research, we cannot restrict to complete it with just the literature review. We need to conduct a semi-structured interview with experts and for this, the healthcare experts will provide the problems in the healthcare supply chain and the blockchain experts will provide the possible solutions for these problems. Analysis of these will help in answering the research questions.

Using blockchain in healthcare might help towards solving challenges connected to data security, privacy, sharing, and storage. One of the crucial points in the healthcare sector is interoperability, for instance securing a high-quality patient pathway through the health system. Parties should have the ability to exchange health-related information precisely, efficiently, and consistently. Blockchain technology electronic health records transactional information could be shared throughout the environment and distributed by different hospital systems. At the same time, the data is very private, and patients should permit to share it regardless of the trust relationships between hospital systems. Healthcare data is diverse, and blockchain technology can be potential to store, manage, and share EHRs safely amongst healthcare communities. It can help to optimize healthcare processes, patient data management, lower costs and enable secure use of healthcare data.

Blockchain technology can also contribute to work of caregivers, pharmaceutical companies, and insurance companies as well as help patients to secure their data. The ability to share healthcare data without any risk of users' privacy is one essential and important step to make the healthcare system smarter and improve the quality of healthcare services.

Background

Developing blockchain-based healthcare system are organized into four layers: data, blockchain technology, healthcare applications, and actors. Data is generated from medical devices, doctors, labs, and other sources. It is the essential ingredient of the whole blockchain-based healthcare, which creates the first layer of the system. Blockchain technology describes different types of blockchain platforms, components, networks (Ethereum, Hyperledger Fabric). The third layer is healthcare applications. It includes supply chain in healthcare, data management as well as IoT devices. The last layer is the actors in the system: government, patients, public, researchers, insurance companies. Together these layers describe the

workflow of blockchain-based healthcare system. Such decentralized technology enables multiple actors to benefit from healthcare applications.

Data security and data ownership is important questions that needs to be addressed. In 2018 alone millions of data breaches related to electronic health records were reported. Furthermore, the patients often do not have control of their own data stored in EHRs (Chen et al., 2019). Blockchain technology is built with security in mind from the ground up and might provide an answer to several of the challenges of existing systems such as enabling patients access to and control over their own data. Today patients usually have restricted access to their own medical data.

Managing patients' Electronic Healthcare Records (EHRs) is probably the area with the highest potential growth. Although the aim of block-chain based healthcare system is to regulate the processing of data, there is still a big gap to cover. From the analysis of literature, a series of limitations of using blockchain technology can be derived. Here we are talking about sustainability, blockchain adoption and interoperability, data management, latency and scalability. One more drawback of using blockchain technology is the waste of resources of the mining network.

Although the application of blockchain to healthcare is a relatively new exploit, more research is becoming available each day. The technology of blockchain can improve security and quality of healthcare mobile application, remote monitoring, accessing and sharing of patient medical records. Blockchain technology can apply for the medical data management system, especially allows patients to retain ownership over their records while allowing hospitals to have easy access.

Various healthcare solutions based on blockchain have been proposed. In this section, the summary of them is given.

Mobile healthcare and remote monitoring

Remote monitoring machines and healthcare mobile applications are crucial for patient care in today's technological age. Blockchain can be used to improve the security of machinery.

For example, researchers created a mobile application (Ichikawa) for cognitive behavioural therapy for insomnia with using blockchain. The application sends all records of the patient to the private blockchain network. Patients can monitor their care by themselves and be sure that data is secure. Patients can record data and sent it to the healthcare workers within minutes. Such a system is resistant to tampering after testing because of the properties of the blockchain.

For remote monitoring devices, smart contracts can help to operate securely. They can verify and monitor the blockchain activity. In such private blockchain, sensors interact with smart devices that utilize smart contracts to record events in the blockchain (Griggs).

Smart contracts enable real-time patient monitoring. All notifications are sent to healthcare providers securely. Also, patients can send notifications any time. Real-time updates are essential for safe care at home and enable patients to take charge of their care while a healthcare provider is always accessible.

Accessing and sharing health data

Usually, medical records are spread out across different healthcare systems. Blockchain technology can be applied to the sharing of patient medical data. Also, patients and healthcare providers can have full and secure access to all medical history.

The approach is to put all patient health records in one accessible place by incorporating different data sets into different blocks on the blockchain. Each block is then encrypted and the chain of blocks carrying the different pieces of one patient's health information is fully accessible to that patient (Roehrs). Patients should be able to access all their medical data in one place, and this access will improve the efficiency of care.

Medical data management system

(Chen et al., 2019) proposed a medical data management system using blockchain, which allows patients and hospitals to have easy access to the records. They based the system on the Ethereum service, a decentralized platform that allows developers to run applications on a custom-built blockchain. Since many times, blockchains do not innately offer sufficient storage, we store the actual medical records on decentralized cloud storage such as Ethereum

Swarm, a native base layer service of the Ethereum web3 stack that functions as a distributed storage platform (Swarm, 2018). Each medical record then has a unique swarm hash, which combined with the decryption key, form the root chunk. Only those that know the reference to the root chunk can access the content. Thus, the root chunks are securely stored in smart contracts through the blockchain and are released only under specific conditions.

To solve the problem of data ownership and control, they employ multi-signature contracts. Both parties use their private keys to sign a transaction for authentication. This way, the patient cannot alter the record without permission of the hospital, but he still has control over who can access his record. A new swarm hash must be generated each time after the data has been accessed (since the old swarm hash is now known), so we add a "last accessed" timestamp. The change in the data will automatically change the swarm hash, which can then be secured once again until it receives the required permissions for access. This model not only provides the security and immutability provided by a blockchain, but also offers a solution to data ownership and accessibility.

2 Theoretical Framework

The application of blockchain technology outside the fintech-industry is still considered to be immature. Hence, explorative research is needed to create new knowledge on its use-potential in general and also for this research within its application for electronic health records.

We suggest applying the mindful use of technology framework proposed by (Verhoeven et al., 2018) to analyse the suitability of the blockchain technology for the use-case of blockchain technology applied within electronic health care records. The framework analyses the suitability of applying a new technology for a use-case according to five mindful technology adoption principles: engagement with the technology; Technological novelty seeking; awareness of local context; cognizance of alternative technologies; and anticipation of technology alteration. The framework applies a critical perspective to ensure a thorough analysis of how a technology with certain features fits whit a specific use-case. Figure 3 **Feil! Fant ikke referansekilden.** illustrate the components of the framework.

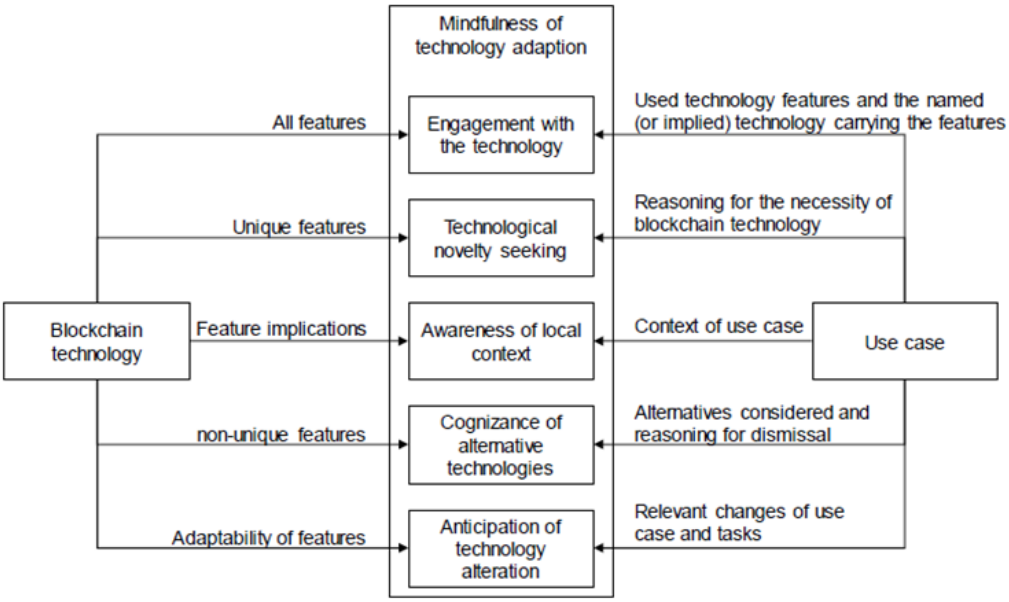

Figure 3: Framework to evaluate the mindful use of blockchain technology in logistics and Supply Chain Management. (Verhoeven et al, 2018).

3 Research methodology

The study intends to identify the possible challenges and opportunities for the adoption of blockchain technology for electronic health records for patients. For this purpose, we will collect and review the existing literature in a structured manner. After which, we will develop interview questions for the healthcare professionals, IT professionals in healthcare and blockchain experts to understand their views of blockchain adoption for electronic health records of patients. This is followed by focused group work, to answer the research questions of this study. All these three processes are further elaborated in the following.

3.1 Systematic Literature Review

In conducting a review for identifying possible challenges and opportunities on adoption blockchain, we will follow a systematic literature review approach similar to Maestrini et al. (2017). This method is built of four steps such as source identification, source screening, source evaluation and data analysis. All these four steps are discussed in detail in the following.

Source Identification:

We aim to get a comprehensive overview of the previous works on adoption of blockchain in different fields to identify the possible challenges and opportunities. For this we gather a wider literature search on scholarly articles, white papers, manifold statements, ideas, and vision of blockchain enthusiasts and opponents. The main reason for including non-scholarly

articles, is to learn about different uses cases and pilot projects implemented (Gupta et al. 2020).

We will explore the databases of the ScienceDirect, Web of Science, IEEE Xplore, Springer and AIS Electronic Library for the research published in journals and conferences. We will use "blockchain" and "block chain" in the search terms in the mentioned databases from the year 2009. Apart from this, we will explore the different blockchain websites such as BurstIQ[1], Mediachain[2], ShipChain[3] and many more to find the white papers and use cases.

Source Screening:

The main step in this systematic literature review process is the source screening. In this step, the criterions for the selection of the papers are assigned. Here, the focus is to identify the possible challenges and opportunities in the adoption of the blockchain. The journal and conference papers are screened based on their title, abstract and keywords. If the paper focuses on either challenges', opportunities, use cases, adoption of blockchain or framework for adoption of blockchain the papers are kept, and the rest are omitted for the next steps. White papers and use cases will be screened in a similar way for this study. The screening process is planned to be performed by all the researchers separately and then compared. During conflicts, the selection of the papers will be debated and finalized for further steps.

Source Evaluation:

The screened papers are evaluated in this step. In this evaluation process, several details such as source information, the main theme of the paper and the details of the paper are studied.

Data Analysis:

The final step in performing the systematic literature review is the analysis step. The main goal of this step is to identify the challenges and opportunities for the adaptation of the blockchain from the selected papers. The outcome is to identify the opportunities and challenges in adoption of blockchain.

[1] https://www.burstiq.com/
[2] http://www.mediachain.io/
[3] https://www.shipchain.io/index.html#home

3.2 Interviews

From the systematic literature reviews, we will develop questions for the semi-structured interviews with healthcare professionals, IT professionals in healthcare and blockchain experts. The reason for conducting the interviews separately is to improve the knowledge. The possible outcomes of these interviews from,

- **Healthcare Professionals** will result in identifying the current issues they are facing while accessing and writing in the details in the electronic health records of patients. Also, to understand whether they know about blockchain and its possible uses.
- **IT Professionals in Healthcare** will result in identifying the possible pitfalls in the current system and the IT knowledge of the people in using the system. This will provide the information about the possible questions to be framed for the blockchain experts.
- **Blockchain Experts** will result in answering the issues of the healthcare professionals and IT professionals in healthcare. They will provide some solutions using the blockchain technology for the current problems.

These interviews will hopefully provide us with some perspectives form each of the professions. This might not provide us the optimal answers. For this we will have focused groups which is explained in detail in the below sub-sections.

3.3 Focused Groups

In simple words, focused groups are nothing but workshops. It is considered an important addition to interviews in this research in that it allows for discussion and hence the co-creation of new knowledge. In this focused groups, each group will consist of at least one member form the healthcare professionals, IT professional in healthcare and blockchain experts. The plan of this focused group is to give each of the group with the common use case and ask them to come up with solutions to identify the possible challenges and opportunities for adoption of electronic health records of patients.

In summary, these three detailed processes are to assist in in answering the research questions of identifying the opportunities and challenges for adoption of electronic health records for patients.

4 Expected Results/Findings

Contribution to Theory and Practitioners

By uncovering opportunities and challenges of the application of blockchain technology within complex healthcare networks, the outcome of this research is expected to contribute to new knowledge of using blockchain technology in inter-organisational applications within the health care industry. Furthermore, to gain insight into the blockchain technology's potential in addressing existing concerns of data security and patients lack of access to and control of their own electronic health record data.

Research Limitations

The focus of this research is mainly on exploring opportunities and challenges associated with use of blockchain technology as a platform for integrating disparate electronic health records stored at different organisations. The blockchain technology's total potential is probably much larger when considering usage for the healthcare supply chain i.e., the usage for tracking of patients, healthcare professionals, drugs and supplies, emergency vehicles and so on.

Originality of study

Based on our study, there are some research taken place in the usage of blockchain in healthcare and other fields. Only limited research has taken place in the usage of blockchain for the electronic health records of the patients. This is based on our limited literature study.

References

A. Azaria, A. Ekblaw, T. Vieira and A. Lippman, "MedRec: Using Blockchain for Medical Data Access and Permission Management," 2016 2nd International Conference on Open and Big Data (OBD), Vienna, 2016, pp. 25-30, doi: 10.1109/OBD.2016.11.

Angraal, Suveen, Harlan M. Krumholz, and Wade L. Schulz. "Blockchain technology: applications in health care." Circulation: Cardiovascular quality and outcomes 10, no. 9 (2017): e003800.

Batubara, F. R., Ubacht, J., & Janssen, M. (2018, May). Challenges of blockchain technology adoption for e-government: a systematic literature review. In Proceedings of the 19th Annual International Conference on Digital Government Research: Governance in the Data Age (pp. 1-9).

Baxendale, G. (2016). Can blockchain revolutionise EPRs?. ITNow, 58(1), 38-39.

Casino, Fran, Thomas K. Dasaklis, and Constantinos Patsakis. "A systematic literature review of blockchain-based applications: current status, classification and open issues." Telematics and Informatics 36 (2019): 55-81.

Chen HS, Jarrell JT, Carpenter KA, Cohen DS, Huang X. Blockchain in Healthcare: A Patient-Centered Model. Biomed J Sci Tech Res. 2019;20(3):15017-15022.

Dubovitskaya, Alevtina, Zhigang Xu, Samuel Ryu, Michael Schumacher, and Fusheng Wang. "How blockchain could empower ehealth: An application for radiation oncology." In VLDB Workshop on Data Management and Analytics for Medicine and Healthcare, pp. 3-6. Springer, Cham, 2017.

Griggs KN, Ossipova O, Kohlios CP, Alessandro N Baccarini, Howson Emily A, et al. (2018) Healthcare Blockchain System Using Smart Contracts for Secure Automated Remote Patient Monitoring. J Med Syst 42: 130

Gupta, Suyash, Jelle Hellings, Sajjad Rahnama, and Mohammad Sadoghi. "Building high throughput permissioned blockchain fabrics: challenges and opportunities." Proceedings of the VLDB Endowment 13, no. 12 (2020): 3441-3444.

Hoy, Matthew B. "An introduction to the blockchain and its implications for libraries and medicine." Medical reference services quarterly 36, no. 3 (2017): 273-279.

Ichikawa D, Kashiyama M and Ueno T (2017) Tamper-Resistant Mobile Health Using Blockchain Technology. JMIR Mhealth Uhealth 5(7): e111

Khezr, S., Moniruzzaman, M., Yassine, A., & Benlamri, R. (2019). Blockchain technology in healthcare: A comprehensive review and directions for future research. Applied sciences, 9(9), 1736.

Kuo, Tsung-Ting, Hyeon-Eui Kim, and Lucila Ohno-Machado. "Blockchain distributed ledger technologies for biomedical and health care applications." Journal of the American Medical Informatics Association 24, no. 6 (2017): 1211-1220.

Liu, Paul Tak Shing. "Medical record system using blockchain, big data and tokenization." In International conference on information and communications security, pp. 254-261. Springer, Cham, 2016.

Maestrini, V., Luzzini, D., Maccarrone, P. & Caniato, F. 2017. Supply chain performance measurement systems: A systematic review and research agenda. International Journal of Production Economics, 183, 299-315.

Mayer, A. H., da Costa, C. A., & Righi, R. D. R. (2020). Electronic health records in a blockchain: a systematic review. Health informatics journal, 26(2), 1273-1288.

McGhin, T., et al. (2019). "Blockchain in healthcare applications: Research challenges and opportunities." Journal of Network and Computer Applications 135: 62-75.

Ølnes, S., Ubacht, J., & Janssen, M. (2017). Blockchain in government: Benefits and implications of distributed ledger technology for information sharing.

Roehrs A, da Costa CA and da Rosa Righi R (2017) OmniPHR: A distributed architecture model to integrate personal health records. J Biomed Inform 71: 70–81

The Norwegian Directorate of eHealth. 2019. A brief overview of health IT collaboration and interoperability in five countries in 2018. ehelse.

Verhoeven, P., Sinn, F., & Herden, T. T. (2018). Examples from blockchain implementations in logistics and supply chain management: exploring the mindful use of a new technology. Logistics, 2(3), 20.

Xia, Bingqing, Dongyao Ji, and Gang Yao. "Enhanced TLS Handshake Authentication with Blockchain and Smart Contract (Short Paper)." In International Workshop on Security, pp. 56-66. Springer, Cham, 2017.

Young, E. (2016). Blockchain in health. How distributed ledgers can improve provider data management and support interoperability, Report.

This working paper is a result by group B in completion of DRL028

Molde University College
Specialized University in Logistics

HiMolde PhD

DRL028 Blockchain Applications in SCM

Credits: 5 ECTS

Time: Week 49, 30 November to 4 December 2020

Supply chains drives the macro economy and global markets. The push towards digitalization and sustainability have intensified the need for interoperability among organisations. Blockchain technologies facilitate coordination of spatially dispersed complex tasks at a low cost. This PhD-course present current research on blockchain applications in supply chains, and offer an opportunity to discuss future applications and research on information sharing in extended supply chains.

Monday 30 November
- Welcome & introduction (By Bjorn, Arvind and Svein)
- Present group work as a Blockchain-SCM Project (Arvind)
- Students presents themselves
- Blockchain technology and SCM (Lecture by Nitin)

Tuesday 1 December
- Paper review & discussion
- Blockchain-SCM Project: Group forming & project ideas
- Blockchain technology and SCM (Lecture by Nitin)

Wednesday 2 December
- Paper review & discussion
- Blockchain-SCM Project: Identify research focus, gap identification & research method

Thursday 3 December
- Lecturer work/research on Blockchain in SCM (Bjorn, Arvind, Svein)
- Paper review & discussion
- Blockchain-SCM Project: Data collection / experimental setup

Friday 4 December
- Blockchain-SCM Project: Group A paper draft presentation
- Blockchain-SCM Project: Group B paper draft presentation
- Blockchain-SCM Project: Group C paper draft presentation
- Summing up

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