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Case Study: Blockchain and E-prescription Process

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Abstract: Healthcare is an industry that highly values security, privacy and accessibility of data between patients and healthcare service providers. Prescriptions are an important part of healthcare services that enable patients to get medicine required for their treatment. About a decade ago, prescriptions were mostly handwritten on paper, today most countries use some form of e-prescription systems. E-prescriptions solved many problems that paper prescriptions had, for example pharmacists correctly not understanding what is written on the prescription and dispensing wrong medicine. E-prescription systems still have problems like lack of interoperability between providers and data security and fragmentation issues. Blockchain is one of the new emerging technologies that enables to securely store data using shared ledger, communicate the data between participants of the blockchain network, perform computational tasks via smart contracts and manage assets. These characteristics have potential to impact healthcare sector including e-prescription process. The thesis investigates how Estonian e-prescription process could be redesigned using blockchain technology. For that a case study is conducted to examine the Estonian as-is state of the e-prescription process and propose redesign based on blockchain technology. During the case study, systematic literature review was conducted on the subject to discover blockchain based redesign opportunities. In addition, redesign heuristics were applied on the as-is model. The results of the case study showed that using blockchain as the underlying technology is possible in Estonian case, but it would no bring significant value compared to existing process and Estonia has solved issues that blockchain can improve using different technologies.

Keywords: Blockchain, E-prescription, Business process redesign, Smart contracts

CERCS: P170 Computer science, numerical analysis, systems, control

Juhtumiuuring: Plokiahel ja digiretsepti protsess

Lühikokkuvõte: Tervishoid on valdkond, kus andmete turvalisus, ligipääs ja privaatsus on olulised. Retseptid on oluline osa tervishoiuteenustest ja on vajalikud, et patsient saaks raviks ligipääsu retsepti nõudvatele rohtudele. Kümme aastat tagasi kasutasid enamus riigid vaid paberretsepte. Tänapäeval on paljudes riikides olemas mingit laadi digiretseptide süsteemid. Digiretseptid lahendasid mitmeid probleeme, mis olid omased paberretseptidele, nagu apteekrite poolt paberretseptidel oleva käsikirja valesti tõlgendamine ja seetõttu vale ravi saamine. Siiski pole kõik probleemid digiretseptidega kadunud. Näiteks on probleemiks andmevahetusalase koostöö puudumine tervishoiuteenust pakkuvate ettevõtete vahel. Lisaks sellele, esineb probleeme digiretseptide turvalisuse, privaatsuse ja andmete ebaterviklikus. Plokiahel on üks tõusvaid tehnoloogiaid, mis võimaldab andmete turvalist hoiustamist hajusraamatus, andmete jagamist hajusraamatu abil, arvutuslike ülesannete täitmist tarkade lepingute abil ja hajusraamatus defineeritud objektide haldust. Need omadused on võimaldavad plokiahela tehnoloogial mõjutada tervishoiusektorit sealhulgas digiretseptide protsessi. Antud magistritöö uurib, kuidas plokiahela tehnoloogia saaks mõjutada Eesti digiretseptide protsessi. Selleks kasutatakse juhtumiuuringu meetodi, et kaardistada kõigepealt praegune Eesti digiretseptide protsess ja disainida see ümber kasutades plokiahela tehnoloogia omadusi. Juhtumiuuringu käigus viidi läbi ka süstemaatiline kirjanduse ülevaade, et leida viise digiretseptide protsessi ümberdisainimiseks. Lisaks kasutati ümberdisainimisel ka spetsiaalseid heuristikaid, mis on loodud protsesside ümberdisainimiseks plokiahela baasil. Juhtumiuuringu tulemus näitas, et plokiahelat saab kasutada Eesti digiretseptide protsessi puhul, aga see ei lisaks uut väärtust võrreldes praeguse protsessiga. Eesti on lahendanud probleeme, mida saab teha plokiahela abil teiste tehnoloogiatega.

Võtmesõnad: Plokiahel, Digiretsept, Äriprotsesside kujundamine, Nutikad lepingud

CERCS: P170 Arvutiteadus, arvutusmeetodid, süsteemid, juhtimine (automaatjuhtimisteooria)

Contents

1 Introduction

Healthcare industry is one of the biggest and most important industries in the world, swallowing around 5-14% of GDP in developed countries [1]. Healthcare industry is technology driven and throughout the digital era more and more healthcare services have been digitized. One of the healthcare industries digital transformations is e-health. E-health systems make medical services available to patients digitally for example via internet. E-health services are becoming more popular around the world and the range of different e-health services is increasing. Digitizing health services has made improvements in the processes and accessibility. One major part within the e-health is e-prescription, that has been made available electronically in many developed countries and involves multiple different stakeholders in the process.

Prescriptions are important part of healthcare services. Doctors often prescribe medicine and patients buy prescribed medicines from pharmacies. It is important that the prescribing process works accurately, and error rate is as small as possible. For example, assigning a wrong dosage for example, can cause harm to patients' life. Before the introduction of e-prescription, prescriptions used to be written on paper and patients would go to the pharmacy where pharmacist filled the prescription. Currently e-prescription has been used in US and various EU countries for almost a decade and number of countries that use e-prescription systems is increasing [2]. Paper prescriptions were much more error prone than e-prescription. Introduction of e-prescriptions helped to reduce risks like medicine interactions or assigning wrong dosage by offering doublechecks [2]. Still, even with the introduction of e-prescriptions prescribing errors haven't totally disappeared [3]. Making errors is not only potentially harmful to patient, but also means more work for pharmacists and costs time for the patient. In addition, e-prescription process includes many different stakeholders and data is accessed from different sources like insurance, medication databases etc. This requires that shared data is secure, valid and accessible. Different providers often do not have data sharing systems in place with other providers and therefore there exists lack of interoperability between healthcare providers [4]. This may cause doctor to make wrong treatment plans, since other prescriptions that the patient has received may not be visible to the doctor and cause harmful medicine interactions. Querying the data is time consuming and, in the end, affects the patient treatment. Although e-prescription solved many paper prescription related problems, as technology advances, possibilities to improve e-prescription should be considered. One of the new technologies that has gained attention worldwide over the last decade is blockchain, that could possibly also innovate e-prescription process.

Blockchain technology became widely known with the creation of Bitcoin in 2008, which is one of the most popular use cases of blockchain until today [5]. Bitcoin is a decentralized cryptocurrency that uses blockchain technology to perform anonymous digital transactions online [5]. However, Bitcoin may currently be one of the most popular use cases of blockchain technology, it is only scratching the surface of potential benefits of the technology. Key aspect of blockchain which makes it a revolutionary technology is, that transactions in the system are not fully controlled by one centralized authority [5]. Blockchain uses decentralized distributed database that contains all the information about transactions made by participants in the blockchain network. All transactions must be approved by the majority of participants in the network and are recorded in a distributed ledger. Second main benefit of blockchain is integrity [5]. When the transaction is recorded in a block, it is very hard if not almost impossible to tamper the recorded data. These new ways of verifying transactions and storing data securely has made blockchain one of the most disruptive new technologies that could affect many big industries currently existing [6].

To investigate the possibilities of innovating e-prescription process using blockchain as the underlying technology, this thesis focuses on the case of e-prescription in the context of Estonia. Estonia is an information society that has been the leader in different digital innovations like e-government, that has made all government services available online [7]. Estonia is also a pioneer of e-prescription. Estonia is ambitious to move to the next level in digital innovations, which makes it a great selection to analyse how to apply new technologies and innovate its important services. The research objective is to investigate if and how blockchain technology can improve existing e-prescription process in Estonia.

To answer the research question, a case study is conducted. During the case study, current e-prescription process in Estonia is defined. Then the current process is analysed and redesigned using Blockchain as the underlying technology. The redesign helps to understand, if and what could be done better in e-prescription process using blockchain technology. The results of this thesis may be of interest to all governmental agencies working with digitalizing processes. Also, developers, analysts project managers etc. who work with blockchain implementations in government agencies.

The remainder of this paper is structured as follows. Second chapter introduces the background of blockchain and e-prescription. Third chapter explains case study research methodology that is used to study e-prescription process in Estonia. In fourth chapter results are presented of systematic literature review, which is part of the case study. Systematic literature review is done in the domain of blockchain and e-prescription to gain insight on how blockchain could affect e-prescription. In fifth chapter, the results of the case study are presented including as-is and to-be process models and they are discussed. In sixth chapter, conclusions are made.

2 Background

In this chapter, background information regarding blockchain and e-prescription is explained.

2.1 E-health

The term e-health first gained popularity in the late 90's and was used when implied to healthcare services related to computers and the internet [8]. There hasn't been one clear definition of the term "e-health", but all definitions include relationship between health and technology [9]. Most cited definition by Eysenbach is: *"e-health is an emerging field in the intersection of medical informatics, public health and business, referring to health services and information delivered or enhanced through the Internet and related technologies. In a broader sense, the term characterizes not only a technical development, but also a state-of-mind, a way of thinking, an attitude, and a commitment for networked, global thinking, to improve health care locally, regionally, and worldwide by using information and communication technology"* [9]. Information technology has been taken into use in healthcare industry in waves [10]. Firstly, healthcare industry used information technology to process statistical data and automate repetitive tasks. The second adaption of information technology in healthcare industry included integrating different parts of core processes within organizations and digitization was also used to support business to business processes. Third adaption is moving towards full digitization. This is still an ongoing process that many countries and private institutions are moving towards.

2.2 Prescribing and E-prescription

Prescriptions are necessary to acquire prescription medicine for treatment. Prescribing is done by licensed medical expert who determines treatment plan for the patient. Before e-prescribing systems were in place, prescriptions were written on paper prescription templates. The patient would take the paper prescription to a pharmacist who fills prescription. Paper prescription however caused various errors. Information written on the prescription like introduction how to take the medicine was sometimes unclear and caused adverse medicine events, which could potentially harm the patient or even cause death. Unclear prescriptions could also make the pharmacist declare the prescription invalid and the patient would have to go to a doctor to get new prescription which costs time for the patient. With paper prescriptions it was also hard to detect medicine interactions which meant that the patient could end up administering two different medicines that do not interact safely. [2]

With digital advancements in healthcare industry e-prescription started to replace paper prescription in late 2000's [2]. Prescribing process via digital system is different to paper prescribing. When the doctor determines that patient needs a prescription medicine, he writes a digital prescription on the computer. Digital prescription is sent over the internet to a database that pharmacies can also access. When the patient goes to a pharmacy and presents identification the pharmacist can access and dispense prescription. The system also checks whether the patient is insured and should receive discounts [11]. E-prescription helped to reduce many errors that occurred in paper prescribing process [2]. E-prescription is not handwritten and therefore occasions of adverse medicine effects due to unreadable instructions do not occur. E-prescription also helps to keep record of prescription medicine used by the patient to avoid medicine interactions which can occur for example when different doctors prescribe medicine to a patient. Although, accessing previous records is often not possible due to lack of interoperability between different healthcare providers [4]. In addition to reducing errors that may cause harm to patients, e-prescription system also helps to reduce costs. For example, time for typing in paper prescriptions and time spent dealing with paper prescriptions that included errors was reduced [2]. Although e-prescribing systems have reduced errors significantly, they are still not completely eliminated [3]. A study which investigate e-prescription errors in community pharmacies concluded that pharmacists still detect various errors in prescriptions. Most common errors were wrong medicine quantity, wrong dosing directions, wrong duration of therapy, and wrong dosage formulation [3]. Main causes for these errors were poor integration of different medical systems not e-prescription system per se [3].

In Estonia e-prescription was implemented in 2010. 99% of prescriptions are prescribed using this centralized paperless system. Estonia’s e-prescription system has access to patient’s insurance status and therefore can determine and assign medical subsidies when buying prescription medicine. The system also enables to refill prescriptions by contacting the doctor via phone or email. [12]

2.3 Blockchain

In 2008 Satoshi Nakamoto published his whitepaper “Bitcoin: A Peer to Peer Electronic Cash System”, that described an electronic currency which used blockchain technology. This event was the start of blockchain becoming more and more popular over the last decade. [13] Bitcoin has been described as the email of the internet, meaning that it is just the first widespread adoption of blockchain technology, that potentially has much greater applications in the different fields and can be called a disruptive technology [14]. Blockchain in its nature is a distributed public ledger that stores all digital events and transactions that have been executed in the blockchain network [5]. Transactions must be agreed by the majority of the nodes in the network to reach consensus. When the information is stored in the blockchain it cannot be removed or tampered with and therefore history of transactions is safely stored in the blockchain. One major reason for blockchains success is that it can offer a decentralized distributed ledger meaning that there is no need for central intermediary authority, for example banks to verify different types of transactions. [5]

2.3.1 Architecture

Blockchain is constructed of sequential blocks that together stores the entire transaction history [15]. One block consists of block header and block body. The body of the block contains transaction counter and transactions. The most important information that a typical header includes is **timestamp**, **a nonce**, which is a random number to verify hash, **block hash,** which represents transaction data in a hashed form and **parent block hash**. The parent block hash points to a previous block. First block in a blockchain is called a *genesis* block and it has no parent block. This concept of pointing to parent blocks ensures the integrity of the blockchain up to genesis block. If the hash value of one block is changed through altering its data, then all the hash values of blocks that come after the modified block would also have to be changed. [15] Example of blockchain that is built from blocks can be seen on Figure 1.

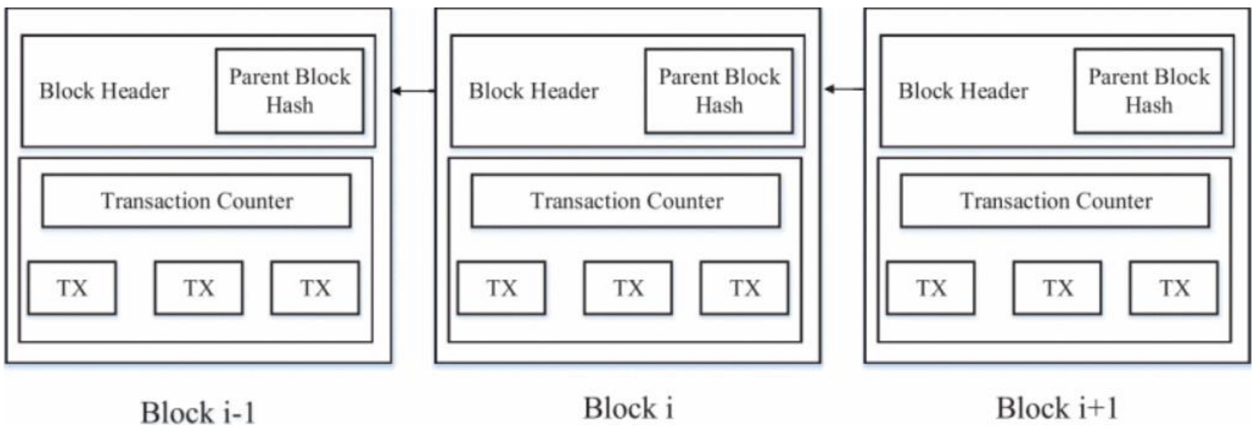

Figure 1. Blockchain of sequential block [15].

Adding new blocks to the blockchain works based on a consensus mechanism. Blockchain ledger is distributed between the nodes of the distributed network. If the nodes reach consensus on the transactions in the block and the validity of the block itself, then the block is added to the distributed ledger and becomes part of the chain. There are various consensus mechanisms. One of the most popular consensus protocol in public blockchain is PoW (Proof of Work). Different nodes in the network called miners compete to add the block to the ledger. For a node to add a block to the ledger it has to first perform mathematical puzzle for calculating the hash of the block. When a node solves the puzzle, it broadcasts the calculated block hash value to other nodes who confirm the correctness of the hash. If it is correct, then the block is added to the blockchain and the distributed ledger is updated. Nodes calculating these values are called miners. To solve these puzzles miners have to spend resources, usually electricity and therefore the node that solves the puzzle is usually rewarded. This reward serves as an incentive to be a miner. As long as the half of the nodes are not controlled by one malicious party, the PoW consensus does not enable to generate new blocks faster than honest miners/nodes.

Permissioned blockchains use different consensus mechanism that have previously been agreed for example Byzantine consensus protocol. The cryptographic hashing and the consensus mechanism make blockchain tamperproof and ensure its integrity. [15]

2.3.2 Public, Private and Consortium Blockchain

Blockchain systems can be divided into public, consortium and private blockchain. In case of public blockchain, distributed ledger is available publicly, which means transactions data is accessible to everyone who are part of the network. Public blockchains is completely decentralized, meaning no central authority has control over the blockchain, including its participants. [15]

In case of consortium blockchain nodes that can take part in the consensus process are previously selected. This means that consortium blockchain is permissioned blockchain. Consortium blockchain is constructed by different organizations and since nodes who can take part in consensus process are selected this type of blockchain can be determined as semi-decentralized. [15] Consortium blockchain can be used by enterprises for collaboration by taking advantage of blockchain possibilities for optimizing processes [16]. Compared to public blockchain it can be easier to tamper with transaction data in consortium blockchain because there are only selected and fewer nodes who take part in consensus process. [15]

Private blockchain is also permissioned blockchain. Nodes who take part in the consensus process usually belong inside an organization. This makes private blockchain more centralized in its nature, because one organization has control over the consensus process and the organization decides which nodes inside it can take part in the consensus process. Like in consortium blockchain, altering data in private blockchain can be easier compared to public blockchain. This is possible, because of limited number of nodes participating in the consensus process and they are also controlled by the organization. On the other hand participants of the private blockchain are usually identified, so harmful activities can be linked to a person. [18]

Public blockchain is usually used for different cases than private or consortium blockchain. In public blockchain there is not trust between the participants and often they do not know each other. There is no central authority that can decide who can participate in the network. Most popular example of public blockchain is Bitcoin. In case of private and consortium blockchain the user i.e. the node of the blockchain system is identified. This enables the organizations and enterprises to define who and what they can read or write on the blockchain system. These possibilities also enable to set different rights for nodes in the system and if someone breaks the rules it can be seen. Because private and consortium blockchains only contain selected nodes which number is usually lower than public blockchain they do not suffer from scalability and transaction speed issues like public blockchain does. Permissioned blockchain also enables to enforce stronger confidentiality measures. For example, Hyperledger Fabric, which is discussed in further chapter, enables private channels within the network to protect company secrets. These characteristics make permissioned blockchain solutions more usable in different business scenarios especially when business process requires multiple entities to be completed. Public blockchain is more used in cases where the main target is the customer. [17]

2.3.3 Challenges of Blockchain

Blockchain has great potential to solve many problems, since it is rather new technology it also faces different challenges. One of them is scalability. Every node on the traditional blockchain network holds a copy of the ledger that is necessary to validate if resources of the transactions are already spent or not. Operating on this large database increases time spent for transactions. Transaction speed is also affected by block size and time interval used when adding new blocks to the chain. For example, Bitcoin can process about 7 transactions per second. That becomes an issue when millions of transactions are done in real time. [15] In contrast, VISA credit card can handle up to 15000 transactions in peak times and 2000 transaction regularly [18]. There are solutions proposed for solving scalability issues. Some of them are more modest like making block size bigger and others propose redesign blockchain or not requiring a node to store a full copy of transaction history.[15] Other challenge that blockchain could face is privacy leakage [15]. This means that although blockchain offers privacy, it is possible to link transactions to user information. Since mining activities requires significant amount of electricity, blockchain is also causing waste of resources [18]. Blockchain also faces a challenge of public perception [18]. Since this technology is rather new people do not rush to trust it. Trust has also been affected by Bitcoin which has been surrounded by different scandals. This uncertainty means that it also takes time and explanation before people would feel at ease when keeping their personal information stored on blockchain based system.

2.3.4 Smart Contracts

One concept that the further development of blockchain technology has enabled, is smart contracts. Idea of smart contracts was proposed about 20 years ago, but technology to implement it was not sufficient at the time [19]. Blockchain technology has made it possible to implement these new kind of contracts [19]. Blockchain enabled smart contracts are a step further from traditional blockchain based currency transactions. Smart contracts are contracts that are executed automatically by code algorithm, when predetermined conditions for the contract are met. This means the transaction on blockchain is fulfilled when specified conditions of a smart contract are met by participants in the contract. For example, a smart contract could be used to send payment to a seller when the shipment has arrived. Another example of smart example on blockchain could be regarding inheritance gift. The gift would become available when the receiver of the gift is at least 18 years old or in case of the bequeather death. Smart contracts could make inquiries to different databases to obtain information needed for verifying conditions. Smart contracts could also be used to determine ownership of properties. These properties could be tangible like houses, or intangible like shares.

2.3.5 Oracles

To use data outside of the blockchain system for smart contracts a blockchain oracle could be used [20]. Oracle enables to access and use data in blockchain system from outside of the system, access a real-world data. Oracle is a gateway to the data not the database itself. Data received via oracle can be used to check whether the conditions of the smart contract are met or not. There are different types of oracles. Software oracle uses outside information that is available online, for example market data. Software oracles obtains the information online and check whether a smart contracts conditions are met or not. Second type of oracle is a hardware oracle. This type of oracle uses data from real world for example through different type of sensors like RFID or Iot sensors and barcode scanners etc. Main issues with hardware sensors are ensuring security when transferring data. Oracles can also be divided into inbound and outbound oracle. An inbound oracle uses external data for completing a contract in blockchain. An outbound oracle sends inside data out if the conditions are met. Biggest challenge of using an oracle in blockchain network is ensuring that data received via oracle is valid, because the oracle itself does not participate in the consensus process. [20]

2.3.6 Hyperledger Fabric

Hyperledger was created in 2016 by the Linux Foundation [21]. Hyperledger is an open source collaborative effort to advance enterprise grade blockchain technologies. Hyperledger Fabric is one of the most successful Hyperledger projects and is started by IBM. Fabric is designed to create permissioned blockchain applications with modular architecture and allows different components to be used as plug and play. The platform is meant to be used in business applications by enterprises that can tailor their specific needs into the implementation. Fabric offers some capabilities that other popular distributed ledger or blockchain cannot and proposes to solve common blockchain limitations regarding flexibility, scalability, resilience and confidentiality. Development community of Fabric is divided and over 35 organizations with more than 200 developers participate in the effort to develop Fabric even further. [21]

Hyperledger Fabric has modular design, which makes it easier to customize for different business use cases, because there is not one standard of blockchain to be used in all applications. At generalized level Hyperledger Fabric can be divided into six modules [21].

- Ordering service, which is pluggable and is used to establish consensus on the order of transactions and broadcast blocks to peers.
- Membership service provider, which is pluggable and is used to link participants of the network to cryptographic identities.

- Optional peer to peer gossip service, which can be used to spread blocks output by ordering service to other peers.
- Chaincode i.e. smart contracts. Smart contracts are called chaincode in Hyperledger Fabric. They can be written in standard programming languages and run in container environment.
- A ledger, that can be set up to support different database management systems.
- Endorsement and validation policy enforcement, which is pluggable and can be configured for different applications.

Consensus process in Hyperledger Fabric traditionally uses crash fault tolerance or byzantine fault tolerance protocols. These protocols require knowing the identity of the participants in the blockchain. As Hyperledger Fabric is permissioned blockchain and has membership service provider. If someone were to exploit the blockchain system, then this behaviour could be linked to an identity in real world. [21]

Smart contracts in Hyperledger Fabric are called chaincode. Chaincode can be written in standard programming languages like Java, Node.js, Go and do not require knowledge of domain specific programming language to construct contracts. This enables companies to create smart contracts without needing additional training.

Many current blockchain platforms that enable smart contracts like Ethereum use order-execute architecture. In order-execute architecture the consensus protocol validates and orders transactions and after that broadcasts them to all other peers. After a peer node has received data it executes transactions sequentially. This architecture causes scalability issues as was introduced in previous chapters. Hyperledger Fabric uses execute-order-validate architecture that helps to solve problems regarding scalability, performance, flexibility and confidentiality. This model divides transaction flow into three steps [21].

- Execute a transaction and check its correctness, thereby endorsing it,
- Order transactions via consensus protocol, and
- Validate transactions against an application-specific endorsement policy before committing them to the ledger.

Main difference with order-execute model is that Fabric executes transactions before reaching final agreement on their order. The architecture enables to execute transactions on subset of nodes not requiring all of them. Enterprise policy can specify how many nodes are needed for endorsement, since Fabric is customizable to different enterprise needs. Enabling transaction executions on subset on peers allows parallel execution of transactions. This improves performance and solves scalability issues. [21]

Hyperledger Fabric also stresses privacy issues. In public blockchain every node in the network executes the transaction and this means contract data and transaction data is accessible to everyone.

Enterprises however require confidentiality and security, for example to hide contract details from some parties or hide company secrets from competitors. Since Fabric is a permissioned blockchain and enables confidentiality through its channel architecture, participants in Fabric based network can create a channel between desired subset of participants who can access data about the transaction. This is useful for cases where privacy is a must. [21]

2.3.7 Current Application and Future Trends of Blockchain

Blockchain applications can be divided into financial and non-financial applications. Currently there are more blockchains solutions implemented in financial industry, but the number of non-financial applications are growing. Examples of financial applications include [19] :

- Different cryptocurrencies
- Securities issuance, trading and settlement - blockchain enables to trade some shares directly
- Insurance - some companies enable to track properties using blockchain
- Notary public - notary type authorization on blockchain

Non-financial applications [19] :

- Music industry - paying royalties and managing rights
- Decentralized proof of existence of documents - validating document using blockchain
- Decentralized storage - sharing documents without centralized mediator
- Decentralized internet of things - storing communication of Iot devices
- Anti-counterfeit solutions - verifying products via blockchain

There are many possible directions for future applications of blockchain. Since one of blockchains main benefit is to decentralize systems then blockchain will probably innovate traditional business models which currently use central agencies for validation [19]. Blockchain could also be used for data management and data analytics [15]. With the help of blockchain, data could be safely stored using its distributed nature. For example, health data is one area where safe storage is necessary. Regarding analytics, blockchain transactions could be analysed and different patterns and predictions could be concluded from that data.

3 Case Study

In this chapter, case study research of the methodology is described and explained why it is chosen for the thesis. Then the case study design for this research is presented where main steps of the case study are brought out. This is followed by the execution of the case study.

3.1 Case Study Research Methodology

The thesis uses case study research methodology. Case study method has been and is used in many areas for research. General objective of case study research strategy is to gain knowledge about a phenomenon and propose changes to the phenomenon researched. At first, case study research strategy was not widely adopted in software engineering community as in some other fields, but today it is a recognized strategy for research on software engineering field. First guide to use case study in software engineering research was published in 2009, however first mentions of using it in software engineering research were in mid-1990's. [22]

Case study is defined as an empirical type of research looking into contemporary phenomena in real-life context using multiple sources of evidence for investigation, especially when boundary between context and phenomena is not clearly specified [22]. Data to explain the phenomenon is collected during the case study and can be qualitative, quantitative or both, but tends to be more of the qualitative type. Case study tends to be flexible in design, meaning during the study key parameters may be adjusted opposed to fixed study where parameters are fixed from the start and do not change. Case study method is suitable for exploratory purposes and to research about the adaption of new technology as case-study investigates phenomena in real-world setting [22]. Characteristics of case study match requirements for this research, as the goal of this thesis being to research ways of using a contemporary phenomenon *blockchain technology* to redesign *e-prescription* process in real-life context. [22]

Case study research strategy follows a framework for the research process. Following the framework enables the research to be replicated, which is important aspect of scientific research. Main steps of a case study include [22]:

1. Case study design – objectives of the case study are described, and the study is planned
2. Preparation of data collection – strategy for data collection is defined
3. Collecting evidence – gathering data according to strategies defined
4. Analysis of collected data – previously collected data is analyzed
5. Reporting – results of the study are reported

However, these are general steps of the case study and each study might implement different steps in slight variation [22]. For this thesis, the overall steps are followed in conducting the case study.

3.2 Case Study Design

As discussed in previous chapter, case study is flexible design in its nature, but this does not mean that clear objectives are not defined from the beginning of the case study. Flexibility is expressed in being able to accept some changes, but not in becoming a new study in the middle of the process. Main steps of this case study are brought out in Figure 2.

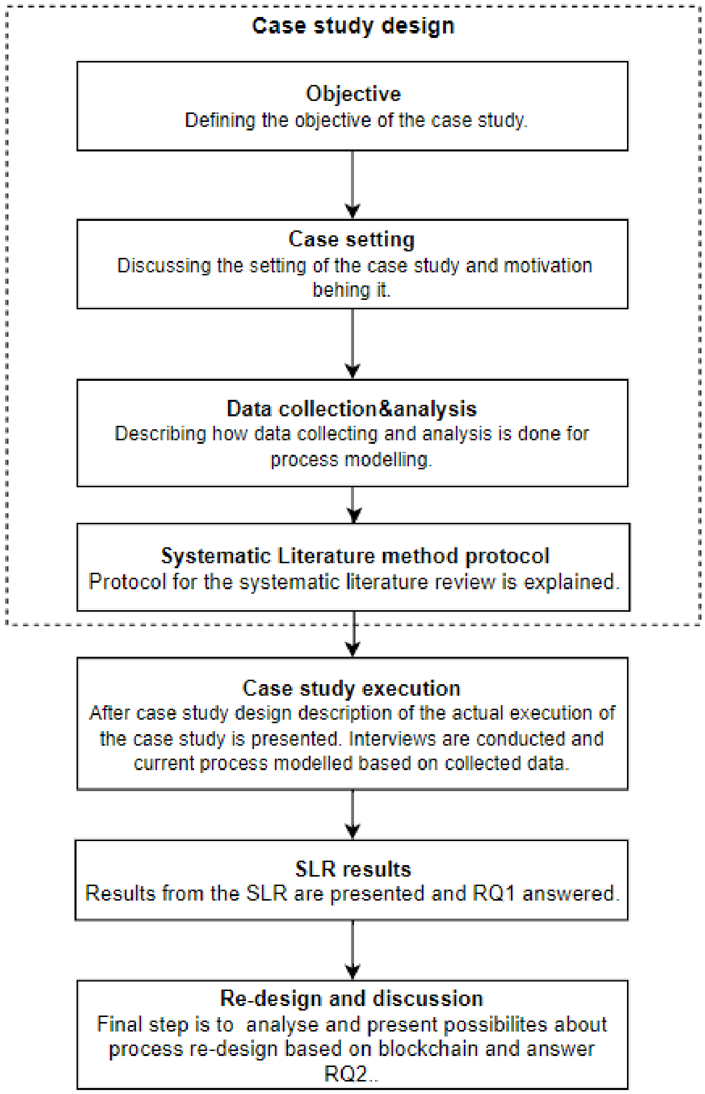

Figure 2. Steps of case study.

3.2.1 Objective of the Study

The main objective of the case study is to explore, if and how blockchain technology can be used to improve e-prescription process in Estonia and if it can, then how it affects the current process. For that the current process is mapped and redesign proposed based on blockchain technology. Redesign possibilities are analysed and positive/negative changes compared to the existing process. From the general objective of the case study, following research questions were defined for the study:

RQ 1: How can blockchain technology improve e-prescription process?

RQ 2: What value e-prescription process using blockchain as underlying technology can bring in case of Estonian e-prescription?

RQ1 aims to understand aspects of e-prescription, that blockchain can affect. To answer *RQ1* a systematic literature review is conducted on the topic. *RQ2* aims to explore, if and how using blockchain as an underlying technology, Estonian e-prescription process can be redesigned. The results of *RQ1* are used as input for answering *RQ2,* by investigating aspects, that blockchain enabled to improve in papers reviewed, impact Estonian e-prescription process.

To fill the objectives of the case study a case must be selected for the study. To find the case for the case study some criteria has to be fulfilled. First, they have to do e-prescription and there should be maturity to the e-prescription process. Secondly, it is important that there is access to information in form of documents, domain experts and stakeholders.

3.2.2 Case Setting

Based on the criteria for the case selection, the case is set to explore how Estonian e-prescription process can be redesigned using blockchain technology as underlying technology. Estonia is an information society that has been the leader in different digital innovations like e-government, that has made government services available online and is also one of the pioneers of e-prescription system [7]. Estonia is ambitious to move to the next level in digital innovations, which makes it a great selection to analyse how to apply new technologies and innovate its important services. There is also access to domain experts and documentation about Estonian e-prescription that is vital for the case study. Described characteristics make Estonia’s e-prescription process suitable for the case study and thus, is used for the research.

3.2.3 Case Study Data Collection and Analysis

One important aspect of the case study is data collection. In this case study, main data for the study is gathered in multiple ways to ensure data and method triangulation. Data is gathered by direct (interviews) and indirect (document analysis) methods.

Direct way of data collecting is done through unstructured interviews where previously set out main themes are discussed with the representative domain experts of the e-prescription in Estonia from Estonian Health Insurance Fund. The main objectives of the interviews are the following:

- Process discovery. Collect data about current state of the Estonian e-prescription process.
- Collect data about possible problems and limitations with the current e-prescription process.

Indirect way of data gathering is document analysis. Documents about the e-prescription process that are available publicly or will be provided by domain experts are gathered and analysed to fill in possible gaps from the interviews and uncover new aspects that might not be discussed in the interviews.

After gathering the data from interviews and documents, the data is analysed to construct the current as-is business process of Estonian e-prescription and map possible issues with the process. For that, the interviews conducted during the data collection are transcribed. Transcriptions are used for mapping the as-is e-prescription process and identifying main limitations of current e-prescription system. Document analysis is done by examining the documents.

During the case study, bulk of the study is gathered in the initial phase of data collection. However, some data is also collected in later stages to verify results of process discovery, business process models that were constructed based on the data gathered in initial stages.

In final phases of the case study the redesign of the current e-prescription process based on blockchain is presented to domain experts and their feedback of the models is gathered. Main workflow of data collection and analysis is described in Figure 3.

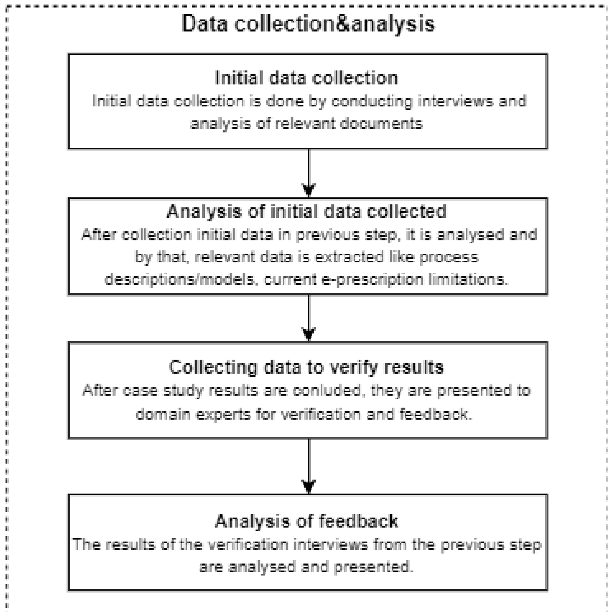

Figure 3. Data collection and analysis workflow.

1. Initial data is collected, about the current state of the e-prescription process in Estonia is which is needed to understand how e-prescription currently operates in Estonia and later propose a redesigned process using blockchain. This is done via interviews and gathering documents on the topic that are available publicly or provided by the domain expert.
2. Data that was gathered is analyzed and as-is description and models of the current e-prescription process of Estonia is constructed. For that, the interviews are transcribed, and transcriptions used for mapping the current state. Documents gathered are analysed to gain more insights that might have been missed during the interviews.
3. After the as-is state of e-prescription in Estonia is described and mapped the results are presented to domain expert in interview format to verify them. If necessary, several iterations are made to map the as-is state. Finally, after the to-be model of the e-prescription process based on blockchain is constructed, the results are presented to the domain expert in interview format. During that interview data is collected regarding the feedback of the proposed redesign and presented after analyzing it.

3.3 Systematic Literature Review Protocol

In order to understand how blockchain can affect e-prescription process, specially what aspects of the e-prescription benefit from using blockchain a systematic literature review (SLR) is done. Insights gathered as the results of the SLR will be used as an input to proposes possible redesign for Estonian e-prescription process and therefore answer *RQ2*. To find such papers describing how blockchain can affect e-prescription, a systematic literature review is conducted. Systematic literature review helps to define important research on the topic in a systemic way and the search strategy is defined before the research is conducted [23]. The SLR is done by following the main guidelines proposed by Kitchenham [23]. Systematic literature review process consists of three main parts which are planning, conducting and reporting the results of the review.

3.3.1 SLR Research Questions

Research questions are defined to guide the review and the research aims to answer proposed research questions. The aim of the SLR is to determine important publications that address the topic of using blockchain technology in e-prescription process. Following research questions are defined:

(SLR)RQ1: What were the characteristics and problems of the prescription process before blockchain technology was considered as the underlying technology?

(SLR)RQ2: What are the characteristics of blockchain based e-prescription?

The first SLR research question aims to understand what the driving factors were to consider using blockchain in e-prescription. The second SLR research question aims to understand what the characteristics of blockchain are based prescription and what aspects blockchain affects.

3.3.2 Search Strategy

Search strategy for the SLR is based on defining search strings from the proposed SLR research questions and main topic of the thesis. Then developed search strings are used in relevant electronic databases [23]. With this search strategy initial set of papers are defined.

Search Strings and Sources

Search strings are formulated based on the research questions and following instructions suggested by Kitchenham [23]. The aim is to generate search terms in transparent way for replicability. The research questions are broken down into individual features and synonyms for these features are found. Then search strings are constructed using Boolean ANDs and ORs. [23]

Terms extracted from the research question are *"blockchain"* and *"e-prescription"* that are also the basis of the main concept of this thesis. Synonyms are also generated for the term *"e-prescription"* since there are various ways to refer to e-prescription. Synonyms are used in search strings to avoid missing important papers for the review. Synonyms of the term *"e-prescription"* that are used in constructing the search string are *"digital prescription"*, *"electronic prescription"*, *"prescription"*. Since *"prescription"* already incorporates *"digital prescription"* and *"electronic prescription"*, only *"prescription"* is used as alternative to *"e-prescription"*.

Based on the terms following search strings were defined to be used in electronic databases:

((“blockchain”) AND ((“e-prescription”) OR (“prescription”)))

Constructed search string was used in multiple electronic databases. Databases that include scientific papers in the field on computer science were chosen in cooperation with the supervisor of the thesis. In Table 1 databases used for the SLR are described.

Table 1. Electronic databases.

Database	Abbreviation	Organization
Scopus	SCP	Elsevier
Web of Science	ISI	Thomas Reuters
IEEE Xplore	IEEE	IEEE

When selecting databases, it was also considered that the university would have a free access to the database.

3.3.3 Paper Selection Criteria

In this chapter paper selection criteria are defined. Paper selection criteria is necessary to select studies that are relevant according to the research questions [23]. There are two types of criteria defined, inclusion and exclusion criteria. Next is described the criteria based on which the paper is either included or excluded.

Inclusion criteria:

IC1: Include if the paper in the domain of blockchain and e-prescription/prescription.

IC2: Include if the paper proposes way of managing e-prescription that is based on blockchain technology.

IC3: The paper is peer-reviewed (journal article, conference paper).

Exclusion criteria:

EC1: Exclude if the full text version of the paper is not available and accessible. Papers that are not accessible via University access or free access are excluded as they cannot be read.

EC2: Exclude if the paper is not written in English. If the paper is not written in English, it is excluded as the contents of the paper cannot be understood by the author.

EC3: Exclude if the paper is a duplicate. One type of duplicate that is excluded is duplicate when the same author has published a paper with same title in different digital libraries in the same year. These duplicates are called exact duplicates. Other type of duplicates are version duplicates when there are multiple versions of the same paper. In that case most complete version is included [23].

EC4: Exclude if the paper is less than 4 pages. Papers less than 4 pages are excluded as it is unlikely, they will go in depth to the topic and propose valuable ideas on blockchain improving e-prescription.

3.3.4 Conducting the Review

In this chapter the review is conducted based on the aspects described in previous chapters. First the search string is used to query previously determined electronic databases. Number of initial query results can be seen in Table 2. After that, the retrieved papers are filtered by duplicates, non-English content, accessibility and paper length. In Table 2 the summary of papers remaining after each step of filtering is shown.

Table 2. Filtering results.

Filter name	*Nr. of papers remaining*
Initial search results	50
Filtered by duplicates	33
Filtered by paper format/access	32
Filtering by title	23
Filtered by abstract	7
Remained for full examination	7

Filtered by duplicates – Following exclusion criteria EC3 17 duplicates were removed and 33 papers remained.

Filtering by paper format/access – Following exclusion criteria EC1, EC2 and EC4, papers that were less than 4 pages long or were not written in English or were not accessible were removed. During this filtering stage I detected one paper that needed to be excluded

Filtering by title – Taking account Inclusion criteria IC1, IC2, titles of the remaining papers were reviewed. Nine papers were found to be irrelevant and removed from further examination.

Filtering by abstract – Abstracts of the 23 papers were read and assessed according to inclusion criteria IC1, IC2, if the papers were relevant for the SLR. Thirteen papers were removed during this filtering step and 7 papers remained for the final review.

3.3.5 Data Extraction Strategy

Data extraction strategy is defined to extract data from final set of papers in documented way. A form is generated for data extraction as is suggested by Kitchenham to reduce opportunity of bias [23]. Data extraction form is designed to address the previously proposed review questions. Data extraction can be seen in Table 3 below.

Table 3. Data extraction form.

Information about the paper	
Id	Identifier of the paper
Title	Title of the paper
Authors	Authors of the paper
Publication year	Year the paper was published
Data about blockchain integration in e-prescription process	
Previous state of prescription process	What were the characteristics of the prescription process before integrating blockchain to the process

Possible drawback of pre-blockchain process	If existing, issues that lead to blockchain based e-prescription system
Type of blockchain	Type of blockchain used. This is important as different types of blockchain (public/private), could have effect on process
Data storage	Way of storing the data, for example on chain or off chain data storage. Relevant factor since data handling can impact processes
Main characteristics of blockchain based e-prescription process	What are the characteristics of blockchain based e-prescription

Table consists of two main parts. First part of the form collects main metadata about the paper. Second part of the data extraction form collects data about blockchain based e-prescription that is discussed in the researched papers. Final set of papers were reviewed by the author of thesis and data extraction form was filled the papers. Finally, the collected data is aggregated and summarized regarding the research questions. Results of the SLR are presented in chapter 4.

3.4 Case Study Execution

Case study design that was described in section 3.2 was executed to reach objectives of the case study. Execution of the case study was done in the following steps.

1. Interview was conducted with Estonia's e-prescription domain expert who works for Estonian Health Insurance Fund - an agency that manages prescription center that is responsible for e-prescription. The objective of the interview was to gather information of the current process of e-prescription in Estonia and lasted around 90 minutes. The interview was done in unstructured format but followed main themes to achieve the goal of the interviews. Main themes were:
    - *a.* Introducing the research.
    - *b.* Gathering information about e-prescription business processes.
    - *c.* Gathering possible issues with the e-prescription process in Estonia.

   During the interview, the interviewee also provided documents about e-prescription that could be used.

2. Interview was conducted with domain expert from Cybernetica AS. Aim of the interview was to gain more understanding about X-Road and Estonian information systems in order to understand their characteristics and analyze their capabilities compared to blockchain. Interview lasted around 70 minutes and was semi-structured in nature. Interview was recorded and transcribed.
3. Documents were reviewed about:
    a. Estonian Prescription center services [24]
    b. Detailed analysis of implementing e-prescription [25]
    c. Presentation used by domain expert when discussing e-prescription
4. Based on the interview and documents described in previous points process discovery was done. The current state and as-is business process of e-prescription was described and modelled using Business Process Model and Notation (BPMN). After creating as-is models of e-prescription process in Estonia the models were verified with the domain expert to ensure the process was captured correctly. Few corrections were made, but overall models were correct.
5. Searching papers for concepts and frameworks/techniques about using blockchain technology in e-prescription was done, to discover techniques and frameworks to redesign the as-is process model using blockchain technologies. This was necessary to find ways to redesign the as-is model so that it would be done using proven concepts. The research was done using systematic literature review, which protocol was introduced in chapter 3.3.
6. Redesigning the as-is model using opportunities and techniques found during the SLR and based on special *process redesign heuristics for blockchain solutions* was conducted.
7. Presenting the to-be business process model to representative domain expert and gathering feedback whether the proposed to-be model fulfills requirements for e-prescription process in Estonia and if it offers additional value compared to current e-prescription process. It was done in form of interview and lasted around one hour.
8. Discussion. Analyzing and evaluating the created to-be e-prescription process based on feedback collected and comparing it to the as-is process.

4 Results of Systematic Literature Review

In this section the results of the SLR are presented. Relevant findings addressing the research question are discussed and *RQ1* is answered regarding how blockchain can improve e-prescription process.

4.1 Pre-blockchain Prescription Systems Characteristics (SLR)RQ1

In this subsection findings of the SLR about the characteristics and problems of the prescription process before blockchain technology was considered as the underlying technology *(SLR)RQ1*, are discussed. Reviewed papers mostly defined states of the prescription process/system that were improved using blockchain technologies and what issues previous prescription systems had. Most papers described that there are e-prescription systems in place before designing blockchain based system, but they feature various deficiencies. Revealing these shortages can help to understand what parts of the prescription process, blockchain could innovate. Papers [4] [26] [27] [28] [29] [30] bring out that main problems with current e-prescription systems are

- Lack of interoperability - communication channels do not exist and data is not shared between healthcare service providers.
- Data inconsistency and fragmentation - all providers do not have same data, rather it is fragmented across providers.
- Privacy and security issues due to single point/s of failure systems.
- Using handwritten prescriptions in large proportions compared to electronic prescriptions.

Next is discussed some specific examples to illustrate these points. Paper [26] determined that there are many different parties involved in the prescription pharmaceuticals process. Therefore, there are many different databases and data inconsistency exists, due to lack of interoperability. Due to these aspects it is hard to monitor and validate correct data. In addition, since many different stakeholders hold data, there are more possible points for privacy leaks, and it could potentially be harmful to the patient.

Paper [4] was mainly trying to improve e-prescription in the US. Currently there is centralized Prescription Drug Monitoring Programs (PDMP), that is state run database and collects prescription related data. Paper brings out that this kind of databases have single point of failure. Also, although PDMP information is shared between some states, still interoperability problems remain with many states and the information is not always containing latest updates and therefore inconsistencies appear between states. Querying data from another system takes time and therefore costs resources both to doctors and patients.

Paper [31] mentions that in India, handwritten prescriptions are still widely used since using e-prescriptions are too costly for many doctors. Handwritten prescription cause problems of pharmacists understanding them and dispensing wrong medicine. Papers discusses mobile based blockchain e-prescription system that is more cost-efficient.

4.2 Characteristics of Blockchain Based E-prescription *(SLR)RQ2*

In this subsection findings of the SLR about the characteristics of blockchain based e-prescription *(SLR)RQ2* are discussed. Section presents aspects of e-prescription that using blockchain technology mostly affects and brings value. Also, what are blockchain based e-prescription system use cases. Reviewed papers saw blockchain as a technology to innovate e-prescription and solve limitations discussed in previous chapter 4.1.1.

4.2.1 Type of Blockchain Used

Blockchains can vary in type and there are different types of blockchain as discussed in background chapter. As different blockchain types have differences in their value propositions, it is important to understand, which type of blockchain is used for e-prescription. Papers [4] [26] [27] [28] [29] [30] [31] suggested using permissioned private or consortium blockchains as opposed to public permission-less blockchain. This means that nodes in the prescription blockchain network must be allowed to the private blockchain network to start making transactions on the network and they are indentified. Reasoning for using private permissioned blockchains is quite intuitive - privacy requirements of the healthcare related data and transactions are strict and access to them should be controlled. In prescription process there are different type of nodes like patient, doctor, pharmacy and they have different rights to conduct transactions in the network. Using private networks gives better opportunities to manage rights of different type of nodes in the network and maintaining security of data.

Some papers also describe using specific blockchain based technology. Four papers [27] [28] [30] [31] suggested running the e-prescription system using Hyperledger Fabric blockchain technology, utilizing its possibilities do give different nodes different rights and using smart contracts (chaincode) to carry out business rules of e-prescription process. Also, Ethereum based private blockchain network [4] was used as the underlying blockchain technology. Ethereum based system used tokens/coins that represent prescriptions and can be transferred on the Ethereum blockchain.

4.2.2 Data Management and Security

One important part of the processes is how data is distributed and communicated between participants of the process. There are different ways to manage data using blockchain technologies. One way is to prescription related data on-chain, meaning that data relating prescriptions and nodes in the network are in the distributed ledger, that is accessible to all participating nodes if they own rights. When new transaction is created it is added to the blockchain once it is verified. Paper [29] suggested keeping data or parts of data in off-chain in secured datastores that participants in the e-prescription blockchain network can access. Only content-addressed hash of the off-chain data and pointer do its location is kept on the blockchain and updated when off-chain data is changed. This suggestion was made based on scalability issues. When number of transactions and data volumes increase and therefore more and more data is uploaded to the blockchain, size of the blockchain increases quickly. This makes managing the blockchain more difficult and at some point, when the size of blockchain is large, adding new node to the network is time consuming, as it must copy the entire blockchain [29]. Also, existing nodes might need to increase their data storage capabilities. Keeping only hashed values of data on blockchain does not increase the ledger size as much and maintains more reasonable volume.

Healthcare related data is sensitive and therefore requires security and privacy of data. Blockchain is seen as technology to create secure prescription data exchange and storage. Blockchain characteristic of data immutability due to hashed blocks, enables to assure that data is not manipulated [28] [30].

Papers presented private blockchains to be used in e-prescription systems, which means that participants need to be registered and verified to make transactions in the blockchain network. This adds extra layer of security since hashed data on the blockchain is not accessible to everyone as in public blockchain. If someone on the network tries to do harmful activities, they can be identified. Owning such control over the participants and allowing also removes likeliness of sybil attack.

Patients should be able to control their prescription data and maintain privacy, when other participants in the network need access to patient's data, patient can give permissions for access [26] [27] [29]. This is enabled through encryption of all or some parts of the data kept on blockchain. Identifying peers and assuring data non-repudiation is also enabled through public key encryption.

4.2.3 Overall Characteristics of Blockchain Based E-prescription

Use cases of blockchain based e-prescription are similar to currently existing non-blockchain e-prescription use cases [4] [26] [27] [28] [29] [30] [31]. Doctors can create and modify prescriptions. Patients can get overview of their prescriptions and buy prescription medicine from pharmacies. Patients also have control over their data and can enable other participants access to it. Pharmacies can verify and execute prescriptions and issue prescription medicine. Blockchain rather changes the way data in the e-prescription process is handled and distributed between different participants in the process. Instead of different organizations keeping centralized databases of prescription data, data is kept and shared through distributed ledger, either on-chain or off-chain databases. When data is kept off-chain its integrity is assured using blockchain and pointers regarding its location are kept on the shared ledger. This enables participants to get up to date information from shared source of truth and inconsistency of data caused by different silos of data storage is eliminated. This way participants can directly interact with each other without third intermediary. Everyone in the network that have the right to access data, can do it quickly and do not have to wait sometime several days for queries that are done to other organizations.

Blockchain based e-prescription use smart contracts to automate certain tasks, meaning some business rules for the e-prescription process are executed using smart contracts [4] [26] [27] [28] [29] [30] [31]. There can be large number of different smart contracts created, for example registering new peer to the network, authenticating user, creating prescription, refilling existing prescription, verifying prescription etc. These smart contracts can be partially of fully automated and execute when certain conditions are met.

Different stakeholders in the e-prescription process, like doctor (clinic/hospital), pharmacy, patient is defined as different nodes in the permissioned blockchain network. This enables to give different rights to different nodes. For example, doctor can have right to read and edit prescription while pharmacists can only read and execute the prescription. Nodes in the network can get same information and do not depend on one central institution updating or fetching information for them.

Paper [27] describes managing node for each organization in e-prescription blockchain network that can register new users to the network. Registration must also be verified and validated by other peers in the network.

4.3 Summary

By conducting the SLR and answering SLR sub research questions, first of the two main research questions is answered that is defined in the case study objective (chapter 3.2.1). Main *RQ1* answers about how blockchain can improve e-prescription process. First, there are four main causes to start redesigning the prescription process. First issue is lack of interoperability between providers of healthcare services, which can lead to medicine misuse since different healthcare providers might not see what prescriptions the patient has been previously prescribed. This may cause medicine interactions that can harm the patient. There are not fast and secure communication options between healthcare service providers.

Secondly, data is often inconsistent and fragmentation between different participants which creates extra cost. Since data may be costly to receive, then once it is received, it is saved on local storage. This can cause extra cost on the overall healthcare systems, since storing same data in various places is not effective.

Third issue is using paper prescriptions, that can cause serious problems to health because mistakes are made more often with paper prescriptions and people may sometimes lose their prescription receipt which costs time to receive again.

Fourth problem which blockchain is seen as solution to is ensuring security for prescriptions as they are part of healthcare data that requires strong privacy. Based on prescription data it can be deducted what disease a person might have. Also, if someone could access and change prescription, fraud could take place, or a person may be harmed due to receiving wrong treatment.

To solve these problems blockchain solutions are proposed. Since all participating entities of the distributed blockchain network can access the same information, problem of interoperability is addressed. Secondly, blockchain based solution relies on electronic systems and prescriptions can be created, updated, viewed and dispensed using smart contracts which work based on previously set conditions and therefore prescription mistakes made because of incorrect data insertion are addressed. Thirdly, one of blockchains main characteristic is also data integrity and immutability, and that characteristic addresses the need to keep prescription data private and immutable. By using blockchain as underlying technology, it is ensured that data stored using the shared ledger is correct and consistent. Also, information shared through blockchain can be encrypted, for example by public keys that ensures that only permissioned parties can see the actual prescription data. Since healthcare data can be distributed between identified and authorized participants blockchain based e-prescription systems use private/consortium permissioned blockchain networks to add extra layer of security. Summary or the SLR results is done in Table 4. To conclude, blockchain can improve e-prescription aspects such as, interoperability, security and privacy, data integrity and immutability, automation of business rules via smart contracts.

Table 4. Summary of SLR results.

Issue	**Blockchain Solution**	**Data Management**	**Blockchain Type**	**Reference**
Lack of interoperability – different providers do not have standardized secure communication channels in place.	Entities that need to communicate and exchange data can do it by participating in blockchain network.	Data communicated is encrypted on the blockchain.	Permissioned private/consortium blockchain. (Hyperledger, Ethereum)	[4, 26-30]
Security/privacy issues due to single point of failure systems – current e-prescription systems are using client-server architecture and the data can be compromised in one location. Also patient do not have much control over their data in different institutions.	Blockchain network is distributed and there is not one single point of failure. Also, blockchain enables patient to have control over his/her data and can decide who has access to it.	Data is distributed between participants in the blockchain network. If one node should be compromised, then others still maintain the integrity of the data. Smart contracts enable patient to decide who can have access to his/her data.	Permissioned private/consortium blockchain.	[4, 27, 28]
Data inconsistency and fragmentation – Data is	Blockchain enables single source of truth	Prescription data can be kept either encrypted on-chain, or	Permissioned private/conso	[4, 26-30]

fragmented across different health service providers and pharmacies. Complete data regarding patient prescriptions should be accessible.	via distributed ledger. All the participants in the network can access the same consistent data.	off-chain. Off chain data content hash and pointer to location is maintained on-chain. Data can be divided between different ways of storing.	rtium blockchain.	
Handwritten prescriptions – handwritten prescriptions can cause adverse medicine effects or wrong treatment, because handwriting can be misunderstood.	Blockchain enables electronic prescriptions and smart contracts can ensure completeness and correctness of the e-prescription.	Prescription data not written on physical receipt but stored digitally on blockchain.	Permissioned private/consortium blockchain.	[31]

5 Results of Case Study

In this chapter, current state of the e-prescription in Estonia is presented. Process discovery results and the as-is models are presented that were derived from the interviews and document analysis. Lastly, redesign opportunities are discussed, and redesign is presented using blockchain as the underlying technology.

5.1 As-is Process of Estonian E-prescription

To propose process changes for Estonian e-prescription process, first the current state had to be defined. For that, interviews with domain experts and document analysis on the subject was done.

5.1.1 General Description of the As-is State of E-prescription in Estonia

E-prescription process in Estonia is managed by government institution, Prescription Centre, that operates the database containing prescription data. Estonian e-service providers exchange data through secure data exchange layer called X-Road [Figure 2]. Prescription Centre uses X-Road to collect data from different databases that through X-Road and distribute it to different participant in prescription process like hospitals, doctors, pharmacists through X-Road.

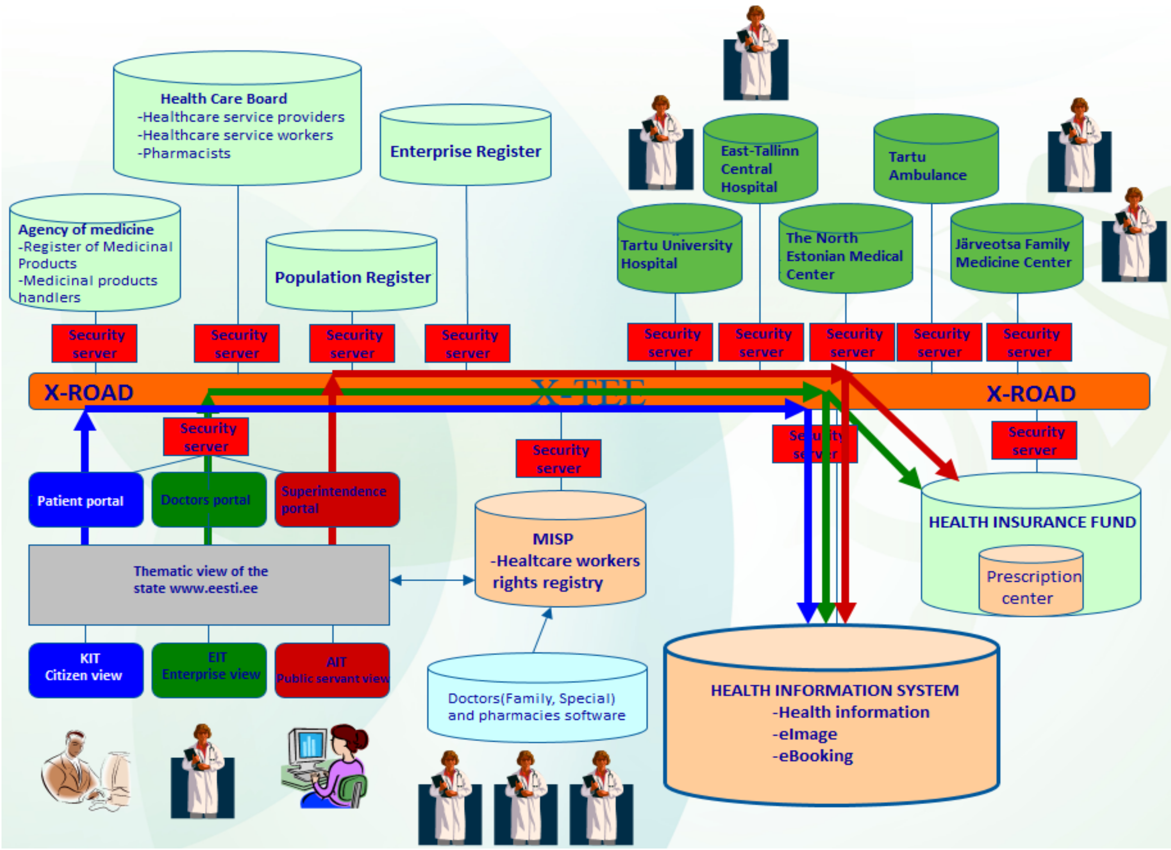

Figure 4. Model of Estonian X-Road services with focus on health care. Provided by Prescription Centre translated by author of thesis.

Most of the information necessary for prescribing or dispensing prescription is synced to Prescription Centre database through X-Road once in 24 hours, but some data is queried in real time when composing of dispensing a prescription. Prescription Centre collects data every 24 hours from:

- Agency of Medicine for pharmacy licensing information.
- Register of medicinal products for medicine data.
- Health Care Board for data about doctors, pharmacists and health care providers.

Only information that is queried more than once a day is data about patient's insurance. Prescription Centre collects data about insurance from Insurance Registry (EHK) in real time during prescription writing and buying.

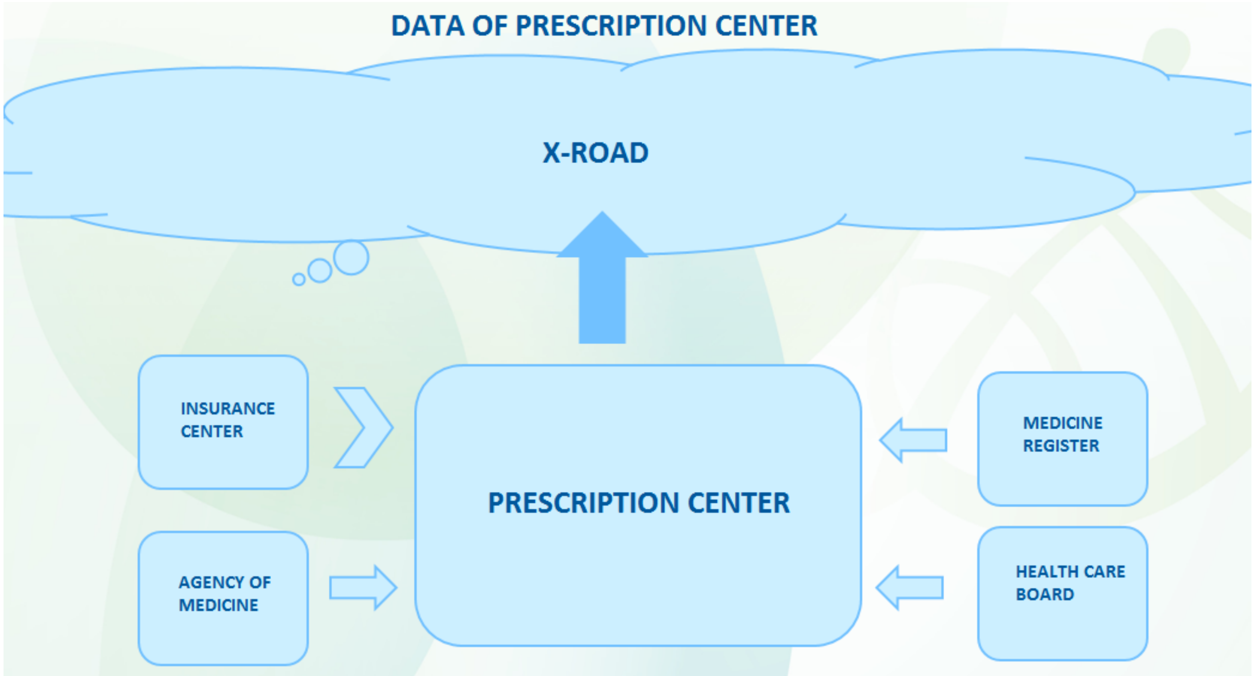

Figure 5. Data of Prescription Centre. Provided by Prescription Centre translated by author of thesis.

There are three [Figure 4] main participants that use Prescription Centre for prescription related use cases. Citizens need services of Prescription Centre to view medicine prescribed to them. Pharmacies use Prescription Centre for selling prescription medicine and generating invoices and Healthcare providers use it for prescribing.

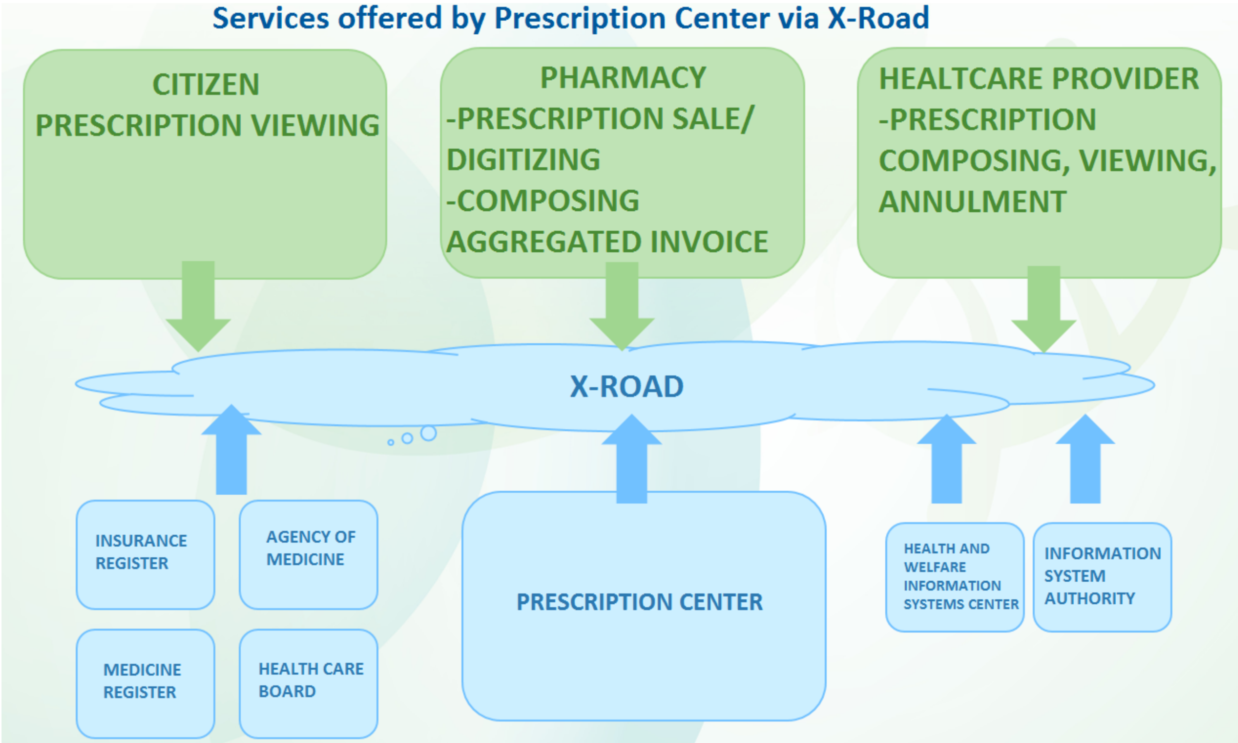

Figure 6. Services offered by Prescription Centre. Provided by Prescription Centre translated by author of thesis.

The e-prescription process starts with patient needing a prescription medicine for treatment and ends with patient receiving the prescription medicine from the pharmacy. For clarity, it is better to divide this process into two sub-processes where one is process of doctor prescribing the prescription medicine and other is process of patient receiving the medicine from the pharmacy.

Each of the participants in the X-Road network access the communication layer through security servers. To become a member of X-Road, an organization must register to the X-Road through X-Road centre. Confidentiality of data sent between members of the X-Road is guaranteed by encrypting the data and sending it directly to another member, avoiding third intermediary party. Data integrity is guaranteed by digitally signing and timestamping messages. Data security between organizations information system and security server must be ensured by the organization using cryptographic protocol.

5.1.2 As-is Process of Doctor Composing E-prescription

First sub-process in overall e-prescription process is prescribing the medicine. When patient needs a prescription medicine for treatment a doctor can create the prescription in the system by using Prescription Centre services.

Process starts when patient needs a prescription medicine for treatment. A doctor enters patient identification details to the system and receives patient data, in that step, query is made to insurance registry for the insurance status of the patient. After that doctor checks for possible interactions with other medicine patient is taking. For that system makes query to Prescription Centre that uses INXBASE medicine interaction database to receive information. If interaction/s exist, then the doctor assesses the interaction and if it is possible to continue, acknowledges the interaction in the system, explains it to patient and continues the process. If interactions are to severe and there is no other choice, prescribing process ends. If interactions are tolerable then doctor enters treatment and dosage details to the e-prescription form in the information system and system checks if treatment has selling license. If there is no selling license for the treatment in Estonia, then process stops but if there is then next step for doctor is to check for discounts using the information system. System does it using Prescription Centre database and insurance registry database queried earlier in the process. System retrieves possible discounts in textual format describing the condition eligible for given discounts. Doctor compares patients' condition with condition described for discount and makes decision on whether to apply discount for the patient. Then the e-prescription is ready, doctor confirms it, if system notifies any issues with the e-prescription for example medicine interaction is not acknowledged then doctor fixes these problems. If the e-prescription is correct it is saved in Prescription Centre database and medicine is prescribed.

In Figure 7 an overall interaction diagram and process flow model of current prescribing process between healthcare provider and Prescription Centre.

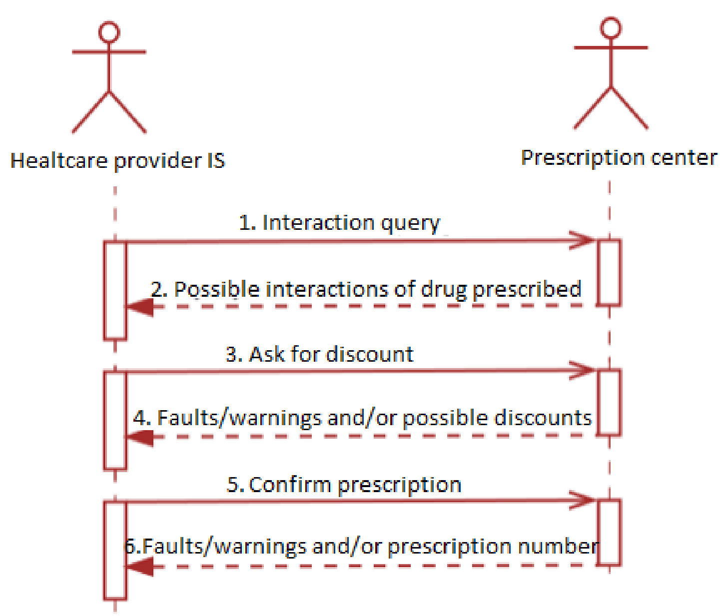

Figure 7. Received from Estonian Health insurance Healthcare provider making a prescription. Translated into English by author of thesis.

Detailed as-is model of the e-prescription prescribing process is model using BPMN and is presented in Figure 8.

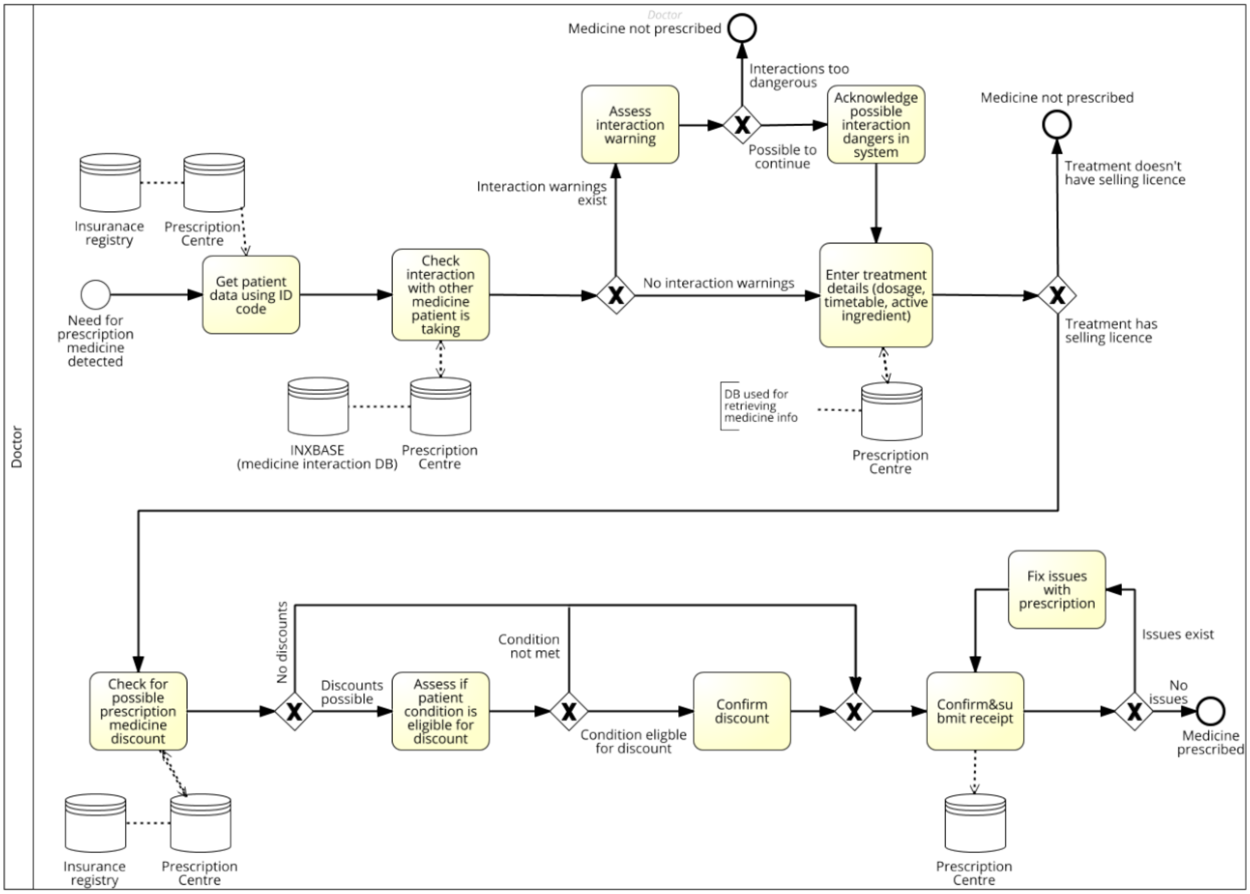

Figure 8. As-is process model of e-prescription prescribing process. Made by author of thesis.

The Estonian as-is e-prescription process is modelled based on process discovery results from interviews and document analysis.

5.1.3 Process of Redeeming the E-prescription Medicine

When the medicine is prescribed by the doctor in e-prescription format, then it can be redeemed from a pharmacy. Medicine can be redeemed by the owner of the prescription when presenting identification or by someone else when presenting prescription owners identification code and their own self-identification document. Then pharmacist can see all patients' prescriptions in the system, when the pharmacist opens wanted prescription from the list, the prescription is booked. Booking the prescription means making it unavailable for 15 minutes to avoid buying it from multiple pharmacies at the same time. If for some reason prescription is already booked and there is reason to unlock it, then pharmacist can unlock it. Prescription can be unlocked for example, when prescription was opened, but the sale did not happen in neighbouring pharmacy and the customer went to another nearby pharmacy in less time than 15 minutes. When prescription is opened then data about prescription is presented to pharmacist. Pharmacist offers medicine from different producers containing the active ingredient prescribed and customer chooses one from the offered producers. Then the medicine is scanned into system and pharmacist can specify the discount in the system. If prescription owner has received better insurance status or discount percentages have been changed then new discount is fitted to prescription. After specifying the discount, sale of the medicine takes place is stored in the Prescription Centre database.

In Figure 9 is an overall interaction diagram and process flow model of current prescribing process between pharmacy and Prescription Centre.

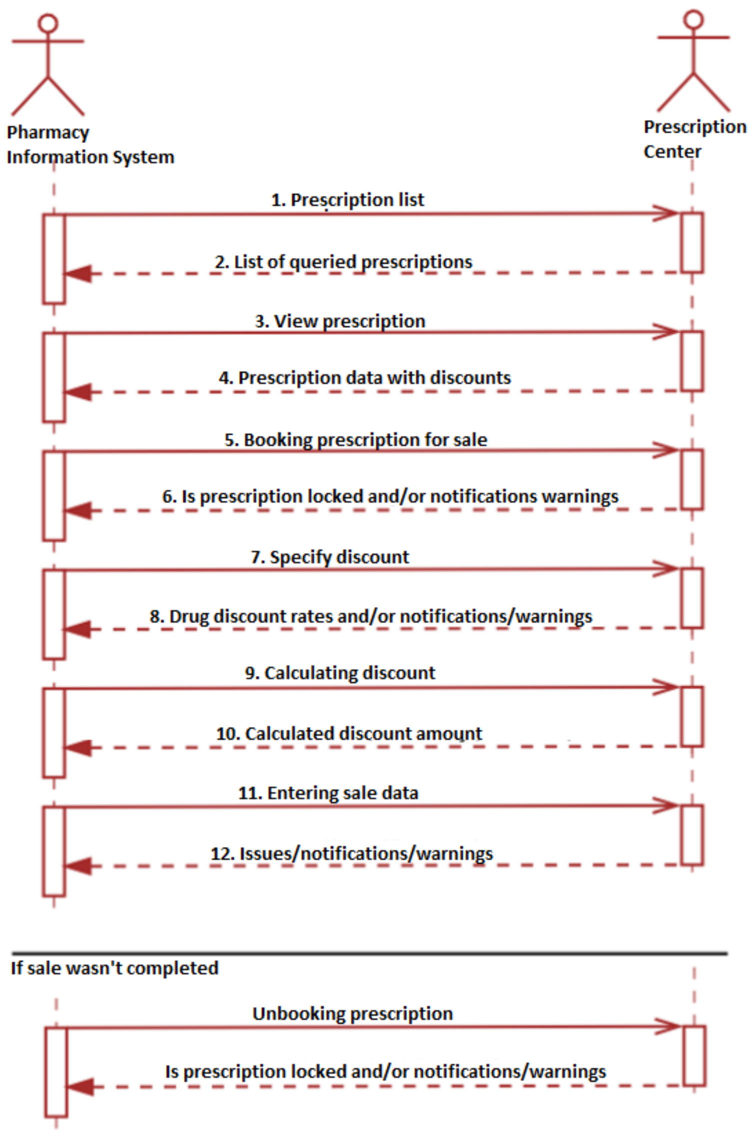

Figure 9. Received from Estonian Health insurance. Process of redeeming the e-prescription medicine. Translated into English by author of thesis.

Detailed as-is model of redeeming the e-prescription is model using BPMN and is presented in Figure 10.

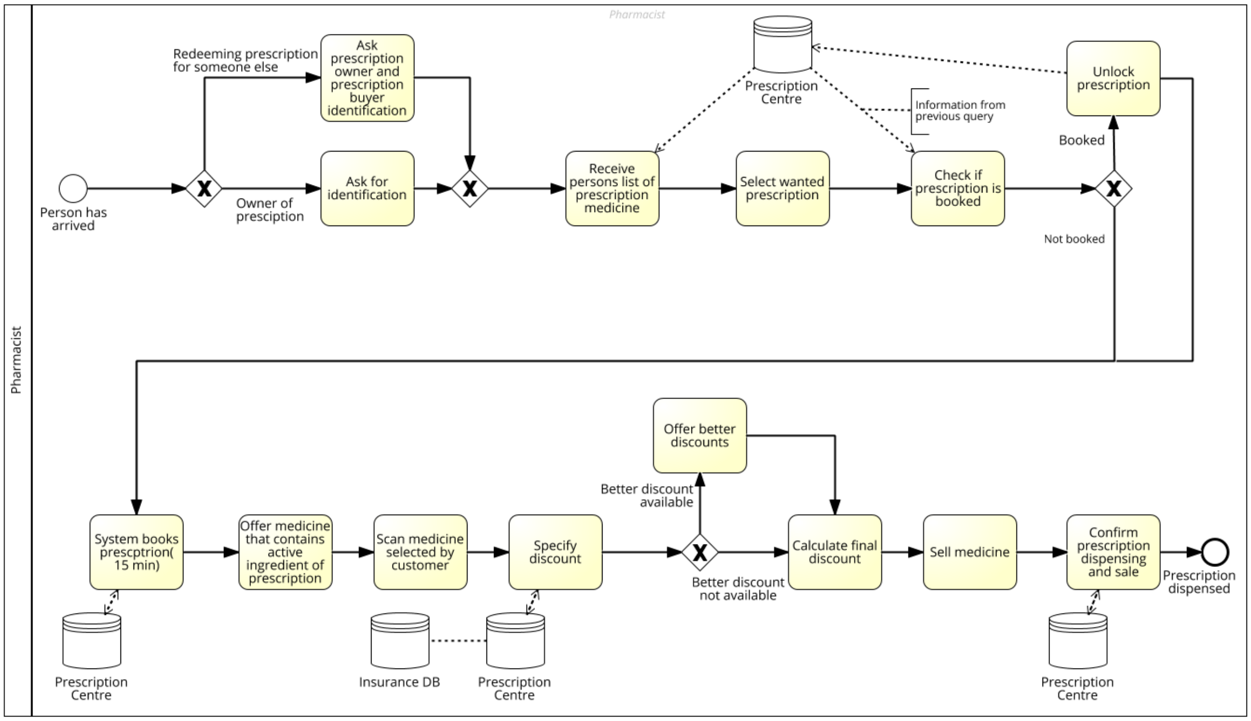

Figure 10. As-is process model of e-prescription prescription dispensing process. Made by author of thesis.

The Estonian as-is e-prescription process is modelled based on process discovery results from interviews and document analysis.

5.2 Process Redesign

To analyse the case of Estonia's e-prescription process and propose redesign, two different redesign approaches are applied. Firstly, input from *RQ1* is used to see how discovered aspects from as result of SLR that have enabled blockchain technology to impact other prescription processes/systems, are applicable in Estonian case. Findings gathered when answering *RQ1* provide more high-level improvements, which are first analysed in Estonian case. If they seem to potentially improve Estonian case, then more specific process changes are deducted.

Secondly special heuristics described in paper [32] about redesigning business process for blockchain solutions are discussed regarding the Estonian case. When the redesign is completed it is presented to the domain expert for feedback. Based on the feedback and contrasting to-be process to as-is process the blockchain based process is evaluated regarding its advantages and disadvantages compared to the as-is process.

5.2.1 Redesign Opportunities From SLR

One aspect that discovered from SLR is that blockchain can affect interoperability, meaning communication and exchange of data between participants. Participants in the e-prescription process can use distributed ledger to store and exchange prescriptions. Prescriptions themselves can be kept on-chain, since they do not include much data and therefore are not large in size. But additional information required in Estonian prescribing process like medicine information, medicine interactions data, healthcare providers and pharmacies licensing data should be kept off-chain and its integrity and completeness ensured by keeping hashes of the content and pointers to its location on blockchain. This data should be managed by Prescription Centre. Insurance status that needs to be accessed every time a prescription is prescribed or dispensed, and it can be accessed by a software oracle and smart contract. Since all the participant can access the distributed ledger, same data is accessible to all nodes of the network who have rights to access it. Off-chain data should be duplicated and synced between some number of databases to avoid data loss and inaccessibility due to one off-chain database failure. This kind of distributed network avoids single source of failure possibilities and if one node should encounter problems it does not mean that other cannot continue operating. If the problematic node re-joins the network, it can sync the latest state of the ledger.

Secondly, security and privacy of e-prescription data will be ensured by blockchains immutability characteristic. Since e-prescriptions will be added to the blockchain as blocks that's hash value depends on previous blocks, they cannot be altered in the future. Prescription data on the blockchain will also be encrypted to ensure that only nodes in the network who have been given rights to access patient prescription data can read it. Patients are owners of the data and give doctors and pharmacist permissions to access it. Prescription blockchain network is permissioned and private, meaning there is a membership provider who manages and adds participating nodes in the network. This is managed by Prescription Centre. They can initiate adding new node to the network with certain rights. Network must confirm the activity by chosen consensus mechanism. Since nodes are identified, if some node tries to perform harmful activities they can be detected.

Smart contracts can be utilized to automate certain tasks in the process. When doctor wants to create new prescription, a smart contract is used to create and add the prescription to the distributed ledger. Prescription smart contract can be defined in a way, that it would ensure completeness and correctness of the prescription given doctors input and prescription related data that is either on chain or off-chain databases. Off-chain data, like license statuses, medicine information, interactions information that are used for prescribing can be accessed with smart contracts which would also compare their content hashes that are stored on blockchain and verify content integrity. These smart contracts can be linked to prescription smart contract and run in parallel. To create a prescription, a licensing check smart contract, must ensure that healthcare provider and doctors license statuses are valid. Necessary insurance data can be accessed through a smart contract and an oracle from insurance database. Smart contracts can also be used when dispensing the prescription in a pharmacy. Insurance can be checked the same way as in prescribing part of the process. Licensing statuses of the pharmacy and pharmacist can also be queried from off-chain database by smart contracts which would also compare their content hashes that are stored on blockchain and verify content integrity.

5.2.2 Redesign Opportunities Based On Heuristics

The input from *RQ1* provided more changes in regard to higher level improvements that blockchain can bring to e-prescription process, rather than detailed redesign suggestions. Therefore, Estonian e-prescription process is also analysed by applying business process redesign heuristics for blockchain solutions, suggested in paper [32]. These process redesign heuristics for blockchain solutions are derived from general best practices of business process redesign by Reijers and Mansar. In the paper, best practises were examined and determined what blockchain capabilities matches each best practice. As the result, based on one or several best practises, redesign heuristics for blockchain based inter-organizational processes were proposed. For example, blockchains property of shared data ledger is best aligned with best practice of centralization, which means to treating geographically dispersed resources as if they are centralized. The heuristics are divided into four categories based on main capabilities of blockchain which are ***shared data storage, computation (smart contracts), data communication, asset management (tokenization).*** Described categories help to redesign processes in context of blockchain, but do not define processes or blockchain systems themselves [32]. Altogether, there are twelve redesign heuristics. In following subsections each of these categories and its heuristics are elaborated and then analysed if and how they can be applied in redesigning Estonian e-prescription process.

Collaboration of Entities

This category of adopted best practices is based on blockchains capability of shared data storage and is called *Collaboration of entities* [32]. It suggests that all entities involved in the process should be able to communicate with each other and therefore are connected. Using blockchain different entities can communicate with each other by shared data ledger, that is immutable and enables verification, storage and different transactions. *Collaboration of entities* category contains two heuristics.

Heuristic 1

Description: First heuristic of, *consider all participating entities required to achieve the objective of the interorganizational process as if they are centralized,* is derived from best practice of centralization which means to treat geographically dispersed resources as if they are centralized. Blockchain has distributed data ledger that scattered entities can access and use it for data exchange [32].

Application: In the current case of Estonian e-prescription there are four main entities that are required to achieve the objective. First is the doctor who creates the prescription, second is patient who is the owner of prescribed prescription an grants other entities permissions to access the prescription, third is the pharmacy/pharmacist, who is responsible for dispensing the prescription medicine, fourth is the Prescription Centre that contains data about licenses regarding rights to act as a pharmacy, prescriptions themselves, contains information about medicines and discounts. Currently these entities can communicate and exchange data each other via X-Road. Organizations, both public and private can join the X-Road network and start using services available via X-Road. So, if new entities would be needed for the process, they can join. Blockchain based e-prescription would enable exchange of data participant via shared ledger and entities can join the distributed network.

Heuristic 2

Description: Second heuristic is derived from best practice of *integration*, which suggests that business process of different type of participants in the process should be integrated. Data should be exchanged during the execution of processes, not after the processes are finished. Redesign heuristic of *consider integrating participating entities' business processes or activities thereof in the inter-organizational process*, suggests using blockchain for process integration by using its shared data ledger to share and receive data when participants are executing processes.

Application: To determine whether and where this heuristic could be applied, the paper suggests searching for sequential dependencies between processes executed by different participants [32]. In the studied case, two main sub-processes, prescription composing process and prescription dispensing process are sequential. Since these processes do not require back and forth data communication between the main actors (doctor and the pharmacist) to complete the processes, then integration is not seen necessary. That is, because by the nature of the overall process, the process of dispensing the prescription cannot do anything with partial prescription data. Therefore, there are no instances detected, where this heuristic can be applied on the current process.

Case Management Structure

Second category of redesign heuristics is *case management structure* and is based on blockchain capability of computation i.e. smart contracts to structure inter-organizational processes. Smart contracts enable to execute predefined activities to achieve specific outcomes based on data provided for smart contracts. Given that smart contracts can execute encoded business logic, they can be seen as sub-processes of larger inter-organizational process. [32]

Heuristic 3

Description: Third overall heuristic, *consider organizing inter-organizational processes around their outcomes and use connected smart contracts for task execution*, is based on three best practices that focus on organizing process around outcomes not tasks and suggests using minimal number of participants and that one resource or team executes as many tasks as possible in the process execution. Smart contracts can execute pre-defined tasks and can do it in collaboration with other smart contracts. By that capability of blockchain, smart contracts can take the role of case manager and task executors. [32]

Application: Paper [32] suggest determining the main outcome of the process to implement this heuristic in the redesign process. The main outcome of the e-prescription process is the patient to receive prescription medicine for treatment in safe and validated way. There are tasks like filling the prescription that could introduce mistakes and make prescription unsafe for the patient. In the current process smart contracts could replace current automated stored procedures that have been created as service by Prescription Centre and made available vie X-Road. A smart contract can be used to create a prescription on the shared ledger. Other smart contracts that can be linked to the prescription smart contract and could be used to perform completeness and correctness checks for the prescription. Making sure that filling prescription details is done correctly. There are several possible issues that could make the prescription medicine unsafe for the patient among the prescribing process. One of them is medicine interactions, meaning that different medicines taken together can have negative effects for the patient. This problem is currently addressed by information system checking for possible interactions and showing a warning to the doctor when prescribing. These tasks in the main process that help to tackle described issues could also be addressed via smart contracts that can collect data about possible interactions or wrong dosages via shared ledger and check whether they are safe for the patient. These smart contracts could be linked to the main smart contract of creating a prescription.

Heuristic 4

Description: Fourth heuristic of, *consider outsourcing complete processes or parts thereof that are executed by participating entities, in particular duplicates, to smart contracts,* is based on best practice of *Outsourcing*, which states that tasks in processes should be executed where they make the most sense and that if external participant can execute the whole process or parts of it more efficiently, they should do it. In blockchain based solutions, parts of whole processes can be outsources to smart contracts, especially if the same process is duplicate by multiple participants, the process should be executed only once, and results can be accessed by other participants through shared data ledger. [32]

Application: To detect how this heuristic can be applied in process redesign, the paper suggests finding processes or parts of processes that are duplicated among the participating entities.

Currently the processes of prescribing and dispensing the prescription share only one duplicated task of checking for insurance status of the patient. This query is done automatically by the information system from the insurance database and it cannot be made only once, for example when doctor is composing the prescription. That is, because insurance status can change between the time of prescribing and dispensing the prescription and different insurance status can result in different price of the medication. Therefore, since this task needs to be done multiple time, it is suitable to be automated. Currently, when the doctor or pharmacist inserts patients' details, the insurance check is done automatically by the system. As in the previous heuristic, this task could be also done by smart contract and oracle in blockchain based system, but it would not change the process itself. To conclude this redesign can be applied on the process, but it would more impact the technological implementation of the task, but not the process.

Heuristic 5

Description: Fifth heuristic of, *consider eliminating unnecessary tasks in the inter-organizational business process,* is based on best practice of *task elimination* and in blockchain context, suggests considering if tasks executed by smart contracts could be eliminated. For example, if they are duplicated partially or completely.

Application: To detect possible applications of this heuristic on the studied process, tasks that could be eliminated or such fragments of process should be first detected. Reviewing the process and analysing interview results with the domain expert, no tasks that could be eliminated were detected, since all steps taken for prescribing and dispensing prescriptions are necessary in the current process to ensure patients safety.

Second option would be to eliminate participating entities from the process, by replacing them with smart contracts. But in the current process, smart contracts cannot also completely remove any deciding entities (doctors, pharmacists) of the process since they cannot replace doctors or pharmacists as each patients treatment must be approached individually and experts input is required.

Heuristic 6

Description: Sixth heuristic of, *consider separating variants of the process into separate smart contracts,* is based on best practices of *Triage,* which suggests splitting general tasks into alternative ones or the opposite and *Order Types,* which considers if tasks are related to the same type of orders. These best practices help to set the scope for smart contracts.

Application: To discover where this heuristic can be applied, tasks of the processes that could be divided into two or more alternative tasks or the opposite. Tasks in the current process are straight forward and no tasks were detected that could benefit from dividing them in two or more tasks or the opposite via smart contracts. Therefore, this blockchain based redesign heuristic is not applied on the studied process.

Heuristic 7

Description: Seventh heuristic of, *consider defining smart contracts that can, given the required data, take autonomous decisions with no or as few manual interventions as possible,* are based on four best practices. Best practice of *Empower* states that power of decision making should be given to the workers. *Task automation* suggests automating activities where possible. *Exception* states that standard flow of the process should be separated from possible exceptions in the process. And the fourth best practice of *contact reduction* on which this heuristic is based on, suggests minimizing number of contacts with other parties. Smart contracts can fulfil the suggestions of these four best practices. Smart contracts can make decisions, they can access required data for the decision. Smart contracts can possibly do it with none or limited amount of interventions and separate exceptions from standard process flow. [32]

Application: As discussed earlier, in blockchain based e-prescription process, smart contracts could replace current automated checks by the system, when different checks need to be made when composing the prescription or dispensing it. For example, smart contracts performing medicine interaction and insurance checks can be automated given required input data.

Heuristic 8

Description: Eight and last heuristic of this category of *consider which smart contracts can be executed in parallel and if they can be optimized by resequencing their order of execution,* is based on best practices of *Resequencing* which states that process might need to be executed in different sequence for better optimization, *parallelism,* which suggests that processes should be considered to be executed parallelly. Smart contracts can easily be defined to run in parallel or various sequences.

Application: To apply this heuristic, places where smart contracts can be used need to be identified. This has been done by analysing previous heuristics, that have proposed where smart contracts can be applied. For example, smart contracts in the studied process can be constructed to compose prescription and conduct licenses, interactions and insurance checks for the prescription. Smart contracts that could run in parallel are performing tasks of checking for medicine interactions and discounts. Results of these smart contracts need to be received for the prescription to be completed and therefore are input for completing the prescription.

Data Management

The third category of redesign heuristics is *data management* and is based on blockchain capability data communication and transfer in redesigning business processes. Blockchain shared ledger makes it possible to store data on the ledger and access it by participant and external data sources. This means that during the business process data can be exchange or between participating entities using blockchain ledger.

Heuristic 9

Description: Ninth heuristic of*, consider using the insights produced by participating or other entities across the inter-organizational process*, is based on best practice of *trusted party*, that suggests when a trusted participant has achieved a result, other participants should use this result as the input, rather than redoing the work to achieve the same result. When some participants in blockchain network has achieved result that another participant needs for its processes, then they should use the distributed ledger to access these results rather than duplicating task.

Application: In the studied process there are four major participants as discussed in the context of Heuristic 1. First step to determine in applying this heuristic is to detect insights participants can provide. Excluding the data about obvious, the prescription itself, there are some other insights that the participants can share. For example, when the prescription is flawed in some way and a pharmacist detects it during the dispensing process, they can share this insight in the shared ledger so that the patient could not go to another pharmacy to try dispense the flawed prescription. Also, sometimes there occurs a shortage of medicine in some pharmacies, that could be shared via distributed ledger.

Heuristic 10

Description: Tenth heuristic of, *consider using oracles as trusted sources of external data*, relies on the same best practice as ninth heuristic but emphasizes on using oracles as trusted parties that provide data to participants of the blockchain network, from outside of blockchain.

Application: To determine how this heuristic can be applied in studied process, possible data that is needed from external sources is defined. In our studied process there is one central Prescription Centre database that queries data from external sources, that is needed for other participants (pharmacists, doctors, patient). These external sources and required data are the following:

- Data about the licenses of pharmacies from the agency of medicine license registry.
- Data about the medicines and their discounts from medicine registry by agency of medicine.

- From healthcare board registry data about healthcare providers, doctors and pharmacists is needed, since only licensed participant can compose of handle prescriptions.

Oracles could be used to access data from these external sources in safe way. Currently it is done vie Estonian X-Road that provides secure encrypted communication directly between the participants. Using oracles would provide safe way of accessing external data and making it accessible via shared ledger in blockchain based solution.

Heuristic 11

Description: Eleventh heuristic of, *consider moving controls closer to the data entry and, when needed, implementing control addition for more complete and correct data capture,* is based on best practices of *control addition* that considers applying controls to some point in the process to ensure the data used as input is complete and correct, *control relocation* suggest moving controls of the data to earlier stages in the process or to customers.

Application: In the studied process there is one participant (Prescription Centre) that stores data other participants access for prescribing or dispensing prescriptions. This is the Prescription Centre database. Ensuring initial data completeness and correctness should be done at its source, at the Prescription Centre database. Checks whether the prescriptions are filled correctly are done when prescribing them, thus the checks are close to the point of data entry regarding the prescription itself. As can be seen in current process checks are done close to their entry point and thus redesign possibilities regarding this heuristic is not detected.

Heuristic 12

Description: Twelfth heuristic of, *consider storing data that is frequently used by smart contracts but not often updated on the shared data ledger and subscribe to updates,* is based on best practice of *buffering*. The best practice proposes storing data from external sources and updating it when needed, opposed to requesting the data every time from external sources. This can be important with data that is needed frequently or might not be accessible through oracles at all times. Blockchain can store this kind of data that is used by smart contracts on the shared ledger and can be updated when necessary.

Application: In the studied case, all data (described at heuristic 10) that is used in the process is accessed frequently, every time a prescription is made or dispensed. This data is currently stored, synced and provided through X-Road by Prescription Centre database, only insurance data is queried from insurance database every time when composing prescription or dispensing it. Other data used regarding licenses of health service provider and information about prescription medicines and its discounts is updated once per 24 hours. In blockchain solution prescriptions could be kept on-chain, since they are not large in size and prescription contents are not update between creating them and dispensing them. Other data should be kept off-chain and hashes of its content and pointers to its location could be kept on blockchain. That is, because this data requires larger amount of storage space and is updated often, every 24 hours.

Heuristic 13

Description: Thirteenth and the last heuristic of the category is *consider capturing data once and at its source from participating entities and oracles.* This heuristic is based on best practice of capturing data once, at the source. When participating entities do not share common data ledger participants often have their own information systems with own data storages. Data entry in this case can be costly. Blockchain enables to capture data once and at its source by storing it using blockchain. In addition, oracles can be used to capture data once from external sources and making it available via shared ledger. In this way requesting data from external sources multiple times by different participants can be avoided and that can save cost on data acquisition. This heuristic also relies on best practice of *interfacing*, which suggest that when manual data entry is needed it is preferred to use standardized interfaces to ensure data completeness and correctness. Smart contracts can ensure correct data entry to shared ledger, data that different participants could use for their processes.

Application: In the current e-prescription process most of the relevant prescription related data is captured once by Prescription Centre. Only insurance data is queried every time a prescription related transaction is made, since it is critical to get real time data about insurance of the patient, to determine possible discounts. Therefore, data is captured by one participant and shared though X-Road communication layer. In blockchain base prescription process, smart contracts should perform checks when prescription is filled to ensure its completeness and also data completeness checks should be done when acquiring additional information, like licenses from external sources. This heuristic would not change the process itself, rather than technical implementation.

Tokenization

Final category of redesign heuristics is tokenization which suggest how blockchain capability of asset management can be used for process redesign. Tokens on blockchain network can represent tangible or intangible objects/assets. Using smart contracts status of these tokens can be managed and digitally represented.

Heuristic 14

Description: Fourteenth heuristic of, *consider digitally representing assets that are used in the inter-organizational process with tokenization,* is based on best practice of *integral technology*, that suggests using new technology to circumvent physical constraints in a process. Blockchain can keep record of the statuses of the assets in form of tokens and can be managed by smart contracts.

Application: In the studied case tokens can represent prescriptions and license data about pharmacies, pharmacists, doctors and healthcare providers. Prescription token status can be either active, dispensed, expired or suspended (error with prescription). Tokens representing license statuses can be valid or invalid. During different parts of the process, the smart contracts validate that the statuses tokens are valid for the normal process flow to continue.

5.2.3 Detailed Redesigned To-be Process

In this section, the detailed process flow of the redesign is described and to-be process models presented. Some preliminaries that are expected to be met before the process starts. Participants, like doctor, pharmacy, patient etc. need to be part of the blockchain network. As SLR discovered, since health data is private and should be accessed by identified entities on need to know basis, then permissioned private/consortium blockchain is used. Prescription Centre is a membership provider node who can handle adding participants to the network that will also be validated by the participants. The following e-prescription process is based on blockchain as the underlying technology and uses insights from SLR and heuristics for processes using blockchain as underlying technology.

Prescribing To-be Process

When patient arrives to the doctor, the patient can give the doctor permission to access encrypted prescription data on blockchain. When new prescription needs to be filled for treatment, a *create prescription* smart contract is used to create a new prescription and add it to the distributed ledger. The prescription is represented by a token. When an identified doctor wants to create new prescription a *licence* smart contract checks for the status of the healthcare provider and doctors' licence to make sure they are eligible to create new prescription. The *licence* smart contracts are linked to the prescription smart contract and input from this smart contract is needed to create the prescription. If the licences are not valid, then *prescription* smart contract cannot be executed.

During the prescription writing, a patient insurance status, possible medicine discounts and medicine interactions with other medicine are also queried from off-chain database. This is done in parallel via two smart contracts that are linked to the prescription smart contract. Based on the input from the doctor (medicine name/patient details) *discount check* smart contract returns possible discounts and *interactions* smart contract warns of possible interactions. This data comes from Prescription Centre off-chain database. Data received via these smart contracts are used for finishing the prescription. When prescription details are filled by the doctor and doctor submits it, then *prescription* smart contract checks its completeness and submits prescription to the shared ledger. The process is modelled in Figure 11.

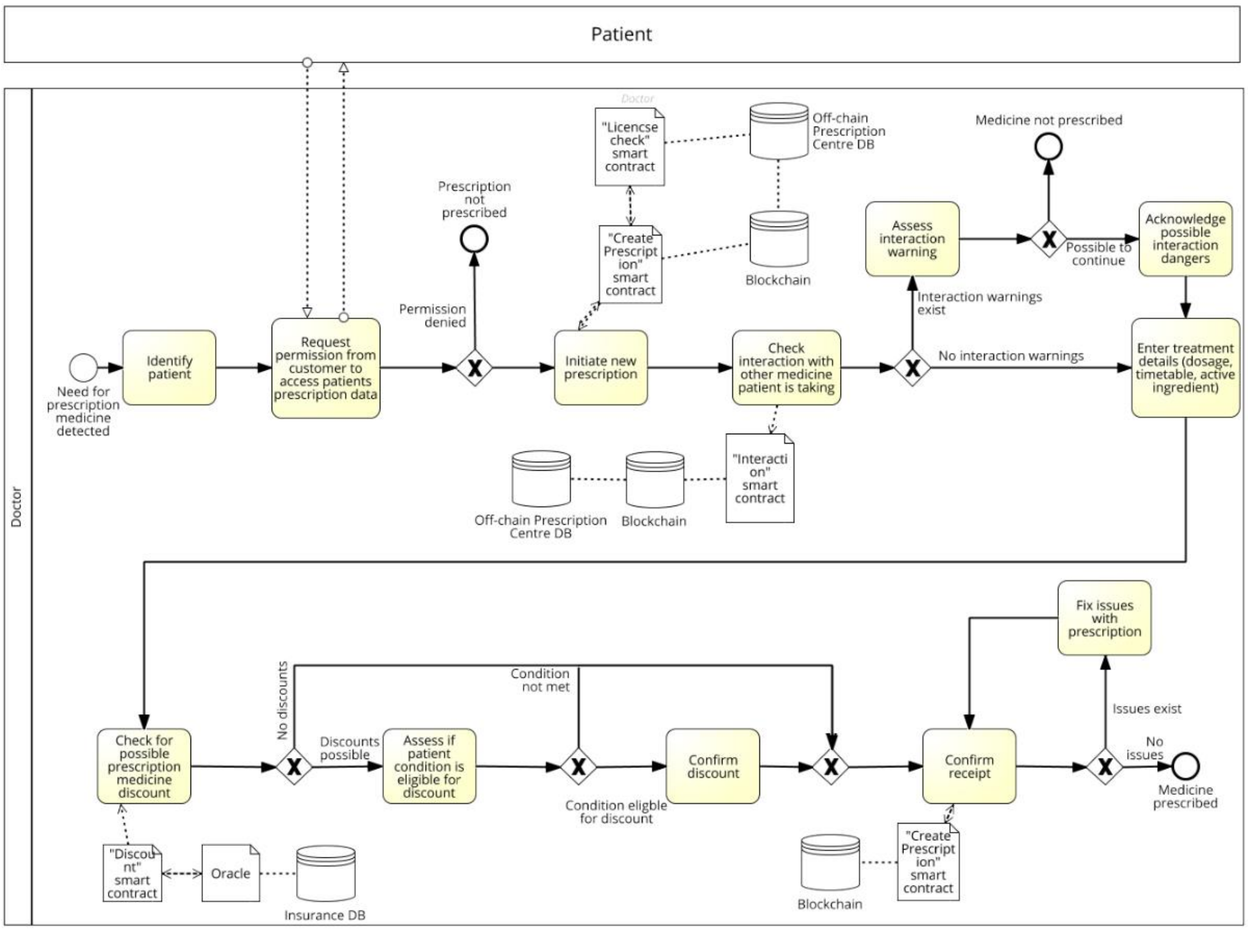

Figure 11. To-be process model of e-prescription prescription prescribing process. Made by author of thesis.

The to-be process model in Figure 11 was modelled using BPMN notation.

Dispensing Prescription To-be Process

When a patient goes to pharmacy, he first identifies himself and gives pharmacist permission to access encrypted prescription on the blockchain. Given permission, pharmacist can access the prescription token via *access* smart contract, that automatically also books the prescription when it is opened via updating prescription token status to booked. Pharmacist can only dispense the prescription, if *licence* smart contract has verified the pharmacy and pharmacist valid licenses. *Discount* smart contract that was also used in the prescribing phase is used again to verify patient's insurance status and medicine discounts. When the prescription is dispensed the status (prescription tokens status) is updated on the shared ledger. If pharmacist should detect any problems with the prescription during the process, prescription token status can be updated to invalid. A smart contract can then automatically inform the doctor who prescribed it to make corrections. The process is modelled in Figure 12.

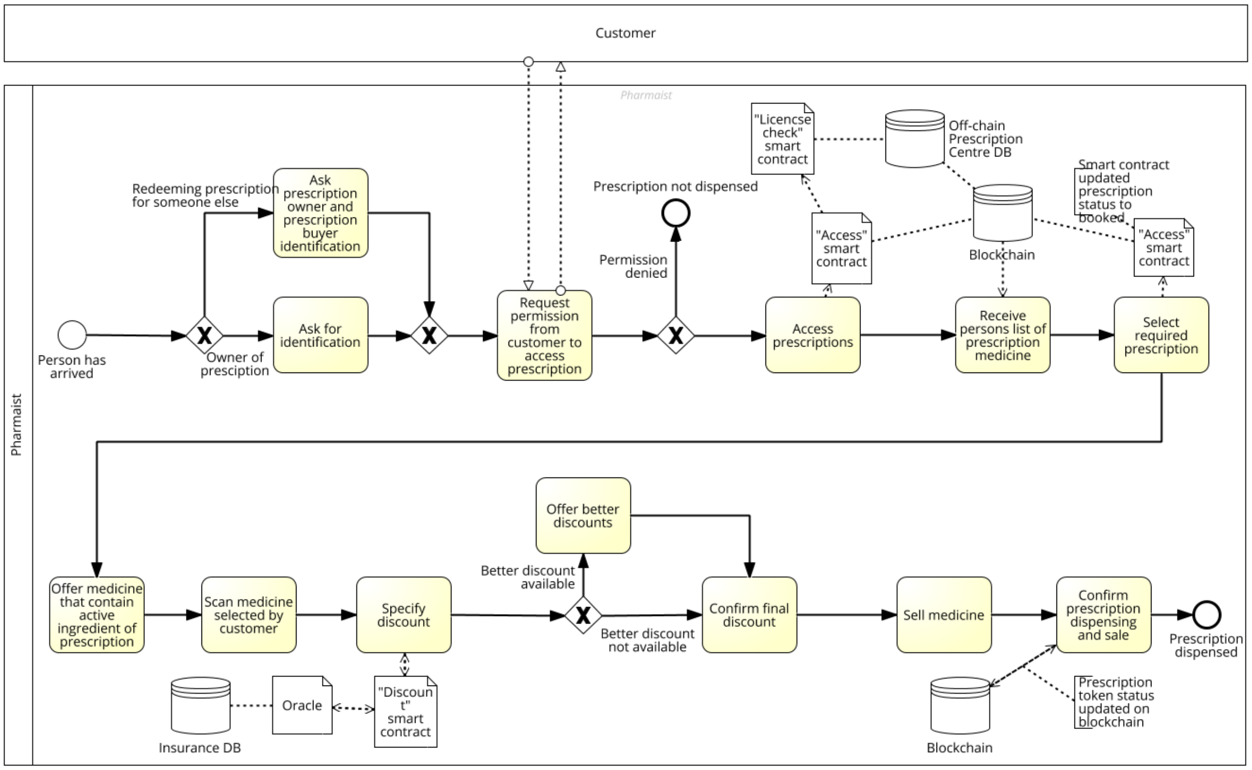

Figure 12. Process model of e-prescription prescription dispensing process. Made by author of thesis.

The to-be process model in Figure 12 was modelled using BPMN notation. Although the exact technical implementation is outside of the scope of the thesis, the blockchain based e-prescription could be implemented using Hyperledger Fabric enterprise grade blockchain technology as was suggested in the papers reviewed during the SLR.

5.3 Discussion

In this section redesigned to-be process is compared and analysed in contrast to the as-is model. During the discussion, case study RQ2 is answered about if and how blockchain can impact Estonian e-prescription process, which is also the overall research objective of the thesis. Firstly, aspects from case study RQ1 discovered as a result of SLR, that were used for redesign are discussed. Secondly heuristics for process redesign based on blockchain are discussed.

Assessing the proposed redesigned models, shows that problems motivating to construct blockchain based e-prescription systems in papers reviewed during SLR, are solved using different technology in Estonia. There were four main reasons for implementing blockchain based e-prescription. First of them was lack of interoperability. Blockchain was seen as solution to that as it enables communication and data exchange between members of the network. In as-is e-prescription state of Estonia, participants in the e-prescription process are connected through secure data exchange platform X-Road. This enables direct communication between the participating entities and does not require a third intermediary. In this sense, X-Road enables similar characteristic to blockchain, where intermediaries between entities can be eliminated.

Other issue was data fragmentation and inconsistency. Prescription Centre operates the database that stores all data necessary regarding prescriptions. Updates made by different participants (hospitals, pharmacies, patients) will be accessible to all from the same source, which ensures data consistency and completeness. Therefore, data fragmentation was not an issue in Estonian case and is ensured using X-Road communication layer and Prescription Centre database.

Third aspect that motivated to use blockchain for e-prescription was old-fashioned paper prescriptions, that are still used in various places around the world. Estonia only uses paper prescription in case of emergency with its information systems and so issues relating prescription mistakes made because of filling and reading paper-based prescriptions are not present in Estonia. Electronic forms that are used for filling out the prescription are standardized and give warnings when there are issues with the prescription that is being filled. This issue can be solved using different technologies, but papers saw blockchain as possible more cost-effective technology behind it that also enables security.

Fourth aspect that was affected by blockchain was data security, immutability and privacy of prescription data. Client-server architecture was seen as possible single point of failure for privacy leaks and single authority controlling all the data could manipulate it. This aspect might seem true in Estonia's case. Prescription Centre managing all the data centrally could seem like one entity has too much control compared to blockchain network principals. However, in Estonian case integrity and immutability aspect is addressed even when using the central database. When the healthcare related data item is accessed using X-Road, its integrity is ensured using Keyless Digital Infrastructure. Healthcare related data in Estonia is secured by hashing its content, adding the hash to Merkle tree that can later be used to ensure integrity of data. Exchange of data via X-Road is secured by encrypting it while in transit, which ensures data security during data exchange as does blockchain.

In addition to insights discovered by conducting the SLR, redesign heuristics for blockchain solutions were applied on the as-is process. As the analysis showed, out of 14 heuristics, 10 were found to be partly applicable. Partly in this case means, that 10 heuristics can be used in the process, but they would not change the process itself rather than technology behind it. For example, heuristics 3,4,7,8 suggested using smart contracts in different ways to automate tasks/parts of process or ensure integrity of data and transactions. This is also done in current e-prescription system via stored procedures offered by Prescription Centre as a service and other entities can access it via X-Road. Automated services are licensing checks, insurance checks, medicine interactions checks, prescription completeness checks are currently done automatically by the system. In blockchain based process, smart contracts can be used to access these services. Thus, these heuristics would change the implementation of how the services would be accessed but not so much the process itself. The same applied about data management heuristics. Process was not affected rather the technology behind it. Lack of significant applicable heuristics shows that blockchain does not help to improve the process.

To summarize, main findings from the systematic literature review were, that blockchain was used in e-prescription process for four reasons, lack of interoperability between entities, data fragmentation/inconsistency, data privacy/security and handwritten prescriptions. These reasons were found to improve by blockchain in countries described in papers. However, in Estonian case these reasons where not found to be an issue. The SLR aspects and redesign heuristics were used for process redesign and afterwards analysed regarding current Estonian e-prescription process. It was found that although blockchain technology can be applied on the Estonian e-prescription process, it does not solve any issues found from literature, since they are addressed using other technology in Estonia through X-Road and Prescription Centre services. This was also confirmed by presenting the blockchain based redesign to the domain expert. Though she understood the way blockchain could enable the e-prescription process to function, she confirmed that it does not seem to bring value compared to current solution. Therefore, blockchain is not seen as meaningful replacement for current technology used in Estonian e-prescription process regarding the redesign aspect found in literature and heuristics. This also answers the main objective of the thesis and case study *RQ2*. Blockchain is currently not seen as technology that could bring value to the Estonian e-prescription process.

Current literature saw blockchain mainly from e-prescription data communication and storing perspective that was equally available with current technology used in Estonia. However, there could be other extended use cases in the future where blockchain could be considered to add value. For example blockchain is also see as improving pharmaceutical supply chain management that could be integrated into prescriptions process [33]. In this case the e-prescription process becomes international and increases in complexity and distrust between entities. Prescription Centre is considering including more pharmaceutical supply data into the e-prescription process and are also planning to widen scope of cross border prescription in Europe. Blockchain could become valuable in these more complex and larger processes that include more different participants. This could be investigated in future research.

5.4 Threats to Validity

When conducting a case study there is threats to its validity [22], especially regarding aspects of external validity and reliability.

External validity aspect is concerned to what extent the findings of the case study can be generalized [22]. In the thesis on case study was conducted. This case study relied on one specific setting and so the findings may not apply on other similar cases with slightly different characteristics. Case study relied on the information provided by the domain expert and therefore other researchers may collect data from different domain experts or in different period of time or in a different way. All these factors may affect the findings of the case study. The process of constructing redesign may also rely on specific researcher and other researchers could come up with different ideas for redesigning processes.

Reliability aspect addresses that data and analysis of the case study are dependent on specific researchers [22]. Other researchers may collect or interpret the collected data from the domain expert in another way, which means there exists threats to reliability of the case study. This threat was addressed by following themes when interviewing domain experts and using document analysis to cross check collected information.

The case study included systematic literature review, which also has threats to its validity [34]. In the case of SLR conducted during the case study, most relevant threats among the threats proposed by [34] are *incorrect or incomplete search terms, incomprehensive databases used for search, bias is study selection, bias in data extraction.* To minimize these threats, some preventive steps were taken. Search strategy including search terms and databases used for the search were presented to and discussed with the supervisor of the thesis. Study selection was done based on inclusion and exclusion criteria set before the selection. Data was extracted using data extraction forms. Still, though preventive measures were taken there remains threat to validity of the SLR.

6 Conclusion

The thesis aimed to research if and how blockchain technology could improve process of e-prescription in Estonia. Thesis set out to achieve this by conducting a case study. Case study was done in the setting of Estonia. During the case study, current process of the e-prescription was first modelled by conducting interviews with domain experts and analysing documents. To propose changes to the e-prescription process of Estonia enabled by blockchain, a systematic literature review was first conducted. The review was performed to answer the first case study research question on how blockchain can impact e-prescription overall. Findings from the SLR were used to answer the second research question about if and how blockchain could impact e-prescription process in Estonia.

Main findings from the systematic literature review were, that blockchain impacted aspects of the prescription processes like lack of interoperability between entities, prescription data fragmentation and inconsistency, prescription data privacy and security and lastly handwritten prescriptions. These aspects were used for process redesign and afterwards analysed in regard to current Estonian e-prescription process. It was found that although blockchain technology can be applied on the Estonian e-prescription process, the capabilities of blockchain that helped improve e-prescription systems in other cases were not found Estonian case. Problems like data communication, security and privacy that blockchain helped to improve, were solved using different technologies in Estonia through X-Road and Prescription Centre services. Therefore, significant process redesign opportunities were not found.

Secondly, to further analyse redesign opportunities, fourteen redesign heuristics that are proposed to redesign processes based on blockchain technology were applied on the Estonian case. Ten heuristics were found to be partially applicable in Estonian case, but even in those cases, the heuristics were found to affect the implementation behind the process/task, but not the process itself. This was also the case with redesign opportunities discovered during systematic literature review. When changing technology behind a process, the process should improve also, otherwise it is not a reasonable investment.

Thus, to conclude and answer the main research objective. From applying the aspects found during the systematic literature review and heuristics, it was found that in Estonian case blockchain technology would not bring process improvements to justify the investment in adapting new technology. This was also confirmed by the domain expert of e-prescription that the blockchain based redesigns were presented to. For future research e-prescription process could consider wider boundaries that introduce more complexity and extended use cases like supply chain management that is related to prescription. Another future research field could be to implement and assess the prototype of the blockchain based e-prescription process for example using Hyperledger Fabric.

7 References

[1] OECD (2019), Health spending (indicator). doi: 10.1787/8643de7e-en

[2] P. Kierkegaard, "E-Prescription across Europe," *Health and Technology*, vol. 3, no. 3, pp. 205–219, Sep. 2013, doi: 10.1007/s12553-012-0037-0.

[3] O. K. Odukoya, J. A. Stone, and M. A. Chui, "E-prescribing errors in community pharmacies: Exploring consequences and contributing factors," *International Journal of Medical Informatics*, vol. 83, no. 6, pp. 427–437, Jun. 2014, doi: 10.1016/j.ijmedinf.2014.02.004.

[4] C. Thatcher and S. Acharya, "Pharmaceutical uses of Blockchain Technology," in *2018 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, Dec. 2018, pp. 1–6, doi: 10.1109/ANTS.2018.8710154.

[5] M. Crosby, "BlockChain Technology: Beyond Bitcoin," no. 2, p. 16, 2016.

[6] B. Marr, "Here Are 10 Industries Blockchain Is Likely To Disrupt," *Forbes*. https://www.forbes.com/sites/bernardmarr/2018/07/16/here-are-10-industries-blockchain-is-likely-to-disrupt/.

[7] "e-Estonia — We have built a digital society and we can show you how," *e-Estonia*. https://e-estonia.com.

[8] G. Eysenbach, "What is e-health?," *J Med Internet Res*, vol. 3, no. 2, Jun. 2001, doi: 10.2196/jmir.3.2.e20.

[9] H. Oh, C. Rizo, M. Enkin, and A. Jadad, "What Is eHealth (3): A Systematic Review of Published Definitions," *J Med Internet Res*, vol. 7, no. 1, Feb. 2005, doi: 10.2196/jmir.7.1.e1.

[10] "Healthcare's digital future | McKinsey." https://www.mckinsey.com/industries/healthcare-systems-and-services/our-insights/healthcares-digital-future.

[11] "Digital Prescription | Drupal." https://www.haigekassa.ee/en/people/digital-prescription.

[12] "e-Prescription," *e-Estonia*. https://e-estonia.com/solutions/healthcare/e-prescription/.

[13] B. Marr, "A Very Brief History Of Blockchain Technology Everyone Should Read," *Forbes*. https://www.forbes.com/sites/bernardmarr/2018/02/16/a-very-brief-history-of-blockchain-technology-everyone-should-read/.

[14] M. Iansiti and K. R. Lakhani, "The Truth About Blockchain," p. 11.

[15] Z. Zheng, S. Xie, H. Dai, X. Chen, and H. Wang, "An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends," in *2017 IEEE International Congress on Big Data (BigData Congress)*, Jun. 2017, pp. 557–564, doi: 10.1109/BigDataCongress.2017.85.

[16] B. Asolo, "Consortium Blockchain Explained," *Mycryptopedia*, Jun. 26, 2018. https://www.mycryptopedia.com/consortium-blockchain-explained/.

[17] D. Massessi, "Public Vs Private Blockchain In A Nutshell," *Coinmonks*, Dec. 12, 2018. https://medium.com/coinmonks/public-vs-private-blockchain-in-a-nutshell-c9fe284fa39f

[18] M. Swan, *Blockchain*. O'Reilly Media, Inc., 2015.

[19] M. Nofer, P. Gomber, O. Hinz, and D. Schiereck, "Blockchain," *Business & Information Systems Engineering*, vol. 59, no. 3, pp. 183–187, Jun. 2017, doi: 10.1007/s12599-017-0467-3.

[20] "Blockchain Oracles," *BlockchainHub*. https://blockchainhub.net/blockchain-oracles/.

[21] "Introduction — hyperledger-fabricdocs master documentation." https://hyperledger-fabric.readthedocs.io/en/release-1.4/whatis.html.

[22] P. Runeson, M. Höst, A. Rainer, and B. Regnell, *Case Study Research in Software Engineering: Guidelines and Examples*. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2012.

[23] B. Kitchenham and S. Charters, *"Guidelines for performing Systematic Literature reviews in Software Engineering Version 2.3,"* Engineering. 2007.

[24] “Retseptikeskuse teenused ja liidestumise juhend(Prescription center services and connecting guide).” https://www.haigekassa.ee/partnerile/it-juhendid/digiretsept, [Online]. Available: https://www.haigekassa.ee/partnerile/it-juhendid/digiretsept.

[25] MicroLink Eesti AS, “ANALÜÜSIDOKUMENT DIGIRETSEPTI REALISEERIMINE SAP PLATVORMIL (Analyzis document about implmenting e-prescription).” [Online]. Available: https://www.riha.ee/api/v1/systems/rets/files/575ce587-0cde-ded9-2725-44e8aec75dba.

[26] B. Ying, W. Sun, N. R. Mohsen, and A. Nayak, “A Secure Blockchain-based Prescription Drug Supply in Health-care Systems,” in *2019 International Conference on Smart Applications, Communications and Networking (SmartNets)*, Dec. 2019, pp. 1–6, doi: 10.1109/SmartNets48225.2019.9069798.

[27] D. K. Meena, R. Dwivedi, and S. Shukla, “Preserving Patient’s Privacy using Proxy Re-encryption in Permissioned Blockchain,” in *2019 Sixth International Conference on Internet of Things: Systems, Management and Security (IOTSMS)*, Oct. 2019, pp. 450–457, doi: 10.1109/IOTSMS48152.2019.8939226.

[28] S. Tanwar, K. Parekh, and R. Evans, “Blockchain-based electronic healthcare record system for healthcare 4.0 applications,” *Journal of Information Security and Applications*, vol. 50, p. 102407, Feb. 2020, doi: 10.1016/j.jisa.2019.102407.

[29] R. Kumar, N. Marchang, and R. Tripathi, “Distributed Off-Chain Storage of Patient Diagnostic Reports in Healthcare System Using IPFS and Blockchain,” in *2020 International Conference on COMmunication Systems NETworkS (COMSNETS)*, Jan. 2020, pp. 1–5, doi: 10.1109/COMSNETS48256.2020.9027313.

[30] M. He, X. Han, F. Jiang, R. Zhang, X. Liu, and X. Liu, “BlockMeds: A Blockchain-Based Online Prescription System with Privacy Protection,” in *Service-Oriented Computing – ICSOC 2019 Workshops*, Cham, 2020, pp. 299–303, doi: 10.1007/978-3-030-45989-5_27.

[31] J. Mahatpure, M. Motwani, and P. K. Shukla, “An electronic prescription system powered by speech recognition, natural language processing and blockchain technology,” *International Journal of Scientific and Technology Research*, vol. 8, no. 8, pp. 1454–1462, 2019.

[32] Frederik Milani, Luciano García-Bañuelos, Hajo A. Reijers, Lilit Stepanyan, “Business Process Redesign Heuristics for Blockchain Solutions,” *2020*.

[33] pwc, “A prescription for blockchain and healthcare: Reinvent or be reinvented.” 2018.

[34] X. Zhou, Y. Jin, H. Zhang, S. Li, and X. Huang, “A Map of Threats to Validity of Systematic Literature Reviews in Software Engineering,” in *2016 23rd Asia-Pacific Software Engineering Conference (APSEC)*, Dec. 2016, pp. 153–160, doi: 10.1109/APSEC.2016.031.

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