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Modelling Business Processes on a Blockchain Eco-System (BPMN)

Master's Thesis (30 EAP)

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Abstract:

Blockchain technology is more and more positioned as a promising technology for changing business processes. This potential has attracted companies to investigate how blockchain can be enable significant benefit gains for companies. However, such gains can only be realized by innovating business processes and not by merely replacing existing technology. Process models play an important role when engaged in innovating business processes because of process analysis and process redesign. This thesis investigates how blockchain-oriented processes can be modelled with the activity-centric modeling paradigm of BPMN. To achieve this, a case study on redesigning the auditing process of a non-profit organization is conducted. The business process is modelled as-is and redesigned by using BPMN. The thesis examines the suitability of BPMN by considering commonly occurring blockchain specific patterns. The thesis shows that blockchain-oriented processes can sufficiently be modeled with BPMN. However, BPMN lack certain elements that could represent commonly occurring patterns more accurately.

Keywords:

Blockchain, Smart Contracts, BPMN, Business Process Models.

CERCS: P170

Äriprotsesside modelleerimine on plokiahela ökosüsteem

Lühikokkuvõte:

Plokiahela tehnoloogiat on järjest enam vaadeldud kui paljutõotavat tehnoloogiat äriprotsesside muutmiseks. Selle potentsiaal on äratanud paljude ettevõtete tähelepanu uurimaks, kuidas plokiahel saab ettevõtetele kasuks olla. Sellist kasu saab siiski saavutada ainult äriprotsesse uuendades, mitte lihtsalt olemasoleva tehnoloogia asendamine. Protsessimudelid mängivad olulist rolli äriprotsesside uuendamisel, kuna nad on analüüsivad neid protsesse ja vajadusel kujundavad ümber. Selles lõputöös uuritakse, kuidas plokiahelale orienteeritud protsesse saab modelleerida BPMN-i tegevuskeskse modelleerimise paradigma abil. Selle saavutamiseks viiakse läbi uurimistöö mittetulundusühingute auditeerimis protsesside ümberkujundamise kohta. Äriprotsesse modelleeritakse praeguses vormis ja kujundatakse BPMN-i abil ümber. Lõputöös uuritakse BPMN-i sobivust, võttes arvesse harjumuspäraselt esinevaid plokiahela spetsiifilisi mustreid. Lõputöö näitab, et plokiahelale orienteeritud protsesse saab BPMN-iga piisavalt modelleerida. Siiski, BPMN-il puuduvad teatud elemendid, mis võiksid täpsemini kajastada korduma kippuvaid mustreid.

Võtmesõnad:

Blockchain, nutikad lepingud, BPMN, äriprotsesside mudelid.

CERCS: P170

Table of Contents

1. Introduction

Technologies are emerging and being adapted to assist and enhance business performance of companies in various fields. Therefore, many enterprises may face a hard decision: which of the available technological solutions makes the best choice in terms of achieving company's goals and meeting its targets.

One of such technologies is blockchain. It is speculated to be disruptive and which potential has not been fully discovered yet [1]. It is being experimented with in domains like finance, business, smart property, identity protection and many others [2]. Startups and incubators working with blockchain implementation are attracting investors' attention. What is more, active investigation and investment is conducted by big banks as well. According to the study of Cambridge Centre for Alternative Finance, 20 percent of central banks around the world will be using blockchain technology by 2020 [3]. Another prominent example are money transfer companies like Bitspark and Abra which use bitcoin to enable fast and secure remittance service. Blockchain technology is also used by startups like Democracy Earth and Follow My Vote for ensuring legitimate and fair voting during public elections [4].

Talking about blockchain mechanics, it is a distributed ledger technology. Every participant is a node in the system, a copy of the full record is stored on each node. Information there is coded and locked into blocks using hash codes which enable high level of data security. A change of a single sign in data object will result in completely different hash code [5]. The algorithm of blockchain generation is the following: when a new transaction is created, mining nodes validate it and add to the block they are building. Afterwards they broadcast completed block to the other nodes. If majority of the nodes verify and approve a new block, it is added on top of existing block structure [6].

Blockchain technology has a potential power to redesign existing processes in the society. However, there is a question how we can enable its value. Historically, it happened that existing technologies were replaced by new ones keeping core processes the same. Only gradually the real potential of innovation was recognized and then processes were reengineered. Significant breakthroughs in performance cannot be achieved without abandoning old business rules and assumptions that underlie operations, and looking at processes from a cross-functional perspective. Failing to break away from outdated business rules poses a limitation to value realization of a new technology. Current use cases of blockchain implementation seem to follow the same pattern as it is widely used as an alternative to existing document storing and sharing technologies. However, this should be considered as a normal flow as technology acceptance and acquisition is naturally a time-consuming process [7].

Implementation of new technologies, especially those which are used to redesign business process, may be quite challenging and requires a precise overview of entire business process before and after technology application. For this aim, business process modeling can be used. It starts with process identification which includes identification of processes related to the problem, defining their scope and relations between those processes. Next step is process discovery. It helps to understand the processes in more detail and results in creation of as-is model. Then process analysis stage starts where a modeler searches for problematic issues and respective possible opportunities to improve existing processes, and then assesses them. Process redesign stage deals with creation of to-be process model. It is a redesigned version of as-is model where all or some of the identified issues are addressed. During process implementation stage identified improvements are implemented via necessary changes in the ways of working and the IT systems. The last stage is process monitoring and controlling where implemented changes are constantly monitored and then is some new problematic issues are identified, the cycle is repeated again [8].

Before approaching process modeling, one may thing about the right tool choice. There are various existing techniques and languages aimed at modeling business processes and their efficiency and applicability are constantly assessed and compared by researchers and practitioners. According to Vergidis and Tiwari, business process modeling techniques can be classified into pure mathematical models, pure diagrammatic models (e.g. flowcharts, RADs (role activity diagrams), IDEF (integrated definition methods)), pure business process languages (BPEL - Business Process Execution Language) and also hybrids of the mentioned above - mathematical-diagrammatic models (Petri-nets) and BPL-diagrammatic models (UML 2.0, BPML & BPMN, jPDL, YAWL) [9]. According to Recker et. al., BPMN is one of the most extensive and widely applied business process modeling techniques [10]. Its objective is to support process management by both technical users and business users by providing a notation that is intuitive to business users yet able to represent complex process semantics [11]. There are three types of BPMN model: Process or Orchestration, Collaboration and Choreography. BPMN Process is suitable for capturing internal processes. All other parties interacting with the business entity are considered as external subjects and modelled in a form of separate pools [12]. Collaboration allows depicting interaction between entities but the focus is on the internal processes of the main entity. Choreography focuses on capturing on information flow and coordination between business process participants though it is concerned with data and message exchange rather than with interaction processes.

As blockchain is one of the solutions that could be applied by managers and decision makers to automate or re-design business processes in their organizations, there is a need to model blockchain-based processes. BPMN, for being industry standard and providing models understandable by both business and technical users, is a potential tool for this purpose. Therefore, the first research question is as follows: *"How can blockchain-based solutions be modeled with BPMN?"* The second research question considers the limitations of BPMN when modeling processes on a blockchain ecosystem and inter-organizational processes running on a blockchain solution. As such, the second research question is as follows: *"What are the limitations of BPMN while modeling processes on blockchain ecosystem?"* These challenging tasks will be approached in this research with BPMN Collaboration and Choreography modelling techniques while capturing and designing real-life processes based on the case study.

The results can be used by process analysts or analysts working with blockchain solutions to get an idea of possible ways blockchain implementation, ways of modeling business processes involving blockchain solutions, and finally, assist managers in making a decision whether to implement blockchain in their companies. Academicians can rely on this research as a starting point of a discussion on how business processes on blockchain-based solutions can be modeled.

The following research is organized as follows. Section 2 gives overview of blockchain technology, existing process modeling notations and BPMN and sets theoretical background for Section 3 which explains case study design, execution and the created BPMN models of blockchain-based processes; Section 4 evaluates those models and addresses research questions and finally Section 5 summarizes the research results.

2. Background

This section is setting a theoretical background for the following case study. Here the focus will be on blockchain technology, its definition, typology and most common existing applications. Moreover, there will be on overview of process modeling notations with further focus on BPMN as a current industry standard and the notation that will be applied in the case study part.

2.1. Blockchain Technology

Blockchain is claimed to be a new disruptive technology that has a potential to entirely redesign business processes in many industries and public domains by replacing centralized authorities by distributed publicly-owned systems. For a long time, there was no solution to the problem of enabling entrusted value exchange between individuals or companies without an intermediary third party. The main issue for both physical and online domains is ensuring trust in transaction fairness. Blockchain managed to address this problem with data encryption and consensus algorithms. Its core characteristics are decentralization, immutability, anonymity and auditability [13] which are enabled by its architecture peculiarities.

Blockchain is a distributed chronological database of sequentially recorder complete list of transactions which is simultaneously updated and propagated to all participating nodes. Each transaction is written as a block of information which consists of a header and a body where actual transactions are written. The header contains valuable information which is needed for blockchain mining. In particular, there is a parent block hash which links a new block to existing blockchain and a nonce which is a key parameter in Proof-of-Work consensus algorithm [14].

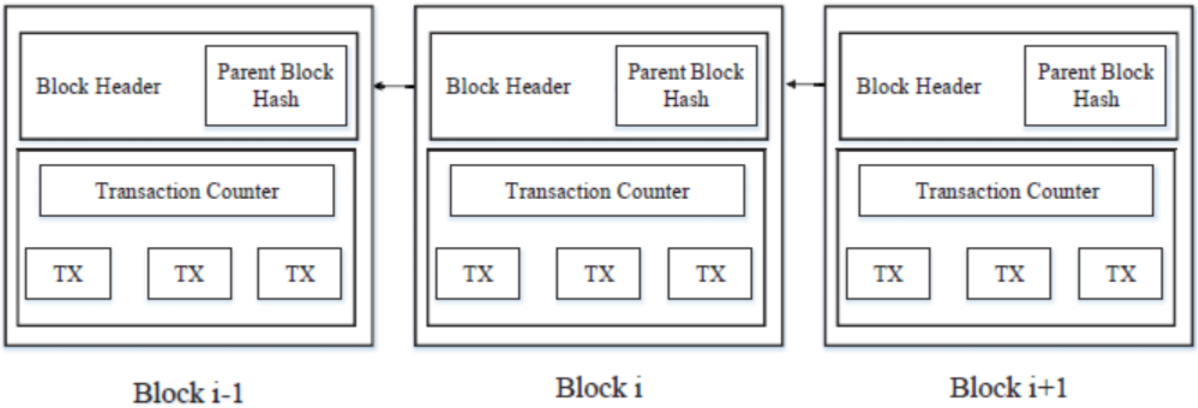

Fig. 2.1 A scheme of block and blockchain structure [13]

The opportunity to add transactions to the blockchain is enabled by digital signature. After joining a blockchain, a new node is provided with a pair of keys: public and private. Private key is used to encrypt the data before sending it to the counterpart while public key is needed to validate the received transaction. Blockchain uses the elliptic curve digital signature algorithm (ECDSA) to generate signatures [13, 14].

Another core component of blockchain is consensus mechanism. It may happen that at a certain point of time several nodes manage to generate a new block simultaneously so that few alternative brunches appear. As long as there is no central authority in blockchain to decide which brunch is legitimate, some set of rules, accepted by all participants, is needed to regulate those situations. There are several common consensus algorithms like Proof-of-Work (most well-known application is done by Bitcoin), Proof-Of-Stake (Peercoin), Practical byzantine fault tolerance (PBFT) (Hyperledger Fabric), Delegated Proof-of-Stake (Bitshares), Ripple and Tendermint. First two algorithms are more suitable for public blockchains as the identity of nodes stays secret but the tradeoff is the considerable computational power that is required to run them. Others disclose identity of participants to each other and therefore are more efficiently applied in consortium or private blockchains where commercial secret can be kept properly.

The core idea of Proof-of-Work (PoW) algorithm is to apply probabilistic approach for addressing the problem of selecting the right brunch in an untrustworthy environment [15]. In order to validate data and generate a block for new transactions that have to be added, a creating node called "miner" should solve a complicated mathematical task. It requires a considerable computational power and therefore there is low chance that more than one node will manage to generate a block at the same time. Even if such case is happening, it is almost impossible that two competitive forks would grow with the same speed. Therefore, it is fixed in PoW algorithm to choose the longer chain as an authentic one. This logic helps to minimize chances that a fraudulent node will introduce a corrupted transaction data into blockchain, it may happen only if it possesses more than quarter of all blockchain computational power. Proof-of-Stake algorithm trusts nodes with bigger amount of currency so that only those participants can append new blocks. To avoid prioritizing the richest blockchain member, some blockchains use random selection between the biggest coin owners or choose miners based on the age of the coins they own [13].

Data on blockchain is protected by applying a hashing function (for instance, Bitcoin is using Secure Hash Algorithm 2 (SHA-2)) [16]. It transforms inputted data into a hash value of a fixed length which is unique to the particular set of data so that if only one digit in the inputted data is changed, its hashed value will be different. This functionality also serves to ensure data integrity on a blockchain.

Blockchain networks can be categorized into several types based on the accessibility and availability of blockchain data as well as based on consensus contributors. Blockchain systems that allow external participants become a member of network and get access to publicly distributed decentralized data are called public [13, 14]. Those which have a predefined set of participants and a fixed range of nodes contributing to the consensus are permissioned blockchains. The core difference in consensus process participation type is influencing blockchain productivity as well: while public blockchains allow every node participate, they are making computational process and consequently a new block generation time much longer; at the same time in permissioned blockchain systems only several nodes participate which makes the generation process much faster and easier to compute. Permissioned blockchains can be consortium (involving several predefined organizations in consensus mechanism) and private (generation of new blocks is totally controlled by one organization). The latter one is an analog of centrally controlled database but still maintains principal features of blockchain such as distributed ledger and secured with hashing function data storage.

Some researchers are categorizing current existing applications of blockchain technology into financial, Internet of Things, public and social services, reputation systems, security and privacy provision [17]. Others are adding distributed and secure data storages, decentralized autonomous organizations [15]. Along with well-known digital currencies, there are some other exciting financial blockchain applications that worth considering. For instance, private securities market is being revolutionized by NASDAQUE Private Equity and Medici which create digital stock exchange platforms that provide fast trading for the pre-IPO and private companies. They are enabled by self-executing smart contracts and therefore eliminate a need in brokerage or bank services [14]. Internet of Things technologies are making use of blockchain to ensure data security and integrity in message exchange between smart devices. Most prominent example is Autonomous Decentralized Peer-to-Peer Telemetry (ADEPT) system which was developed by IBM and Samsung to link smart devices into network and is based on file sharing, smart contracts and peer-to-peer messaging technologies [17]. As for public domain applications, public voting deserves special attention. Data protection and integrity as well as participants` anonymity associated with blockchain technology are enabling safe and reliable digital or online voting. General interaction scheme is similar for all applications of this type: a person uses his or her private key to access the system and then makes the vote with public key. Most impactful examples are BitCongress (based on Ethereum platform), Remotengrity and AgoraVoting (based on BitCoin network) [18].

One of the most prominent applications that were enabled by blockchain are smart contracts. Those are legal contracts automatically enforced by computer protocols [15]. At the same time, Clark et al. define smart contracts as an automatable and enforceable agreement. Automatable by computer, although some parts may require human input and control. Enforceable either by legal enforcement of rights and obligations or via tamper-proof execution of computer code [19]. Therefore, existing research considers smart contracts from two angles: legal-specific and software-specific. However, in both cases the core element is automatic enforcement of some aspect of a legal agreement. Reliable contract enforcement without an involvement of third party became possible due to the distributed blockchain technology which provides secure and immutable environment. All parameters stated in the legal contract are written into code so that after certain conditions are met, smart contract performs respective action e.g. automatic asset relocation. Despite all advantages of fully automated contract enforcement, some researchers still prefer partially apply traditional ways like court enforcement because of the following reasons: it is quite hard to predict and include all possible outcomes into the smart contract code; therefore, there should be a room for human management of exceptional cases. What is more, some parameters fixed in the legal document cannot be controlled by the distributed network because they exist and can be checked only in the physical world [19]. Currently, smart contracts were mainly used to execute financial instruments like derivatives and options but at the same time some use cases of applying this technology to the Internet trading are also appearing [13].

However, smart contracts have one limitation: there is no built-in functionality to retrieve external data which may be needed to execute business logic of the contract. This capability lack is motivated by the deterministic nature of distributes ledger as all nodes should be able to arrive to the same calculation result at any point of time. However, there may be cases like temporary unavailability of server providing external data which restrict some blockchain participant from completing calculations [20]. Therefore, there is a need in third-party trusted provider of external data which is satisfied by the notion of oracles. It is an interface that provides data on request or pushes it automatically to smart contracts [21]. Oracles ensure authenticity of transferred data. In order to ensure that data is not tampered in oracles while transferring, certain validation mechanisms like TLSnotary (provides proof of communication between data source and the oracle) can be applied [21].

Another core aspect while investigating blockchain applications is tokenization. Token is a digital code that represents ownership over some kind of asset e.g. currency, contract; while tokenized blockchains are those which can generate tokens, either by consensus process via mining or by initial distribution [21].

Along with the growing popularity and diversity of blockchain applications, various risks and challenges arise. One of those issues is scalability, distributed ledger nature requires all nodes to record and store every transaction which makes individual nodes databases considerably heavy. What is more, transaction speed is significantly reduced due to block generation time limit. Another big challenge is privacy leakage which appears because transaction privacy is hard to maintain. As long as transaction values are publicly visible, it is possible for the fraudulent agents to trace those transactions to reveal particular user information, transaction origin or relationship between nodes. Moreover, selfish mining phenomenon raises big concerns. This strategy allows miners to get more profit by not publishing their private brunch until they make sure it is longer than the public chain. Therefore, all honest miners are ending up wasting their computing power and selfish miners are getting an opportunity to violate blockchain recorded data [13]. Some researchers and practitioners are also mentioning adoption lag problem as such a radically new technology needs time to be accepted by society as reliable and become a standard solution implemented by majority of players. That lag is deepened even more by complications related to process and information migration from old systems to blockchain as well as imposed governmental control and monitoring [14].

Various issues and limitations of existing blockchain solutions like hard-coded consensus (meaning that consensus rule cannot be changed once the platform is established), ability to write smart contracts only in non-standard, domain-specific languages (while contracts written in general-purpose programing languages were causing non-deterministic results and creating “forks” in the distributed ledger), significant speed limit due to sequential execution rule and confidentiality problems were addressed by new concept of hyperledger fabric [22]. It is an open-source modular and extensible system for permissioned blockchains developed under one of the Hyperledger projects hosted by Linux Foundation [23]. Unlike many existing blockchain applications which first order all proposed transaction before being executed by all nodes, the Fabric has a different architecture motivated by execute-order-validate algorithm: a client proposes transaction by sending it to other peers, after executing the proposal peers send their results or so-called “endorsements” back to the client who gathers them and sends to them to a separate node called ordering service which is responsible for transaction results validation and propagation to the distributed ledger. Ordering service also eliminates those transactions which were based on outdated blockchain state [22, 23]. Such an algorithm allows simultaneous execution of several transactions, significant reduction of collective computational effort and increase in execution time. However, it is only applicable for consortium blockchains as there should be a trusted node that has an exclusive power to validate transactions.

2.2 BPMN (Process and Collaboration)

While approaching business optimization and redesign tasks, it is crucial to get full-fledged and precise understanding of the existing process. Firstly, on should identify problems and issues, then develop alternative solutions to address those issues and also evaluate their impact on business process performance in order to choose the best alternative scenario. On the initial stage of existing process exploration, a business process flow should be captured step by step to get a clear picture. There are different ways to perform this task; at first, business processes were mainly captured textually but as long as processes were becoming more and complicated, involving various participants and containing a lot of details and exceptions, the need in more precise description appeared. Therefore, a graphical representation came into place and enabled building a systematic holistic view on processes which can be easily read and understood by all engaged partied such as process owners, managers, technical engineers etc. no matter the level of technical understanding and expertise [24].

There are various existing techniques and languages aimed at graphical modeling business processes and their efficiency and applicability are constantly assessed and compared by researchers and practitioners. According to Vergidis and Tiwari, business process modeling techniques can be classified into pure mathematical models, pure diagrammatic models (e.g. flowcharts, RADs (role activity diagrams), IDEF (integrated definition methods)), pure business process languages (BPEL - Business Process Execution Language) and also hybrids of the mentioned above - mathematical-diagrammatic models (Petri-nets) and BPL-diagrammatic models (UML 2.0, BPML & BPMN, jPDL, YAWL) [25]. For this research Business Process Modeling Notation (BPMN) was applied as a widely used and proven industry standard. Its objective is to support process management by both technical users and business users by providing a notation that is intuitive to business users yet able to represent complex process semantics [26]. According to Recker et. al., BPMN is one of the most extensive and widely applied business process modeling techniques [27].

According to Michele and Trombetta, Business Process Model and Notation (BPMN) is the de-facto standard for representing in a very expressive graphical way the processes occurring in virtually every kind of organization [24]. The primary goal of BPMN is to provide a notation that is readily understandable by all business users, from the business analysts that create the initial drafts of the processes, to the technical developers responsible for implementing the technology that will perform those processes, and finally, to the business people who will manage and monitor those processes. Thus, BPMN creates a standardized bridge for the gap between the business process design and process implementation [28]. Rich toolset is another big advantage of BPMN as it gives a great flexibility to model practically any business process. However, some experts argue that it may be considered as disadvantage as well because of introduced confusion to the users [27].

BPMN emerged due to the effort of collaboration between various companies, modeling companies and individual experts formed into the Notation Working Group under the supervision of BPMI.org in 2004. The main idea was to develop a notation supporting needs of business users. Therefore, it was agreed to make it as a graphical tool being quite straightforward for non-technical people. BPMN differs from many other notation and graphical representation methods in the way that it was initially created by companies and modeling tool vendors to provide a single representation way for majority to adopt. Their aim was to minimize adaptation and learning effort for providers and users, and establish a unified standard in the industry. What is more, BPMN was designed to have a capability to easily translate built models into Business Process Execution Language (BPEL) which enabled creating executable processes. Due to those well-managed design objectives and efforts, BPMN was adopted as an OMG standard [29]

BPMN has several application forms (Process or Orchestration, Collaboration and Choreography) which serve different purposes. BPMN Process is used to depict business processes inside the organization while either not showing any interaction with other parties or depicting interaction with an external party while the processes of the latter are left as a black box. The next and more advanced form is Collaboration which combines processes of different interacting organizations into one model and captures interaction between them, mainly via message exchange. Choreography is a high-level view on collaboration which is useful when there are more than two interacting organizations or internal processes are not clearly defined yet. Here activities are representing interaction between parties instead of capturing tasks as it is in Collaboration [30].

As long as BPMN Process is technically a simplified version of BPMN Collaboration, from now on only Collaboration will be addressed meaning that BPMN Process uses the same modeling elements and logic. BPMN Collaboration elements for depicting processes are usually divided into core (most commonly used) and extended (more advance elements, designed for capturing exceptions, special cases etc.). For the sake of simplifying model understandability, core elements are divided into five categories: flow objects, data objects, connection objects, swimlanes, and artifacts. Flow objects category contains events (occurrences, usually have cause or an impact, represented as circles on diagrams and can be of three types: start, intermediate or end), activities (representing tasks which are performed by organizations, depicted as rounded rectangles on diagrams) and gateways (used to control divergence and convergence of sequence flows and determining branching, forking, merging and joining of paths, represented by diamond shape with internal markers indicating type of behavior control), data – data objects (what information is required or is produced while activities or tasks are performed), data inputs, data outputs and data stores, connection objects – sequence flows (shows order of activities), message flows (shows the flow of messages between two participants), association (used to link information and artifacts with BPMN graphical objects) and data association, swimlanes – pools (graphical representation of organization) and lanes (sub-partitioning within a pool, may represent internal departments or agents inside organization) [28].

To illustrate the described elements and give a better understanding, one example of BMPN Process will be given.

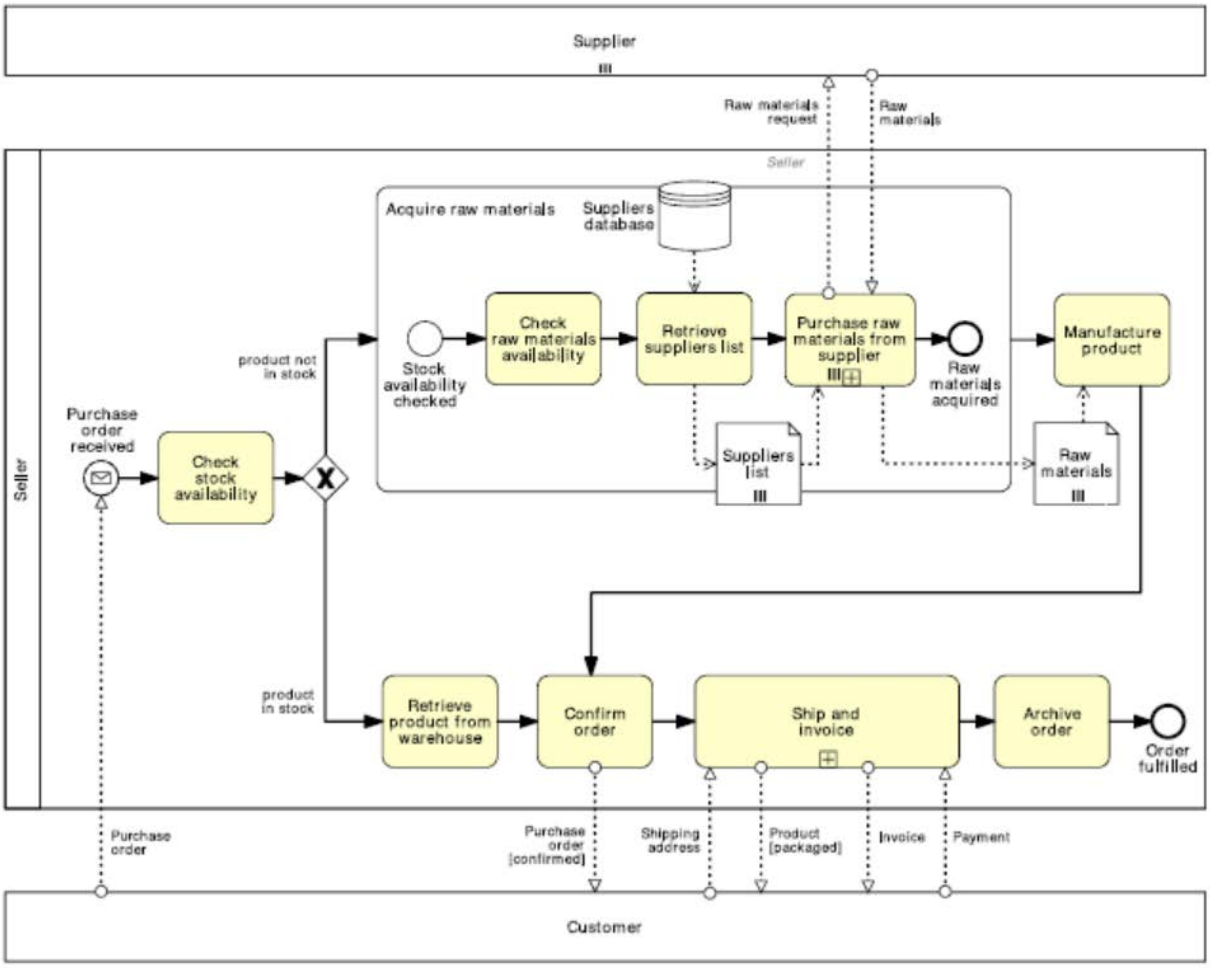

Fig. 2.2 BPMN Process model of order-to-cash process [30]

By having a quick look at this model, one can conclude that it uses more advanced modeling elements than the core ones described above but in most cases they are just special cases of the latter. Figure 2.2 depicts a process within an actor called “Seller” who is dealing with order-to-cash process. It interacts with Customer and Supplier but internal processes of those actors are taken as a black box so that only their message exchange with Seller is modelled. The process starts at receiving by Seller a purchase order from Customer (modelled as a catching message start event), then the Seller checks the stock availability and depending whether the product is in stock or not there are two alternative scenarios which are happening independently. In case the product is in stock, the Seller retrieves it from the warehouse and confirms order by sending a confirmed purchase order to the Customer. Then shipping and invoicing is happening (modelled as a collapsed subprocess), meaning that the Seller receives the shipping address from the Customer, delivers packaged product, sends invoice and receives payment. In case the product is not in stock, the Seller needs to manufacture it. For that, it checks raw material availability, retrieves suppliers list from the Suppliers database, sends raw material request to the Supplier and received the materials (this part of process was modelled as an expanded subprocess as it can be summarized as “Acquire raw materials task”). After that, the Seller manufactures the product and then the process goes to confirming order task and follows the same flow as in the previous scenario. After either of alternative scenarios is fulfilled, the process end by “order fulfilled” end event.

2.3 BPMN (Choreography)

A separate type of process representation provided by BPMN is Choreography. On the contrary to Collaboration, it focuses not on the activities and tasks performed by participants but on their interaction, message exchange and the sequence of messages. Choreography depicts exchange of information between actors and sometimes called as a type of business contract between organizations [28]. Previously the focus was on Collaboration where all processes were happening inside pools and lanes. On the contrary, in Choreography all activities are occurring outside pools. It can be seen as abstracted version of Collaboration where all internal activities and events are dropped and only the message exchange in between pools is left to be modeled. Therefore, Choreography may be quite helpful when clarifying high-level interaction activities between partners at the initial business collaboration stages when detailed process flow is not yet defined or in cases when organizations are not willing to disclose their internal process flows to other parties for the sake of privacy or business secret [30]. Moreover, it may be useful to model complicated communication and “red tape” documentation flow in order to avoid duplications and conflicts that may arise [28].

Some structural elements in Choreography are the same as in most BPMN processes, like start and end events, sequence flows and activities. However, activities here are depicted in a different way because they are representing not a unit of work but an interaction between parties. Those interactions are called message exchange patterns (MEP) [28]. They may occur one-way or two-way and depicted by task objects. Task objects are represented by rounded rectangular shape with participant bands on the top and bottom of rectangular (see fig. 2.3). The participant who is an initiator of the communication is marked with white band while others are marked with light shaded band. The task name band is usually wider and located in between participant bands. What is more, choreography tasks may be marked as loop (cyclical arrow directed counter-clockwise), parallel multi-instance (3 vertical lines) and sequential multi-instance (3 horizontal lines) with a respective sign at the bottom of task name band. Messages are attached to the respective senders; the initiating message icon must be unfilled while responding messages are filled with grey color. There is an option to create sub-choreography and expanded sub-choreography as an analog to sub-processes in Collaboration. The sequence flow is modelled in the same manner as in Collaboration, however, Choreography has a limitation that a participant cannot be an task Initiator if it was not involved in previous tasks as either Initiator or Receiver (that of course does not imply to the first task in the sequence) [28].

Choreography has two main limitations that are imposed by its nature. Firstly, due to its focus on message exchange it ignores the internal processes which are happening inside participant entities and therefore has no tools to illustrated data management which is supporting those processes. Choreography does not have a central control mechanism to maintain data so neither data objects nor data storages can be depicted [30]. Secondly, complex choreographies are vulnerable to errors. Creating and tracking the proper message sequence may become a difficult task, especially after introduction of sub-choreographies and multi-instance tasks. Those errors may lead to deadlocks in a process model [28].

Choreography tools and modelling will be illustrated with the same case example which was used in Figure 2.2.

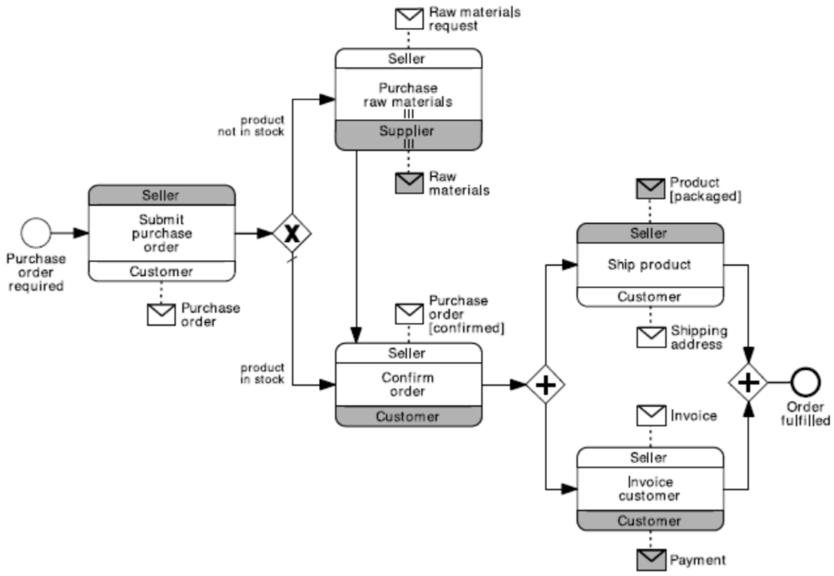

Fig. 2.3 The choreography model for the collaboration model in Fig. 2.2 [30]

As it is visible from the fig. 2.3, the order-to-cash process is much more simplified here as the focus is shifted to participants' interaction and document or material exchange. The process starts with a task "Submit purchase order" initiated by Customer and an initiating message object "Purchase order" is associated with this participant. After the XOR split there are two sequential tasks but in both cases Seller is an initiating participant (there is no sequence conflict as long as it was engaged in the previous task). Raw materials are modelled as a shaded message object as they are sent in the response to initiating message "Raw materials request". After confirmed purchase order is received, two parallel tasks are executed: shipping and invoicing. On the contrary to the collaboration equivalent of this process model, those two processes are modelled separately while in the fig. 2.2 they are depicted as one collapsed sub-process.

2.4 Comparison

To begin with, BPMN Collaboration and Choreography are similar conceptually because they both are aimed at capturing interaction between two or more parties. What is more, both notation types have sequential process flow logic so that tasks are ordered horizontally and therefore performed from the left to right. As for the graphical representation, both types have the same signs for start and end events as well as gateways, intermediate events and sequence flow arrows.

However, there are a number of significant differences. First of all, Collaboration is designed to model business processes (including communication between parties) while Choreography exclusively made for capturing communication flow and message exchange. Processes in Collaboration diagram must be modeled inside pools or lanes representing borders of particular organizations inside which they take place. On the contrary, there is no such thing as pool or lane in Choreography because its processes (represented by Choreography Tasks or Sub-processes) already include several participants depicted with top and bottom bands inside Task object. Therefore, process space is not separated and is the same one for all involved parties.

Collaboration can be best applied to modeling business processes inside organization while showing interaction with other parties. It allows having a deep micro-level view on an organization and getting a full complete understanding of how its work is organized. What is more, it has a rich toolset for capturing almost any kind of process or exception that may occur which makes it so popular among practitioners and academicians. At the same time, Choreography strength is to depict high-level picture of communication flow between organizations when there is a need to abstract from small details or hide confidential business logic. Its focus on message exchange is quite helpful for modeling complicated bureaucratic procedures where the sequence of various message flows is not quite clear from the first sight.

As for the weaknesses and limitations, Collaboration has too many modeling tools to offer so majority of users limit themselves to just a few core elements in their everyday practice. At the same time, as long as it was designed for modeling internal and interaction process with a high level of detailing, it encourages users to build low-level models. Those two factors combined lead to creating quite big and unreadable models. Therefore, the main aim of BPMN to make modeling clear for all types of business users is failed. On the other hand, Choreography has more significant limitations. First of all, it can be used only for capturing message exchange while ignoring all other processes. Secondly, it focuses only on the external interaction while internal communication is ignored. Thirdly, there is no such notion as central data control system so there is no way to model data objects or data storages. Fourthly, even though capturing sophisticated message exchange processes has been already mentioned as an advantage of Choreography, it can also show its weakness and vulnerability to errors because if some errors occur, they may lead to deadlocks.

2.5 Summary

In this part of the paper, the focus was on the central research notion such as blockchain, its architecture, typology, existing applications, challenges and limitations as well as smart contracts, oracles and hyperledger fabric. What is more, roots and principles of Business Process Modeling Notation were described as well as its main application types: Collaboration and Choreography.

Blockchain is a secure, transparent, tamper-proof distributed ledger technology that is run on all participating nodes simultaneously. Most prominent blockchain applications are crypto currencies, Internet of Things, public and social services, reputation systems, security and privacy provision, distributed and secure data storages, decentralized autonomous organizations. Main challenges of blockchain expansion nowadays are scalability, privacy leakage, selfish mining as well as significant adoption lag. Smart contracts as one of the most prominent blockchain applications is a digital contract which stands for legal contract automatically enforced by computer protocols. Smart contracts are enabled and run on blockchain technology. As long as smart contracts cannot retrieve data from external sources due to their architecture logic, a third-party technology called oracle fulfills this function in case smart contracts require external information for executing their business algorithm. Finally, hyperledger fabric enables creating consortium blockchain and smart contracts with general-purpose programming languages. What is more, it supports much faster and less computationally heavy transaction creation and approvement.

BPMN is an industry standard notation adopted by Object Management Group (OMG) which was developed to enable easy and single for the whole industry way of modeling business processes; it can also be used to translate graphical representation into programing language (BPEL). There are three types of BPMN sub-models while here the focus was on Collaboration and Choreography. Collaboration is best used for capturing detailed internal organization processes as well as interaction between several parties while Choreography can help to depict high-level interaction between parties focusing exclusively on message exchange.

3. Case Study

In this section, the case study research method will be used to address the following research questions:

- RQ1: How can blockchain-based solutions be modeled with BPMN?
- RQ2: What are the limitations of BPMN while modeling processes on blockchain ecosystem?

Firstly, general information on case study method will be given by defining the method, describing its classification and explaining motivation for choosing it for this particular research. Secondly, case study design and execution will be presented by defining methods, case study subject etc. and describing actual performance steps. Finally, the designed models and underlying processes will be presented and explained.

3.1 Case study method

Case study research is an empirical method aimed at investigating contemporary phenomena in their context utilizing multiple sources of evidence while the boundary between the phenomenon and its context may be unclear [31]. Usually it is focused on investigating one or several subjects, quite flexible in design, and relies on both qualitative and quantitative data. This research method is suitable for exploration of particular phenomena and explanation of underlying logic and mechanics. It was applied and proved to be helpful in software engineering researches.

There are four research categories according to the aim of a study: exploratory (aimed at building new knowledge about unexplored or poorly explored phenomenon), descriptive (illustrating or reflecting current situation), explanatory (finding reasoning and explanations for examined issues) and improving (bringing positive change into examined phenomenon) [32]. Due to its flexibility and close collaboration with research subject, case study is being applied to all of those types in current academic research. As long as the aim of this research paper is to explore the ways of modeling blockchain-based processes with BPMN and there is not much prior research done on this topic, exploratory research is the most suitable type. At the same time, using real-life business case as a research subject gives broad spectrum of application use cases and design patterns to be modelled with BPMN, as well as more challenging requirements for the research outcome. Therefore, exploratory case study method was chosen for the current research.

3.2 Case study design

Case study was designed with respect to existing academic standard. According to Runeson et.al, case study usually starts with designing when objectives and research plan are formulated, later follows preparation for data collection and its execution, finally, collected data is analyzed and documented into a report. Creating a precise research plan is necessary for a case study however due to its flexible nature, the plan as well as methodologies and data collection technologies may change. Therefore, iterations through the steps mentioned above may happen. Generalized case study plan should consist of: objective (what should be achieved during the study), the case (what kind of organization, department etc. is being studied), theory (description of used theoretical framework and prior research if applicable), research questions (what results or conclusions should be achieved), methods (applied algorithms and techniques for collecting data), selection strategy (where to seek data) [32]. For this thesis research, a general structure will be followed by stating objectives, describing case study subject, data collection and analysis methodology and continued with case study plan, executed data collection and analysis of received data.

Criteria for selecting a case study use case were a proper suitability and need for blockchain-based solution, and availability of complete information that can be received from company representatives. Therefore, for the following case study NEPCon (Nature Economy and People Connected) NGO and their auditing of timber-to-charcoal process have been chosen. It is an international non-profit organization focused on fostering sustainable land use and responsible trade in forest products [33]. Core services offered by NEPCon are capacity building via trainings, conferences and round tables, consultancy for building efficient sustainable strategy, timber and biomass certification, agriculture and tourism certification. For the purpose of this research, the focus was on the Estonian branch and particularly on their FSC timber to charcoal process certification (certification standard established by Forest Stewardship Council).

Charcoal certification process starts with signing a certification contract, followed with initial inspection of premises and documentation. In case of positive inspection result, a certificate is issued and then yearly inspections are taking place to ensure certificate validity.

This process has several weaknesses, first of all, because of limited capacity, checks are taking place only once a year; secondly, documentation for the inspection is usually provided by the certified company representatives. Those factors together give a potential opportunity to hide violations on the certified enterprise. Additionally, certification is valid only in case of using certified raw materials which mean all suppliers should have valid certificates. Taking into account that those enterprises are also inspected once a year only, it becomes quite difficult to undoubtedly ensure that produced goods are actually facing the standards. What is more, documentation checks are quite time-consuming and distract NEPCon experts from inspecting other issues of sustainability standards violations e.g. child labor exploitation. Consequently, there was a need for automation and one of the solutions that are considered by the organization owners is enforcing business rules and automated checks with smart contracts on a permissioned blockchain, which is suitable for ensuring data and decisions validity in the environment with lack of trust between participants.

For this reason, NEPCon was quite suitable subject for our case study as organization members were considering implementation of blockchain and required modeling of business processes of this potential solution. Moreover, Roman Polyachenko, Director of NEPCon Estonia and Chain of Custody Program Manager, who was our main interviewee, has attended several blockchain conferences and acquired solid background knowledge of smart contract solutions which enabled discussing processes of potential application on more technical level. What is more, timber-to-charcoal process is quite suitable for smart contracts application firstly as a charcoal is completely changing the form and therefore is difficult to track the incoming and exiting volumes; and secondly, because volume reports and conversion rates are a sensitive commercial information that cannot be either displayed in public register or stored in centralized database due to the risk of third party intervention.

Data collection for this research will be performed using data triangulation. This approach means taking different angles towards the studied object and thus providing a broader picture which is important to increase the precision of empirical research [31]. As long as it is planned to mainly collect qualitative data, triangulation is necessary to ensure its unbiasedness. According to Sate's classification of triangulation types, there will be applied data and observer triangulation. Data will be collected via unstructured interviews (a list of questions is prepared in advance but they are not necessarily asked in the same order as an interviewer adapts to the natural interview flow [32]) which will be combined with workshops aimed at building conceptual current and future state process model, as well as one presentation to demonstrate research results to the company representative. What is more, data will be collected via document analysis, access will be given to some company reports, certification procedure guidelines and document templates. As for the observer triangulation, interviews will be conducted by a group of researchers: my thesis supervisors, I and another master student who is working on a related topic based on the same case study subject. It is important to mention that independence of our research studies will be ensured properly: there will be no exchange of results, during workshops only conceptual modeling will be used in order to avoid a bias of using particular notation, cooperation will happen only on data collection phase.

Confidentiality and ethical rules will be followed by presenting research results to the company representative and clearly explaining what information will be published so that he is fully aware while giving his consent for publishing. In case of some objections from the company representative side, the research text should be edited according to his feedback.

3.3 Case study execution

Case study was performed according to pre-defined design described above and consisted of the following steps:

1. Conducting workshop for discovering as-is process. For this purpose, the research group had a meeting with NEPCon representative and collectively mapped current state of timber-to-charcoal certification and auditing process as well supply chain processes of certified companies that are checked during auditing. Drawing was used to map the process conceptually in order to avoid bias of using particular modeling notation.
2. Modeling of as-is processes. Based on collected information, drafts of current state processes were modeled in BPMN and presented to the company representative. Important to note that models were created only in BPMN Collaboration and Choreography as long as BPMN Orchestration (or Process) shares the same elements and logic (the only difference is that processes on external parties are left as a block box) with Collaboration, and therefore it was

covered while creating the Collaboration model. Drafts were modified several times after receiving feedback and contacting company representative online for process clarifications. Final models were verified with NEPCon to make sure all processes are depicted properly and all presented information is approved to be published. There was no collaboration and models sharing with another master student researcher on this step.

3. Conducting a workshop for developing to-be process. The research group has met NEPCon representative once again to understand better their process needs and collect requirements for the new solution. During the workshop, a future state blockchain-oriented process model was collectively designed. Again, the model was done conceptually with high-level drawings which avoided using tolls of some particular modeling notation.

4. Modeling of the to-be process. Here again, draft were created then refined several times according to the feedback. To-be process modeling was more challenging than as-is modeling because of the lack of previous research and use cases. Therefore, more iterations took place which also involved consultations with the thesis supervisors. Similar to step 2, there was no results exchange or collaborative modeling with another master student researcher.

5. Conducting analysis and evaluation of created models. Designed to-be models were analyzed and evaluated a pattern collection framework for blockchain-base applications according to Xu et al. (2019).

Overall, there were 6 interviews and meetings with NEPCon representative and the research group including 3 workshops (for as-is and to-be processes mapping as well for presenting final research results) which all lasted for around 90 minutes each. Interviews were conducted in semi-structured form, all participants of the research group were able to participate and take notes which enabled observer triangulation. However, it was ensured that no model drafts performed in particular modeling notation were exchanged. For the documentation analysis, NEPCon has provided their certification process instructions, misconformances checklist for conducting audit, annual trade volume template, audit report and certificate document examples. Finally, a documentation of verified models (Section 3.4) as well analysis and evaluation findings (Section 4) was done.

3.4 Timber-to-charcoal process

In this part, as-is and to-be certification and auditing processes are described as well as limitations of current state process.

The as-is processes

Firstly, let us focus on the timber-to-charcoal process which is the object of certification. It starts from cutting wood by forest owner, this material is then provided directly or via a broker (Roundwood trader) to the charcoal processor who processes wood into charcoal by burning it. This process has a conversion rate of 80% which means that only 20% of inputted volume stays in the output after processing wood into charcoal. Produced charcoal in general containers is sold to secondary processor who is putting charcoal into packs ready to be sold in retail shops. Here conversion rate is 90% (10% of initial volume is lost during packing). Then charcoal packs are sold to retailer directly or via a broker (Bulkbuyer).

Certification process has two parts: onboarding or initial certification and yearly auditing. As for the onboarding, it starts with signing a contract, then initial inspection takes place consisting of a premises check (in case of a Forest Owner NEPCon inspectors are checking forest conditions), documentation check and check of suppliers' certificates. During documentation check inspectors go through job and safety instructions, reports etc. Turnout volumes are provided to inspectors in an aggregated form by certified company representatives who fill in NEPCon Excel spreadsheet template. However, sometimes inspectors can check actual invoices if there is a need for more precise evaluation. Suppliers' certificates are checked against FSC database. After completing audit report, it is checked by another NEPCon expert. In case of positive decision, it is recorded in FSC database and a certificate is issued. After 1 year passes, annual audit (second part of certification process) takes place which has basically the same steps as initial audit except signing the contract and issuing certificate. What is more, in case less than 5 misconformances are discovered, a company is given around 1 month to fix them and be re-audited again. For the BMPN model of supply chain and as-is certification processes refer to the figures 3.1 and 3.2.

After completing modeling, several issues were encountered in those processes which in the environment with lack of trust between participants may lead to violations and undermine the validity of results. Firstly, audit happens on a planned date because a certified company should make sure that all relevant employees are present on that date. Therefore, it gives time and opportunity to get ready for an inspection and potentially hide evidences of violations in place. Secondly, volume turnout consolidated report is prepared by client company representatives, which gives a potential opportunity to report wrong figures and hide violations. Thirdly, audit is happening only once a year which allows a client company potentially selling goods which do not face the standard up to one year. Fourthly, suppliers' certificates status is checked against FSC database, those statuses are updated also once a year. Therefore, if potentially a supplier starts producing goods which do not meet standards just after confirming certificate validity, a client company would use improper raw materials for as long as for one year. Fifthly, NEPCon inspectors are occupied with this job for a long period of time and do not have enough time and resources to pay more attention to other parameters on the auditing checklist. In order to generalize, mostly all those issues are caused by a lack of capacity to check input and output volumes in real time between different companies to ensure up-to-date validity. Those issues were used as a basis for requirements for the to-be blockchain-based process.

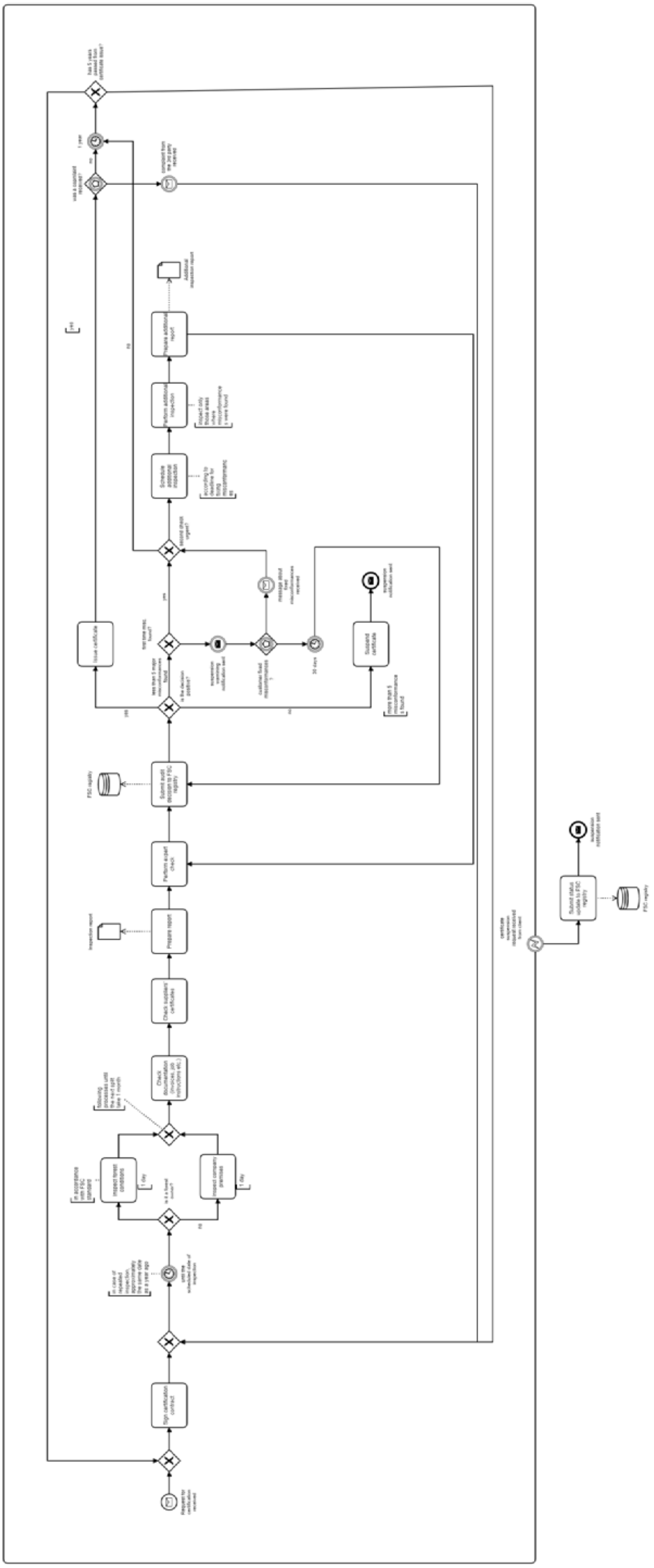

Fig. 3.1. Certification process modeled with BPMN Collaboration

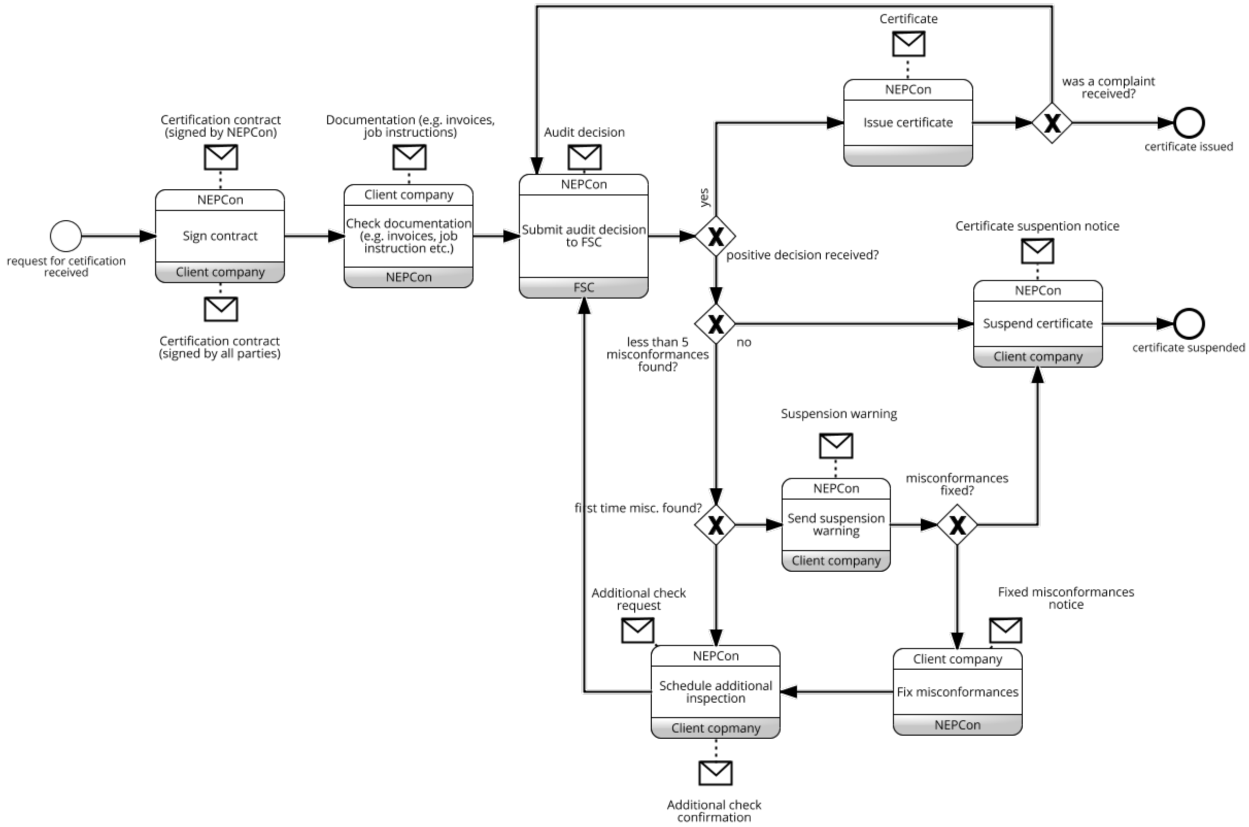

Fig. 3.2. As-is certification process modelled with BPMN Choreography

The to-be process

The designed blockchain-based solution required all process participants, NEPCon, all client companies that are certified as well as other certification organizations should be linked with one permissioned blockchain.

The process starts with signing the contract and initial audit which is similar to the as-is process. In case of positive initial audit outcome, a new active token for the certified client organization is created on the blockchain (see fig. 3.3). This is an initiation step when the certified company is included into the permissioned blockchain and sets its own node. From now on, all changes happening on the blockchain will be recorded on its node as well.

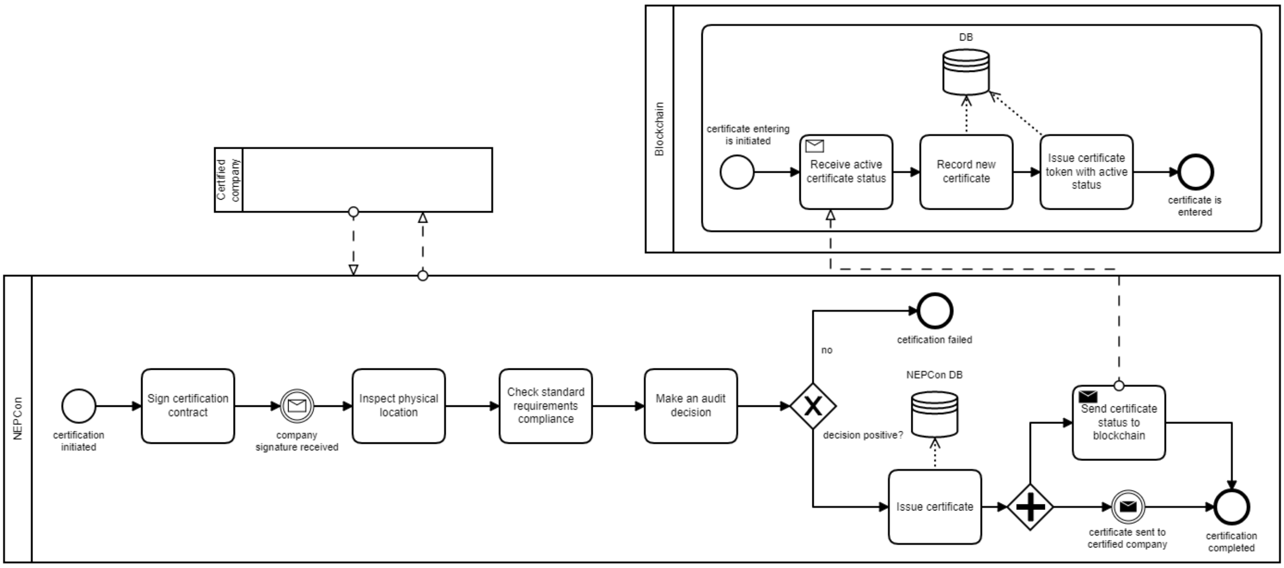

Figure 3.3. Initial certification and onboarding of the client company in the to-be process (modeled with BPMN Collaboration)

Automation of auditing business processes is achieved by a combination of four smart contracts running on blockchain and one more – running on the analytical node. For the BMPN model of to-be auditing processes refer to the figure 3.4.

The first smart contract enforces change of certificate token status based on NEPCon decision, this logic was motivated by NEPCon requirement for the to-be process that the company should maintain full control over the certificate status change.

In order to automate the verification of volume data of certified companies, they should upload their invoices to the blockchain. However, they are not allowed to do that unless certificate tokens of them and their supplier in that particular business transaction are proved to have active statuses, this is enabled by the second smart contract.

After a certified company has passed a certificate validity check, they submit invoice document to the blockchain. However, the document is not uploaded to the blockchain directly because it is usually saved in electronic form like pdf while only invoice transaction details are required to be submitted to the blockchain. Therefore, those details are extracted from pdf documents firstly and then both volume data and invoice document are hashed to ensure security and consistency of data. All these processes are performed on an external technological solution which is called invoice upload and hashing system in the designed process model.

Afterwards, hashed volume data is submitted to the blockchain and duplicated on all participating nodes. As long as this solution is quite advanced, not all client companies would have it internally built but rather outsource from the third party provider.

Another process that has being automated with a separate smart contract is conversion rate update check. Conversion rate is a quite important parameter reflecting production efficiency which influences revenues and market leadership. Consequently, processor companies aim at advancing their technologies in order to improve it. However, there may be also cases of intentional conversion rate change in order to hide some improper transactions. Therefore, the certified company is firstly sending a request to change a conversion rate. It is automatically compared with the previous one and deviation is calculated. In case the deviation exceeds the accepted limit, a notification is sent to NEPCon. Then regardless the case, NEPCon is making decision whether to approve conversion rate change or leave the older one.

Input and output volumes verification is conducted on a separate node controlled by NEPCon in order not to overload permissioned blockchain. Involved computations are quite processing intensive so in case all those calculations had to be duplicated on all nodes, it would considerably reduce the process speed on blockchain.

Therefore, actual computations are moved to the analytical node while only final result will be recorded on the blockchain. Every 3 months, in and out volume data is extracted from blockchain and two checks are performed: 1) whether volume-in was greater than volume-out multiplied by a conversions rate; 2) whether actual conversion rate calculated based on volume data is equal to the one reported by the certified company. Conclusions of both checks are recorded in the database of the analytical node and also on the blockchain.

All messages and triggers are sent to NEPCon from blockchain through the application called monitor. Physical audit process sequence is similar to the as-is process, however, documentation check is replaced by receiving audit conclusions from the blockchain. What is more, at the end of audit, certificate status update is sent to the blockchain.

The designed to-be process addressed issues which were encountered in the as-is process. Firstly, trust and anonymity is ensured by distributed ledger technology so that everyone owns up-to-date copy of the data. At the same time, all individual transaction details are hashed so that commercial secrecy is ensured. Secondly, transactions volumes audit is taking place in real time, therefore, there is no more lag between potential violation and regular inspection. What is more, this process is automated so NEPCon auditors would have more time and capacity for inspecting physical premises and pay attention to other items on the audit checklist. Thirdly, it would not be possible to trade with uncertified supplier any more. Fourthly, volume data will be taken directly from invoices and verified against the same data of the supplier; consequently, there would be less room for data manipulation from the client company side.

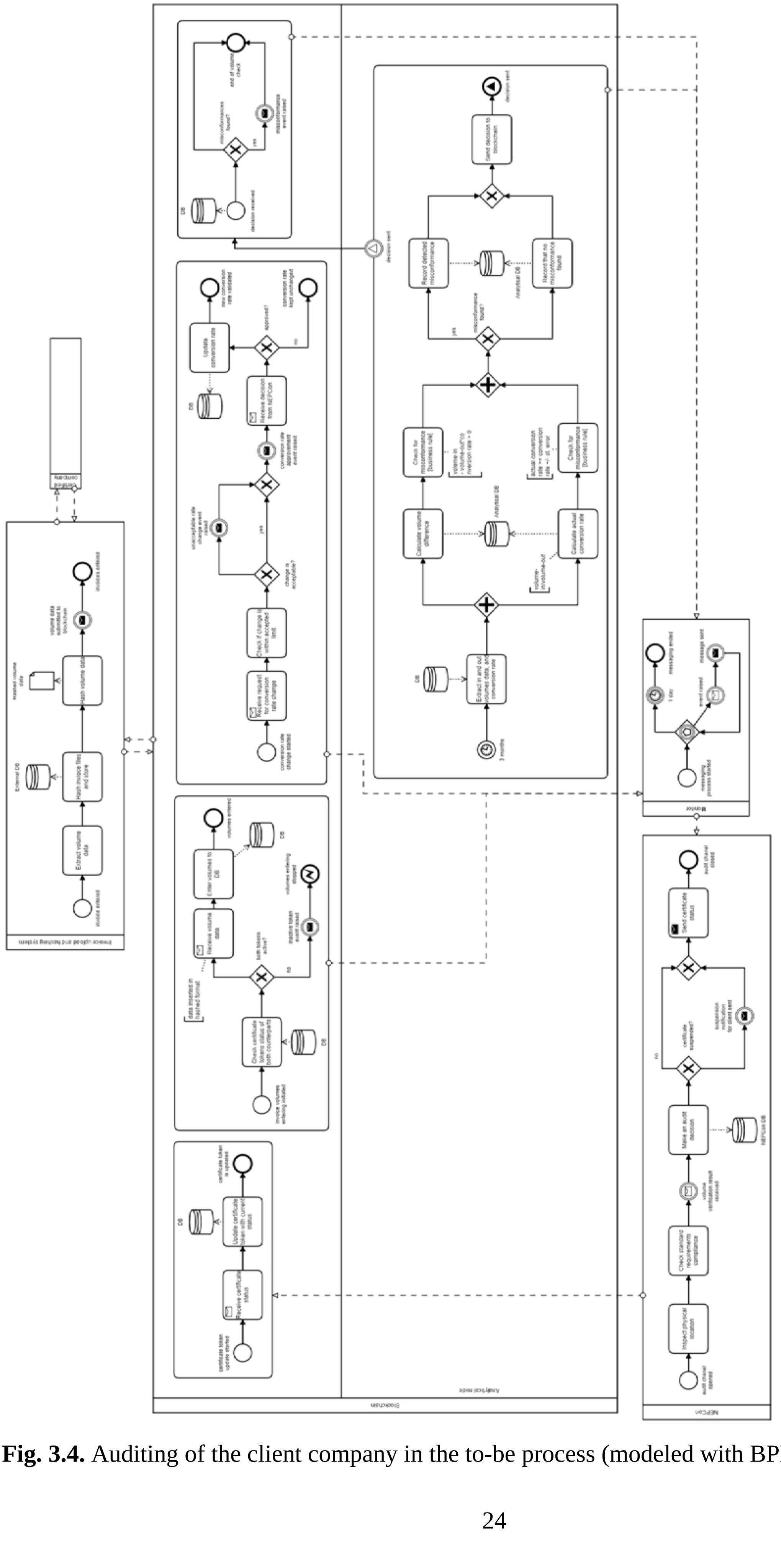

Fig. 3.4. Auditing of the client company in the to-be process (modeled with BPMN Collaboration)

4. Discussion

In order to address research questions that were initially formulated, let us evaluate how effectively common elements or patterns of existing blockchain-based use cases were modeled during this case study. For this purpose, Xu et al. (Xu et al. 2019) are referred to, who have made systematic research of currently existing patterns in smart contract and blockchain-based solutions and developed a pattern typology. There are fifteen patterns which were grouped into four categories. First three patterns belong to a type called “Interaction with external world” and represent ways of exchanging data and signals between blockchain environment and real world. Next four patterns form Data management type representing on- and off-chain data management processes. Three more patterns stand for Security type and mainly deal with authorization issues. Last five patterns fall into Contract structural type dealing with optimizing smart contract size by simplifying the code.

In the following part, all of the above mentioned patterns are defined, elaborated and used to evaluate suitability of BPMN for blockchain-oriented business processes. In so doing, the focus is on designed to-be model.

The only exception will be Contract structural patterns because they are mainly applicable for public blockchains where structural design of a smart contract influences computational cost and time required; it may cause significant delays and therefore inconveniences in blockchain-based solution exploitation. The less code is written to execute a smart contract and the less data is stored there, the cheaper it would be for the future owner. In particular, Contract Registry pattern enables smart contract upgrades and Data Contract pattern helps to keep data on-chain separately in order to simplify those upgrades. For this particular case study, based on the company requirements to have a limited number of blockchain participants, it was chosen to apply permissioned blockchain. Therefore, the fourth group of patterns was not captured in the model. However, the observed private blockchain may grow to a bigger scale over time which could require application of those patterns.

4.1 BPMN Model Structure

To-be model was performed only with BPMN Collaboration because it allows depicting processes inside several entities simultaneously as well as interaction between them, which is necessary for the current case study. At the same time Orchestration stands for Collaboration’s simplified version where processes on interacting pools are kept as black boxes, while Choreography is only capable to depicting interaction or message exchange between parties and more suitable to high-level overview of interaction process. Therefore, in order to address the stated research questions (how BPMN can be used to model blockchain-based processes and what its limitations are with regards to this application) it was considered reasonable to use BPMN sub-model with the richest toolset to utilize its full potential. However, further in the research while considering particular patterns of blockchain-based applications, alternatives ways of modeling with BPMN Orchestration and Choreography will be described.

Firstly, let us look at the way how blockchain ecosystem was modeled in the designed to-be model. As far as all processes are simultaneously executed and distributed on all nodes, blockchain application was modelled as one pool connected with all participating entities’ pools via message exchange. As it was defined in the Background section, smart contracts are autonomous algorithms that automatically execute business rules and change state of some object or trigger action. It was decided to depict them with an expanded subprocess which is ideally suits this purpose: by its logic, subprocess should have its own start and end event, and be autonomous. As a result, the modelled blockchain pool consists of five smart contract expanded sub-processes. In such a way, blockchain and smart contract-based solution logic was properly mapped. At the same time, I have encountered a limitation of the modeling notation. According to BPMN notation, expanded sub-processes inside one pool should be interconnected into one general process that should have start and end events. However, it contradicts smart contract autonomy therefore smart contract expanded sub-processes were deliberately left disconnected from each other.

From now, the focus is on particular patterns and how they were represented in the designed model. For each pattern, a brief theoretical description is given (for all the patterns it is based on Xu et al. (2017)), which is followed by its case study context and description of the way it was captured with BPMN in the designed to-be model.

4.2 Patterns overview

Patterns for Interaction with External World

Pattern 1 and 2: Verifier and Reverse Verifier

<u>Description</u>: Existence of those two patterns is caused by closeness and immutability of blockchain internal environment. Smart contracts on blockchain can access only data stored in blockchain internal database; however, sometimes a data exchange with outside world is needed to perform certain functions either on blockchain or in external systems. Verifier is an external technology that provides blockchain and a particular smart contract with information about external world state that is necessary to launch or execute some function inside blockchain. Reverse verifier, being also an external trusted system, provides external systems with relevant data acquired from blockchain [34].

<u>Context</u>: For the studied case, those two patterns were identified where the decision on certificate status made by the company (NEPCon) outside blockchain has to be inserted into the smart contract (Verifier) and where the misconformances found by the smart contract have to reported to the company`s external system in order to provide a basis for certificate status change (Reverse Verifier). Here it is obvious that performed actions depend on information exchange, however, blockchain itself cannot send or receive emails so an oracle is needed.

<u>Way of capturing with BPMN</u>:

In order to model those two patterns, an intermediary throwing and catching message events (named in the model as “event raised”) were used in order to illustrate an information exchange flow (see Fig. 3.4). What is more, an external oracle (Verifier or Reverse Verifier) is modelled as a separate pool between blockchain and the company to depict its role of intermediary third-party system. Alternatively, if the modeling aim would be to capture high-level interaction of blockchain with external party, it could be done with Choreography by creating a chain of task objects where message would be sent from external party to Verifier and then from Verifier – to blockchain.

Pattern 3: Legal and Smart Contract Pair

<u>Description:</u> Blockchain is considered to be a perfect environment for enabling efficiency of digital legal contracts as long as certain contract parameters can embedded and enabled by smart contracts. What is more, blockchain can serve as a secure storage of a legal document due to its secured and immutable nature [34]. However, blockchain is quite immature technology so there is no legal

binding or regulation of its operations in most of countries. Therefore, its applicability for enabling legal documents is limited.

Context: In the studied case, there is no digital legal document in place; however, some aspects of physical legal documents could be modeled. For instance, inserting certificate status and triggering suspension of certificate (Fig. 4.1 and 4.2), as well as the rules for identifying misconformances which lead to certificate suspension, were modelled.

Way of capturing with BPMN: Certificate insertion and suspension were modelled trough tasks of issuing and deleting of certificate status tokens which followed catching message events reporting current status to the smart contracts. Certificate contract conditions were modelled through an annotation to the task of verifying transaction volumes. Alternatively, if could be modelled in the same manner with Orchestration if processes on external parties would be not relevant for the modeling purpose.

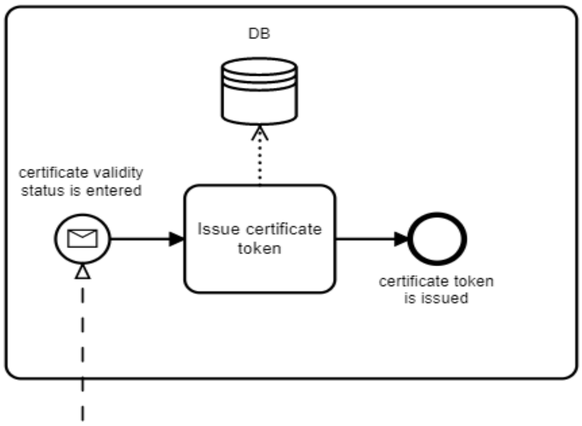

Fig. 4.1 Inserting certificate status as Legal and Smart Contract Pair pattern modeled with BPMN

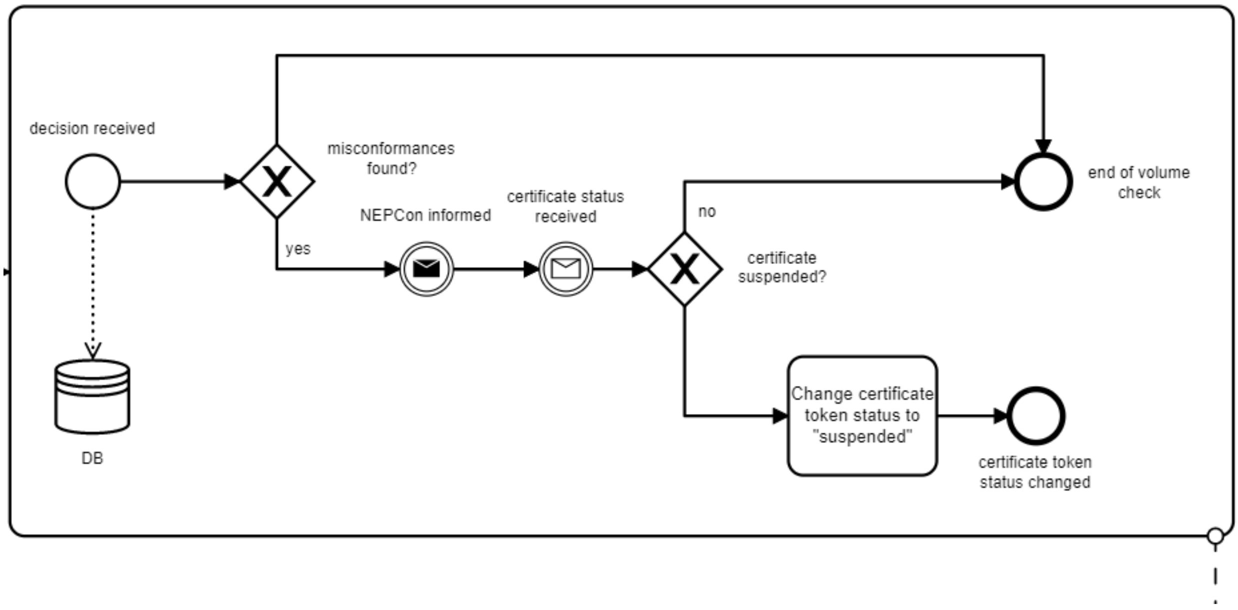

Fig. 4.2 Certificate suspension as Legal and Smart Contract Pair pattern modeled with BPMN

Patterns for Data Management

Pattern 4: Encrypting On-chain Data

Description: As long as blockchain technology enables equal access for all participants to all data and transactions registered, there is a need to ensure a privacy of some commercially critical data. For this purpose, data encryption is introduced which means that certain data in encrypted before entering into blockchain, its owner and trusted parties receive a private key to decrypt this data so that only those actors can have access to this particular part of on-chain data.

Context: For the studied case, data encryption is crucial to enable the process because audited companies would agree to use blockchain only if the confidentiality of all their transactions will be ensured.

Way of capturing with BPMN: Despite the fact that this pattern should certainly be introduced in the to-be process, it is quite difficult to model in BPMN as there is no way to show the distinction between encrypted and not encrypted data. Processes of data encryption, as well as key generation and management are of quite technical nature and the modeling capabilities of BPMN, which was aimed at capturing business processes in the first place, are not enough to capture them. However, one of the solutions is to upgrade BPMN notation and introduce a special task activity for data encryption which will be "decorated" with a new non-standard figure. Another approach is to add a text annotation for tasks of data entrance that data was encrypted before being entered into the blockchain.

Pattern 5: Tokenisation

Description: Tokens are created to represent some valuable goods that are not easily exchangeable in order to reduce risk and increase transaction speed. What is more, it can also represent intangible goods or access rights.

Context: For the researched case, there is no way to represent traded goods with tokens because they are transformed along the supply chain e.g. from round wood into charcoal. However, it is possible to represent certificate as a token which is issued when a certificate contract is signed and deleted if there is a decision to suspend it.

Ways of capturing with BPMN: Certificate token was captured as a data object which is created by task and stored into blockchain database (Fig. 3.4). After a catching message event is received from a Verifier with information about certificate suspension, token is deleted by the assigned task. Another way to model certificate status introduction into blockchain is to enter a task of querying NEPCon database for certificate validity status. This way could be also enabled with Choreography by creating message exchange tasks. However, eventually tokenization pattern was used to simplify the model.

Pattern 6: Off-Chain Data Storage

Description: In order to reduce the volume of information stored on blockchain and therefore lower costs related to initial writing data to blockchain, the solution is to store considerably bid data (when data volume if bigger than its hashed value) off-chain while creating its hashed equivalent that will be securely stored on-chain in order to ensure integrity.

Context: In the studied case, storage cost is not the major issue because the considered blockchain is private and due to the limited number of participants, cots of storing transaction data won`t be significant. However, there is also a need to store invoices as the main reference documents. Those documents accumulated over time may require significant storage capacity and therefore should be stored off-chain in order to enable effective functioning of blockchain system and reduce storage costs. Technically, it will be enabled by the external system that would receive invoice documents from audited companied, extract transaction volume data and hash it, as well as initial invoice files. Hashed documents will be written to blockchain while initial invoices will be stored in the external database. Additionally, automated volume data extraction by an external system will prevent from manual errors which could occur during volume data entering by company representative.

Ways of capturing with BPMN: In order to show hashed value with BPMN, a document artifact can be used with annotation or alternatively a special artifact type could be created. However, hashing procedure was modelled only conceptually as BPMN Collaboration (as well as Choreography) tools are not able to reflect its complicated technical nature. External database for invoice storing was modelled inside external system pool as BPMN does not allow putting it outside any entity.

Pattern 7: State channel

Description: There are certain cases when the value of transaction that should be carried out on blockchain is actually smaller than the cost of this transaction (also called as transaction of tiny monetary value). Even though these operations are not economically viable and appear to be quite time-consuming due to blockchain nature, there is a significant demand for them. In order to tackle this issue, an off-chain state channel is created to conduct micro-decisions faster and cheaper so that only final decision over a certain period of time is recorded to blockchain.

Context: For the researched case, it is not that critical to optimize transactions quantity because the blockchain is private. However, there are certain micro decisions related to conducted audit that cannot be performed on blockchain, e.g. physical premises check. Therefore, there was a need to model a state channel off-chain showing all those audit steps leading to certificate status change which is then sent to dedicated smart contract and written on blockchain.

Ways of capturing with BPMN: In order to depict state channel in BPMN, a sequence on micro decisions were modeled as tasks in the NEPCon pool and the final decision is sent to blockchain with intermediate throwing message event, through Oracle.

Patterns for Security

Pattern 8 and 9: Multiple Authorization and Off-Chain Secret Enabled Dynamic Authorization

Description: Those two patterns allow dynamic binding of participants who can authorize a transaction on blockchain meaning that those participants should not defined from the moment a smart contract is created but can gain control on later stages. In case of Multiple Authorization, M out of N pre-defined parties should unlock a transaction in order to bring it to execution. Therefore, if one of the authorities is no longer available or lost its key, the transaction would still be performed. On the contrary, Off-Chain Secret Enabled Dynamic Authorization allows provide access to parties which are unknown at the moment of smart contract initiation. Both of the patterns to some extent are solving a problem of control loss in case of losing a key.

Context: For the studied case, those patterns cannot be fully applied because, as it was mentioned before, the blockchain system is private; therefore, all participants are defined from the beginning. However, the concept of multiple authorization can be used for conversion rate update because in any case a suggested update should be approved by the auditing company (NEPCon). What is more, there is a possibility that due to some conceptual change e.g. implementation of new technology it would become complicated to estimate a new conversion rate so an external expert should be involved. As long as that third party was not known initially, an off-chain secret may be sent to it to enable dynamic binding.

Ways of capturing with BPMN: Multiple authorization is modeled by intermediate throwing and catching message events sent to and received from the auditing company. No special objects for capturing signing process were applied because there is not much difference between approving and signing from modeling perspective. In case of receiving a key, conversion rate will be updated meaning that it was approved as valid. If the key is not received, the update is not recorded on blockchain (Fig. 3.4).

Pattern 10: X-Confirmation

Description: When new transactions are added to blockchain there is certain time needed to approve and add it on top of other blocks. However, an alternative version of transaction may be competing to be the recorded at the same time. Those chain forks may be used to violate transaction data and cause risk of immutability loss. In order to mitigate it, X-confirmation was introduced so that an activity should wait until X number of blocks is added and only then it is validated and added to the blockchain.

Context: In the studied case, this pattern was not be applied because it is primarily meant for public blockchains.

Ways of capturing with BPMN: X-confirmation is a quite technical and difficult to model with BMPN tools. As long as the model built for this research is conceptual, this pattern was not applied and modeled. However, it could be depicted similar to monitor used in the created model. A new sub-process within blockchain could be created so that whenever a new transaction block would be added, a message would be raised for event listener (or a monitor). The event listener would count the amount of added blocks and send a message to blockchain whenever the minimum number of required blocks is achieved. That message would trigger securing the transaction and changing its status.

Table 4.1. Comparison between BPMN Collaboration and Choreography elements while modeling design patterns for blockchain-base application

Patterns	BPMN Collaboration	BPMN Choreography
1. Verifier 2. Reverse Verifier	As separate pools with message events for communication with blockchain	With message exchange tasks
3. Legal and smart contract pair	A sub-process for the smart contract	With message exchange tasks
4. Encrypting on-chain data	With annotation	Not applicable
5. Tokenization	As a sub-process	Not applicable
6. Off-chain data storage	Implicitly stated with the pools	Not applicable
7. Sate channel	Separate pool for the external process and a subprocess for	Not applicable

	the update (blockchain) process	
8. Multiple authorization	Roles as pools and communication via message events	With message exchange tasks
9. Off-chain secret enabled dynamic authorization		
10. X-confirmation	Separate pool with message events for communication	With message exchange tasks

In the following sub-section, acquired research results will be summarized by addressing research question stated at the beginning of this paper.

4.3 Conclusion on BPMN modeling capabilities for capturing blockchain-based processes

BPMN Collaboration (the same applies to Orchestration for being a simplified version of Collaboration) has a number of strengths enabled by its standard and modeling elements in terms of capturing blockchain-based processes. First of all, it has pools which enable visual separation of blockchain internal processes from the external environment. This modeling capability is crucial because it reflects immutability of blockchain environment. Secondly, having expanded sub-processes in its toolset helps to capture smart contract processes properly, meaning that autonomous nature of smart contract is represented by sub-process boundaries as well as by a complete internal process with its own start and end events. Thirdly, the modeling elements for messaging and data management enable capturing interaction with external world.

However, there is a number limitations discovered during this research. There are certain aspects of blockchain-based solutions which are difficult to model with BPMN Collaboration but are important for representing essence of the solution. Even though it is possible to model smart contracts with independent sub-processes within blockchain pool, according to the notation, they still should be connected into one general process with a start and end event. This contradicts the idea of autonomous smart contracts which are executed independently from each other. What is more, it is quite difficult to capture hashing and encryption processes due to their technicality, even though they are core aspects of blockchain technology; BPMN was initially created to comfort needs of business users and is not suitable for capturing technical algorithms.

Another limitation is lack of modeling elements to capturing certain processes on a blockchain. For instance, encryption process could be modeled by a simplified representation as a task but the produced hashed document is hard to model because there is only one element for capturing a data artifact and therefore hashed and unhashed documents cannot be distinguished from each other. One solution one can use is to add annotations to reflect that data in a particular artifact is encrypted. While it is possible to address those limitations by adding annotation, an alternative way is to suggest addition of new modeling elements for depicting blockchain processes.

BPMN capabilities were also evaluated in terms of modeling commonly occurring patterns in blockchain-based solutions. Interaction with external world patterns were captured fully via throwing and catching message events and separate pools for external third-party trusted Verifier of Reverse verifier systems. Talking about patterns for data management, tokenization was depicted with message exchange and task for token creation or status change. However, encryption was failed to be modeled because of the complexity of a process. It is also impossible to model a distinction between hashed and unhashed data artifact; the solution was found to either add an annotation to hashed artifact or suggest adding a new data artifact to the notation. Another limitation encountered while modeling Data management patterns is that there is no way to capture external data storage as according to BPMN standard, data storage should always be inside a pool. Security patterns were modeled using message exchange and separate pool for external intermediary entity called monitor..

To finalize this analysis, let us refer to the research questions and address them with the research results: "*RQ1: How can blockchain-based solutions be modeled with BPMN?*" and "*RQ2: What are the limitations of BPMN while modeling processes on blockchain ecosystem?*" For the first research question, blockchain-based solutions can be modeled both with BPMN Collaboration and Choreography. Choosing one of them depends on the modeling purpose: Choreography would be more suitable for high-level overview of message exchange processes between blockchain and external parties, while Collaboration enables detailed capturing of processes inside and outside blockchain as well as message exchange between two environments. In BPMN Collaboration, blockchain environment can be modelled as a separate pool while smart contracts can be represented as separate expanded sub-processes. As for the second research question, BPMN is not able to reflect fully the autonomous nature of smart contracts; encryption and hashing processes are difficult to model due to high level of technical complexity; BPMN is lacking certain modeling elements like data artifact for encrypted documents; external data storage is impossible to model because database element can only be modeled inside a pool.

4.4 Threats to validity

Case studies typically have threats to validity [31], in particular case study external validity and reliability threats should be addressed.

External validity is concerned with how well findings of one case study can be generalized and used in other researches and use cases. As long as case study is conducted on the basis of one or several subjects, it may be limited by subject-specific factors which are not applicable to wider spectrum of use cases. For the current research, BPMN model was developed based on the data collected from one case study subject and defined by particular research aim. Even though BPMN standard was strictly followed while modeling and the model verification with two other experts took place, there is certain degree of external validity threat.

Reliability stands for dependency between results and the researcher who produced them. This threat was addressed by verifying models with the domain experts and peer debriefing. What is more, data and observer triangulation [31] were applied meaning that several data sources were used (interviews of domain expert and documentation analysis) and two researchers were observing the same case study subject.

5. Conclusions

I have set up this research to understand how business processes on a blockchain eco-system may be modeled with BPMN. As long as there was not much of prior investigation in this field, my research was aimed to explore the topic and set up a background for the future research.

I have done it by conducting case study based on business process of NEPCon NGO. As for the prior theoretical preparation, I have researched blockchain architecture, as well as its history, typology and existing applications in order to have sound knowledge while designing blockchain-based solution for the case study subject company. Particularly, it was decided that permissioned blockchain is the best choice for a limited number of participants and necessity to keep information confidentiality from the external environment; business rules should be executed with smart contracts which enable automation, unbiasedness and security of the processes. What is more, I have looked into existing process modeling notations, their classifications and comparisons, and explained the choice of Business Process Modeling Notation (BPMN) for this research as for being industry standard, most widely used by business people and having the broadest toolset for depicting exceptional cases. While researching on BPMN, its application types (Process or Orchestration, Collaboration and Choreography) were precisely analyzed and compared in terms of toolset and modeling potential which enabled better preparation for developing new approaches to modeling business processes on blockchain eco-system.

Case study was conducted according to the standard case study plan by designing processes, executing the plan, analyzing and documenting the results. The research team conducted several semi-structured interviews with the case study subject company representative in order to capture and model current state, collect requirements for the desired state and eventually design the to-be blockchain-based process model. Validity of research was ensured by applying data and observer triangulation as several data sources were used and several research group participants were conducting interviews and documenting responses. Analysis of designed model was done by evaluating the quality of modeling representation of existing blockchain application patterns. In such a way I was able to evaluate BPMN modeling potential for capturing all widely spread process patterns that may take place on blockchain eco-system.

Answering to the first research question, I have found that BPMN applications, Choreography, Orchestration and Collaboration, do not entirely fulfil needs of modeling business process on blockchain eco-system; it is not possible to properly model the whole spectrum of blockchain solution patterns. Firstly, to-be model was performed only with BPMN Collaboration because it allows depicting processes inside several entities simultaneously as well as interaction between them, which is necessary for the current case study. At the same time Orchestration stands for Collaboration's simplified version where processes on interacting pools are kept as black boxes, while Choreography is only capable to depicting interaction or message exchange between parties and more suitable to high-level overview of interaction process. Therefore, in order to address the stated research questions (how BPMN can be used to model blockchain-based processes and what its limitations are with regards to this application) it was considered reasonable to use BPMN sub-model with the richest toolset to utilize its full potential. Alternative ways of modeling blockchain-based use cases with Choreography are possible for those patterns which were modeled using throwing and catching events; modeling with BPMN Orchestration was not discussed as long it is technically a simplified version of Collaboration and its capabilities were already represented in Collaboration model. Secondly, Collaboration was efficiently applied to model majority of the common blockchain application patterns. Blockchain was represented by a separate pool and connected with participating entities' pools via messaging. Smart contracts were depicted as separate expanded sub-processes inside blockchain pool which well reflected their autonomous nature. At the same time, independence of smart contracts cannot be properly modeled with BPMN because according to its rules, expanded sub-processes inside one pool should be linked into one process which should have start and end event. Smart contracts are triggered and executed independently which cannot be displayed with currently existing BPMN tools. Talking about particular blockchain application patterns modeling, BPMN was successfully used for modeling patterns for interaction with external world. Trusted third party applications enabling data exchange with blockchain were modeled as separate pools and data exchange was depicted with throwing and catching message event. However, while modeling patterns for data management, BPMN lacked capacity to capture more technical process of hashing and encrypting data as well as distinguishing between encrypted/hashed and non-encrypted/-hashed data objects because there are no special data artifacts for modeling that. For addressing latter issue, it was suggested to either put annotations for those data objects or create new data objects for hashed/encrypted data. Capturing of those processes could be done only conceptually with BPMN, there may be created task objects with special “decorations” to depict encryption or hashing. Similarly, X-confirmation pattern which belongs to Security patterns group was not modeled due to its technical complexity which is not possible to capture with BPMN. Therefore, I can conclude that BPMN can be only partially used for modeling business processes on blockchain eco-system and requires some advancements of toolset in order to be more suitable for that purpose. It has a number of limitations when it comes to modeling more technical processes and while capturing independent processes happening in the same environment or pool.

As for the continuation of this research, I would investigate more on modeling capabilities of BPMN in terms of modeling blockchain-based processes comparing with other modeling notations. It would be useful to evaluate them in terms of complexity and understandability of models for the target users.

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