Estimating the Duration of Blockchain-Based Business Processes Using Simulation

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Abstract. Information systems automate parts of business processes and support involved stakeholders. Recently, blockchains and other distributed ledgers are considered to extend the possibilities for automating inter-organizational processes: these technologies offer a new paradigm for such processes as they may automatically enforce contractual agreements without a trusted third party. Although existing research shows that inter-organizational processes can be enacted based on blockchains, fundamental question, such as *What is the impact of blockchain on the process?*, remain open. This work focuses on analyzing the duration of blockchain-based inter-organizational processes using simulation techniques.

Keywords: Business Process Management · Blockchain · Simulation.

1 Introduction

With business process management (BPM), enterprises can structure, document, and enact their processes [15]. At the core of BPM, process models (e.g., modeled using the Business Process Model and Notation (BPMN) [10]) can capture process elements, such as tasks and data, the elements' relations (e.g., causal and data dependencies), as well as the process' interactions.

Process engines use various technologies: databases store process relevant data, mobile devices enable ubiquitous access, IoT technologies establish cyber-physical connections, and more. Recently, the BPM community researches the application of blockchain, especially in inter-organizational processes [8]. The blockchain technology can enforce the execution of programs by creating transparency and integrity, so collaborating parties can rely on the blockchain as a source of truth. Most research focuses on the blockchain-based execution and mediation of processes: in a setting in which mutual distrust prevents any participant from acting as a central coordinator, authority, or platform provider, blockchain technologies can replace a trusted third party [3].

However, for some inter-organizational business processes, blockchain-based solutions are inefficient and not viable. Some methods employ model-driven development to speed up the development cycle, but expertise and manual effort is required for blockchain-specific configurations. For enterprises it is difficult to decide whether a blockchain is applicable and whether it is efficient enough to

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be viable. Additionally, most of the current solutions are tailored to one specific blockchain implementation (e.g., Ethereum [16] or Hyperledger Fabric [1]), but each technology has different characteristics and the implications for the process vary. Process analysis techniques, such as process simulation, can provide insights to support decision makers.

In this paper, we sketch an approach for analyzing the duration of blockchain-based business processes using simulation. The analysis is based on a configurable model of the blockchain's behavior, which can be integrated in process models to simulate the blockchain's impact on the process execution. Combined with general information (e.g., the technology's security guarantees), the results help businesses to make an informed decision about whether to apply blockchain.

The remainder of this paper starts with an example and an overview of works on blockchain-based BPM (Section 2). In Section 3, we present our approach of estimating the duration of blockchain-based processes. Finally, we discuss our approach and list directions for future work (Section 4).

2 Blockchains for BPM

In BPM, blockchains are mostly applied to inter-organizational (collaborative) business processes [8]. Initially, blockchain was proposed to power the cryptocurrency Bitcoin [9]. It supports simple money transfer and advanced concepts such as escrows.

The so called 2^{nd} generation of blockchains supports smart contracts: programs that are executed by the nodes of the blockchain network. Just as the blockchain-stored ledger, smart contracts are tamper-proofed, transparent, and permanent. These properties guarantee that the program is executed when it is called (stopping the execution requires manipulating the ledger); thus, smart contracts can enforce contractual agreements. Since inter-organizational process models describe an agreement on responsibilities (by whom and in which order are actions performed?), smart contracts can enforce them.

2.1 Related Work

The BPM community focuses mostly on the blockchains with smart contract capabilities. The degree of blockchain integration can vary from simple monitoring tools to blockchain-based process engines: Weber et al. demonstrated blockchain-based monitoring and execution of inter-organizational business processes [14]. The tool Caterpillar by Lopez-Pintado et al. extends this idea to an Ethereum-based process engine — the work takes classical process models [6]. Similar works with different foci exist: Sturm et al. focus on the flexibility of processes [13], Madsen et al. on declarative processes [7], and Hull et al. on data centric processes [4].

Generating smart contracts from process models reduces the development time. However, blockchain-based process execution may have non-functional requirements, i.e., temporal constraints. The mentioned works help to estimate aspects such as the duration; however, this still involves manual configuration and a blockchain setup. The same holds for the work by Yasaweerasinghelage et al.: their approach uses process simulation to send transaction to a blockchain in order to estimate its latency [17].

2.2 Motivating Example

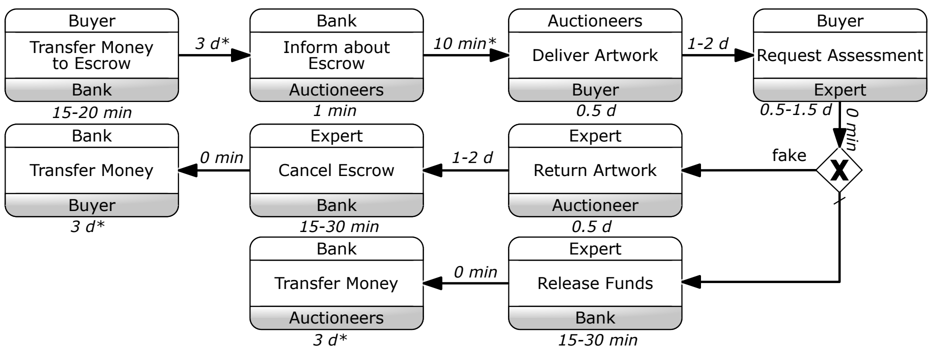

Fig. 1. A choreography model depicting the process of purchasing artworks; tasks are annotated with the time between detecting the previous message and sending the next; control flow is annotated with the time between sending a message and the next initiator detecting it; times marked with * do not exist in a blockchain-based process.

Figure 1 depicts an example inter-organization process as a BPMN choreography model: a *buyer* purchases an artwork from *auctioneers*. Since the purchase may bear a high risk, the buyer first opens an escrow. The auctioneers send the artwork to the buyer and an *expert* assesses it. The expert is a neutral party trusted by both the auctioneers and the buyer. Based on the expert's assessment the money in the escrow is released, and the money is sent to the auctioneers (if the artwork is real). In case of a fraud, the artwork is sent back, and the escrow is canceled (transferring all funds back to the buyer).

Blockchain technologies can take on different roles in *the art-dealing* example. Blockchains with inherent cryptocurrencies often support escrows. Thus, blockchain technologies can replace the *bank* (a trusted intermediary). With smart contracts, the process can further be enhanced: the contract can track the correct progression of the process, for example that the escrow is created before the artwork is delivered. Furthermore, blockchain-based identities can restrict the execution of actions to specific roles. By storing a fingerprint of messages or proficiency data, the blockchain can support the process as a data storage.

In the following, we describe initial work on simulating blockchain-based processes that helps stakeholders to estimate the process execution time and which can be configured towards various blockchain implementations. For the choreography, we consider two types of durations: the time between a message being sent and being detected by the initiator of the next task (annotated on edges) [5] and time between detecting a message and sending the next one (annotated on tasks). For the former, we lift the assumption that interactions in choreographies are timeless.

3 Analyzing Blockchain-Based Latency

A blockchain is a decentralized system for reaching consensus in a peer-to-peer network. Due to its nature, blockchains introduce additional latency: transactions are submitted, shared, verified and processed, and eventually incorporated in the consensus. Afterwards, participants are accountable for their transactions.

Inter-organizational business processes can employ blockchain in various ways. For the art-dealing example, we consider blockchain-based process execution: The bank is replaced by a smart contract and all interactions are logged by a smart contract, which enforces the right ordering of the actions. The triggering participant sends a transaction at the end of each interaction, i.e., the auctioneers send the transaction for the shipment after handing over the artwork.

The transactions trigger the progression of the on-chain process instance. The network managing the ledger processes a transaction in steps: a local transaction is shared with the network but remains pending, a pending transaction is mined (included in a block that extends the ledger), and the mined block with all its transactions is confirmed (succeeded by a certain number of blocks). The duration of each step depends mostly on the blockchain and the underlying network: in Bitcoin, a transaction needs a couple of seconds to spread, and a new block is appended approximately every 10 minutes; for Ethereum, transactions diffuse the network similarly fast; however, a block is added every 15 seconds. We assume that a transaction is included in the first block that is mined after the transaction became available to the network (the reality may be more complex and influenced by transaction fees, network load, and throughput).

In most cases, a participant waits for all preceding transactions to be confirmed. However, if the same participant triggers two subsequent interactions, the participant does not need confirmation of his or her own action. Additionally, if an interaction is physically, such as shipping the artwork, the transaction must be confirmed and the interaction must be completed.

Figure 2 partially shows a timed Petri net representation of the inter-organizational process. Each interaction task of the choreography model is translated into corresponding transitions: the firing of such a transition indicates the completion of the respective interaction. It progresses the state by producing an unnamed token for the control flow. Further, each interaction puts a token identifying the interaction on the `Transaction Local` place. The net includes the blockchain-based transaction processing: a transaction is sent, diffuses the network, is included in a block, and eventually the block is confirmed. The transition `Mine Block` consumes all tokens on `Transaction Pending` and produces respective tokens on `Transaction Included`. Each interaction depends on the previous one; thus, the respective transition can only fire if the previous transaction is

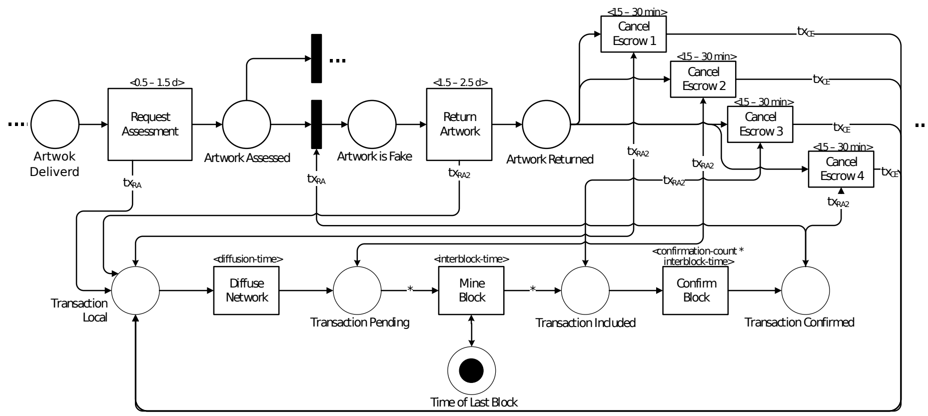

Fig. 2. A timed Petri net showing the three interactions *Request Assessment*, *Return Artwork*, and *Cancel Escrow* including the blockchain's transaction processing

in the place `Transaction Confirmed`. This requirement is represented by the labels on the respective arcs. In the example, the expert is performing two actions in a row, and does not need confirmation of the first transaction. The transitions with label `Cancel Escrow` represent the different options: the escrow can be canceled immediately after `Return Artwork`; thus, there is a transition for `Cancel Escrow` for each possible state of the `Return Artwork` transaction (local, pending, included and confirmed).

Each transition is annotated with ranges for the duration of the respective choreography task/blockchain action [12]. We derived the time by assuming 8h per day. A transition is annotated with the sum of the choreographies task duration and the communication (outgoing arch), for example `Return Artwork` is annotated with <1.5–2.5d> which is the sum of the duration 0.5d and the communication 1–2d. While the duration of a choreography task is domain and instance specific, the duration for a blockchain action depends mostly on the implementation. For this purpose, we introduce a blockchain configuration: 1. the **diffusion-time** — the time until a transaction is known by the network (e.g., around 15 sec for Bitcoin [2][1]); 2. the **inter-blocktime** — the time between the mining of two blocks (e.g., approximately 10 min for Bitcoin, about 15 sec for Ethereum[2]) 3. the **confirmation-count** — the number of blocks that follow an included transaction until it is consider confirmed (e.g., Bitcoin recommends a confirmation-count of 6, Ethereum one of 12, and most private blockchains use 0). These parameters are set according to the used blockchain. The product of inter-blocktime and confirmation-count denotes the time between mining a transaction and confirming a transaction.

The Petri net semantics equipped with temporal information of the choreography and a blockchain configuration allow a simulation of the blockchain-based

[1] Bitcoin diffusion-time: http://bitcoinstats.com/network/propagation/ (02/06/2019)
[2] Ethereum inter-blocktime : https://etherscan.io/chart/blocktime (02/06/2019)

inter-organizational process. We use CPNTools[3] to model[4] all aspects of the Petri net and simulate the process quantitatively and manually step-through simulation techniques. Running 100 instances, we derived an average duration of about 8 days for the version not using blockchain and about 3 days for a blockchain-based version (0 min diffusion-time, 10 min inter-blocktime, 6 blocks confirmation-count; duration ranges where simulated via a binomial distribution). While the blockchain causes delays, it enables process changes that reduce the overall duration: in the example, the replacement of the bank improved the process performance. By simply adjusting the blockchain configuration, it is possible to estimate other blockchain implementations.

4 Discussion and Future Work

In some cases, blockchain technologies may remove the need for trusted intermediaries in inter-organizational business processes. However, such solutions have drawbacks: the distributed nature limits the throughput and causes latency. We sketched a method to analyze the duration of blockchain-based processes.

The analysis relies on formal semantics, domain specific information, and a configuration for a certain blockchain implementation. The configuration comprises three parameters; thus, adapting to different blockchains is simple. Through simulation, the analysis estimates the duration of blockchain-based processes with little effort compared to prototypical and model-driven implementations. However, the impact of blockchain-based implementations on processes is not always significant: especially processes that are executed frequently and that are highly automated might be slowed down by blockchains. Processes that contain various manual and physical tasks may be delayed insignificantly by blockchains or even speed up as manual tasks are automated or third parties are replaced by smart contracts.

The presented work is in an early state. In future work, we will support BPMN choreography models by integrating our approach into a business process simulator, which takes a blockchain configuration as well as an enriched BPMN choreography model as an input. Additionally, different ways of blockchain-based process support exist: we want to investigate existing solutions (such as Caterpillar) to estimate different implementations and paradigms. Furthermore, the blockchain behavior can be modeled and configured on different granularity levels: currently we do not consider that blocks are limited in size, the processing of transactions might be prioritized based on transaction fees, and that block propagation depends on various factors [2].

Additionally, execution time of processes is only one aspect affected by the underlying technology. Public blockchains include a cryptocurrency: a transaction has costs depending on its priority and payload. This may or may not have a significant impact on the overall costs of a process. Related to both costs and

[3] CPNTools homepage: https://cpntools.org (1/7/2019)

[4] Models and results: https://owncloud.hpi.de/index.php/s/iGVqu7WkgMYXIpW

duration is the throughput of blockchains: when a blockchain is used for multiple purposes or by many participants, transactions may remain pending longer.

Analyzing various aspect of blockchain-based processes requires a detailed understanding of the technologies as well as the configuration points. In future work, we will explore such behavioral properties and derive a formal model of blockchains that can be configured towards specific implementations. Detailed models can provide insights in blockchain's behavior as well as its impact on business processes beyond latencies. Such models equipped with empirical data [11] may lead to higher precision in simulating the processes.

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