Blockchain Technology Adoption in Outbound Logistics for the Fourth Industrial Revolution

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***Abstract*—There are opportunities for disruptive applications of blockchain technology in outbound logistics management, especially with peer-to-peer networking support to keep records of verified transactions in distributed ledgers without control by an intermediate party. The impact of implementing a blockchain solution in logistics processes and the effect on process parameters is not well understood or quantified in the literature. The objective of this study is to investigate whether there are opportunities in outbound logistics operations to benefit from the application of blockchain technology and to evaluate the impact of implementing a blockchain technology solution in a specific industry use case. A design science research process, which combines qualitative and quantitative research methods, guided this study. A stochastic discrete event simulation model was developed to evaluate the impact of a blockchain solution for an industry use case in an outbound logistics process. The time to reach visibility is quantified for a Hyperledger Fabric implementation. The results indicated that it would have a significant effect on the time it takes to gain insight into the process and transparency. This study provides evidence that a blockchain solution can have a notable impact on information availability and transparency in an outbound logistics process.**

I. INTRODUCTION

The entire supply chain is affected by the introduction of Industry 4.0 into manufacturing. It involves the global transformation of the industry by introducing digitalisation and the Internet, which will result in ground-breaking developments in design and manufacturing practices, operations, and services [30]. Opportunities to leverage technology to increase transparency, anticipate demand better, and prepare more effectively will increase drastically, which will result in improved inventory planning, warehousing and distribution and communication between supply and demand. Horizontal integration is one of the features of Industry 4.0, with a next generation of global supply chain systems. It is crucial that suppliers, manufacturers, and customers collaborate to increase transparency throughout the supply chain [30].

Blockchain technology is receiving increased attention due to controversies surrounding its possible applications and the resulting business ramifications. It has been called "the most important invention since the internet" and that it has "the potential to revolutionise the digital world" [9]. Cryptocurrencies like Bitcoin and Ethereum are the most popular use cases of blockchain application, but the technology has also gained traction in broader financial technology (Fintech.) Financial companies have started to develop blockchain-based infrastructure to support their service delivery [34].

The question arises whether distributed ledger implementation has the potential to improve business processes in other areas of industry, and if so, how it can be applied in logistics or supply chain management to resolve emerging Industry 4.0 challenges.

II. RESEARCH OBJECTIVES AND QUESTIONS

A research project was undertaken to answer the above question with the objectives:

- To investigate whether there are opportunities in outbound logistics operations to benefit from the application of blockchain technology.
- To develop a model to evaluate the impact of the application of blockchain technology in a specific use case.

The research questions for achieving the research objectives are the following:

- What are the potential applications of blockchain technology in outbound logistics operations?
  - What are the features of blockchain technology?
  - What are the advantages of blockchain technology?
  - What are the disadvantages of blockchain technology?
- What will the impact of the process be if blockchain technology is introduced to the outbound logistics system?

III. RESEARCH METHODOLOGY

Offermann et al. [22] propose a design science research (DSR) process, which combines qualitative and quantitative research methods. The process is structured with three main interacting phases: Problem Identification, Solution Design, and Evaluation. This research used the DSR process to answer the research questions.

IV. PROBLEM IDENTIFICATION

A. *Identify the problem*

In Section II an initial problem has been identified and refined in the tasks and phases described below. The research problem is of interest to more than one entity [22] involved in outbound logistics.

B. *Literature research – part I*

A literature review can be used to identify an initial problem. Literature research is also required to review the current context of the identified problem or analyze possible difficulties for a potential solution [22]. The problem definition is refined during this task.

During the research, this task resulted in a better understanding of the problem environment.

1) Industry 4.0

The complexities and requirements in the manufacturing industry have progressively increased, and the challenges that companies face are, including, amongst others, growing global competition, increased market volatility, and shorter product life cycles. Existing approaches to cost efficiency, flexibility, adaptability, stability, and sustainability are no longer suitable and sufficient [13]. Rapid technological progress has created a range of new business opportunities with the increasing relevance of modern technologies, e.g., digitalization and the Internet of Things (IoT) [2].

Gerbert et al. [10] list simulation, automated robots, horizontal and vertical system integration, and cybersecurity as characteristics of the Fourth Industrial Revolution. Nagy et al. [19] add that the foundation of the fourth industrial revolution is data, that is, the collection method, analyzes and use for decision support. The application of Industry 4.0 features will require the following elements to support all emerging technologies [32]:

- A value chain that is horizontally integrated.
- A "networked production system."
- Vertical integration.
- End-to-end digitalization of engineering design.

An impact of the fourth industrial revolution is that with the support a single digital ecosystem could be created for the supplier, producer and customer where all the important data and information should be accessible instantaneously to enable efficient coordination. This would change the relationship between manufacturers, suppliers, and customers [27].

Industry 4.0 will transform supply chains, which means significant changes are expected for outbound logistics management. The common factor in supporting this is the integration between stakeholders in the value chain of which the supply chain is part.

2) Blockchain technology

Blockchain technology is a distributed digital ledger and can be used for recordkeeping of transactions [23], e.g., in a supply chain. It is a decentralized implementation [12] and is not controlled by a single entity that supports the concept of horizontal integration required by Industry 4.0 [32]. The records captured on the blockchain are also considered to be accurate as a result of the consensus process [20].

Blockchains are suitable for the transactional processing and recording of events or records. As data management is a challenge for an extensive distributed network, blockchains have great potential to improve performance without depending on trust relationships among collaborating parties. Blockchain's three key characteristics are [12]:

- Decentralized through peer-to-peer networking.
- Verified through signatures.
- Immutable through the consensus algorithm.

Currently, blockchain systems are roughly categorized into three types: public, consortium, and private. In a public blockchain, all records are available to the public, and anyone can participate in the consensus process. In a consortium, a group of pre-selected nodes can participate in the consensus process. A private blockchain allows only nodes from a specific organization to participate in the consensus process. A private blockchain can be considered a centralized network as the entire system is fully controlled by a single organization [5][20].

a) Advantages and disadvantages of blockchain

Niranjanamurthy et al. [20] list the following as advantages of blockchain technology:

- *Disintermediation:* It enables a database to be shared directly without a central entity or administration.
- *Empowered users:* All the information and transactions are controlled by the users.
- *High-quality data:* The data on a blockchain is complete, consistent throughout, accurate, and broadly available.
- *Durability, reliability and longevity:* It does not have a single point of failure and can better withstand cybersecurity threats.
- *Process integrity:* Users can be sure that transactions will be executed precisely as per protocol demand, removing the need for a trusted third party.
- *Transparency and immutability:* The blockchain is accessible by all parties, creating transparency, and the transactions cannot be altered.
- *Ecosystem simplification:* All transactions are contained in a single ledger, which reduces the complexity and clutter of numerous ledgers.
- *Faster transactions:* Usually transactions between banks can take days before clearing, and blockchain transactions can reduce the transaction processing time to minutes.
- *Lower transaction costs:* When the third party is eliminated, it reduces intermediaries and overhead costs for exchanging assets.
- *Self-describing electronic transactions:* Context-aware transactions can be created through smart contracts in complex arbitration.
- *Business benefits:* These include efficiency, auditability, traceability, transparency, security, and feedback.

Many of the advantages of blockchain technology can lead to benefits for outbound logistics. Having high quality data [20], transparency [9], immutability [18], a simplified ecosystem [20], faster transactions [20], low transaction cost [20] and smart contracts can be especially beneficial in supply chains [4]. High-quality data will improve analytics and decision making in the supply chain. The fact that blockchains are transparent, immutable and that there is a single ecosystem will reduce any disputes that occur between supply chain parties [4]. Faster transactions and low transaction costs are beneficial, especially due to the high volume of transactions that occur in a supply chain. Smart contracts have many potential applications in the supply chain environment, for example, to ensure payments occur within the agreed time period [4].

The challenges facing blockchain technology are:

- *Scalability:* Zheng et al. [33] illustrate this with Bitcoin's previous block size limited to 1MB, and only every 10 minutes a block was mined. Thus, the Bitcoin network could only handle seven transactions per second and could not deal with a higher transaction rate.
- *Consensus algorithms:* Consensus algorithms are experiencing challenges, for example, "proof of work" is electricity intensive, and the "proof of stake" type of consensus processes can perpetuate the situation where the rich are becoming richer [33].
- *Redundancy:* In a centralized database, transactions are processed once or twice, but blockchain transactions are processed by every node in the network. More work is done to achieve the same result [20].
- *Integration concerns:* Blockchain solutions require substantial changes to or replacements of existing systems. Companies will have to develop a proper strategy to enable the switch [20].
- *Cultural adoption:* Blockchain technology requires a complete move to a decentralized network, which will require the acceptance of various stakeholders [20].
- *Cost:* Blockchain offers potential savings in transaction costs, but it requires high initial capital expenditure [20].

Considering all the challenges blockchain technology is facing, scalability [33], cultural adoption, integration concerns, and cost [20] will likely challenge supply chain applications of blockchain the most.

b) Supply chain management and logistics applications

Logistics is the division of supply chain management process that "plans, implements and controls the efficient, effective, forward and reverse flow and storage of goods, services and related services between the point of origin and the point of consumption in order to meet customer requirements" [31].

Blockchain technology can revolutionize the supply chain by providing traceability throughout the process, especially for companies with a wide variety of products and complex distribution channels. It can provide visibility over the entire supply chain and enable everyone involved to trade real-time data and information securely and effortlessly, saving time, reduces cost and manages payment disputes. It simplifies multi-party processes and creates trust among all involved parties.

There are examples of blockchain technology applications in supply chain management and logistics:

- Ease of processing of extensive paperwork for shipping containers [12].
- Records or certificates on a blockchain to identify counterfeit products [12].
- Facilitate the tracking of the origin of food items [12].
- Operate the Internet of Things [12].
- Enhance supply chain security through smart contracts, asset tracking, secure and error-free order fulfillment, and cybersecurity [18].
- Data management and big data analytics [33].
- Transportation and logistics management [25].

C. Expert interviews

An outbound logistics process expert was interviewed to gain an understanding of the workings of outbound logistics processes in the industry, as the well as essential parameters in such a process, as per [22]. The time it takes to reach full visibility of transaction information at different interfaces in the outbound logistics process is dependent on human interactions and can vary significantly.

D. Pre-evaluation for relevance

Once a suitable problem has been identified, the pre-evaluation for its relevance must be done. This task includes creating a general research hypothesis [22].

Examples of different applications of blockchain technology in supply chain management and logistics in the literature support the case for utilizing blockchain technology in logistics applications. Blockchain technology can be used to integrate freight, fleet, and logistics management to reduce complexity in transportation and logistics systems. It enables instantaneous visibility over a logistics process which will lead to increased productivity, improved end-to-end visibility, reduced errors, and standardized processes and operations [25].

There is not much knowledge in the literature about the impact of implementing a blockchain solution in a logistics process. The effect it has on process parameters, e.g. time to reach process visibility, is not discussed in the literature. It is challenging to recognize and quantify the impact that a blockchain implementation will have on a logistics process.

This study is contributing to understanding of blockchain-technology implementation in a logistics process, specifically outbound logistics. It is focused on understanding the process parameter relating to the time it takes to obtain transaction visibility in an outbound logistics process, and to analyze and quantify the effect of a blockchain implementation.

V. SOLUTION DESIGN

A. Artefact Design

Artefact design is a creative engineering process. During this step, the problem can be restated by iterating the activities from the Identify Problem phase [22].

A model of a specific outbound logistics use case in Fig. 1 was developed to evaluate scenarios of normal operations compared to that of the hypothetical implementation of a

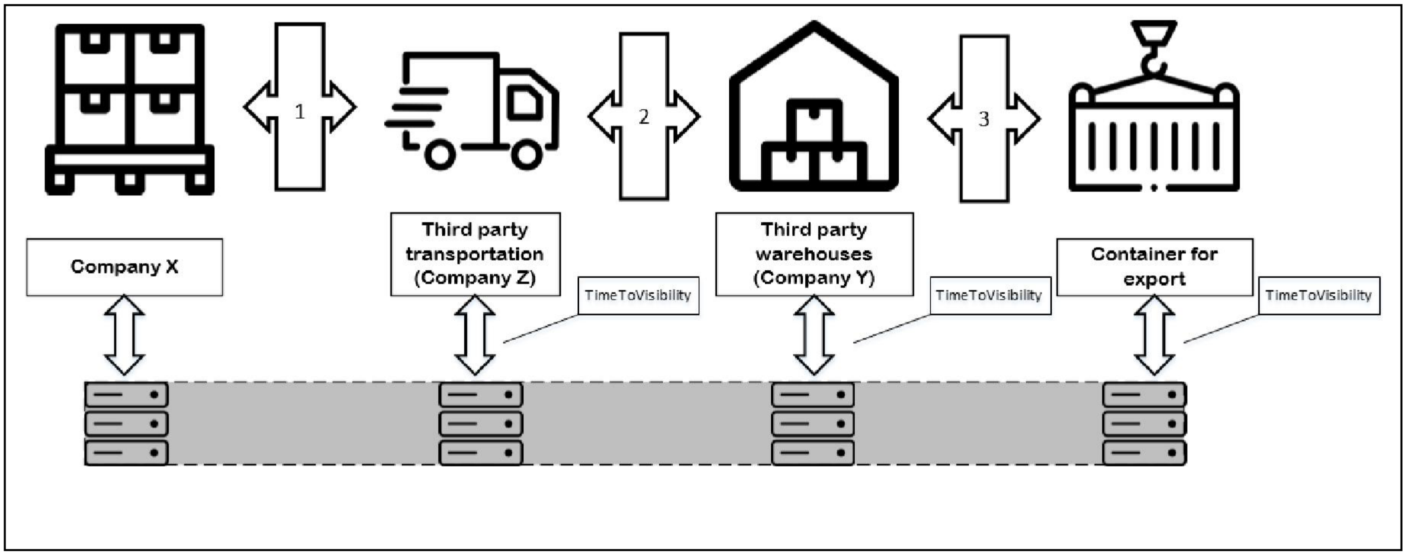

Fig. 1. Use-case concept model without blockchain technology.

blockchain technology solution in Fig 2 below. A specific use case of an outbound logistics process was selected as it is unrealistic to develop a model that represents all outbound logistics processes.

Company X manufactures a variety of products which are sold locally and exported to international customers. The company has many different outbound logistics processes to cater for the different products. One of Company X's outbound logistics processes was selected to determine the impact that a blockchain implementation will have on such a process. The process involves exporting the product to other countries.

Company X exports the product in shipping containers. The company does not load containers with the product itself, but outsource this activity to a third-party warehouse provider (Company Y). Company X is not located close to the seaport; however, the third-party warehouses are (Company Y).

The product is transported from Company X's warehouse to the third-party warehouses using a third-party transportation company (Company Z).

The process flow is indicated in Fig. 1 above. Company X loads the product onto Company Z's trucks, and then the product is transported to the Company Y warehouses. Company Y stores the product, which is then at a later stage packed in a container, by Company Y, for shipping.

There are three interfaces in this outbound logistics process, that is, where the product is transferred from one party to another. At each interface, information is captured by the specific parties involved in that interface. When Company X loads the product onto company Z's trucks, it is captured by Company X and Company Z. When Company Z delivers the product to Company Y it is captured by company Z and Company Y. When Company Y loads the product into the shipping container, it is captured by Company Y. Each of the parties in the process has their own unique system in which the information is captured, as indicated in Fig. 1.

Based on the expert interview, the critical parameter to measure blockchain technology performance and supported in the specific use case is the time to reach process visibility (*TimeToVisibility*). This refers to the time it takes to have access to all transaction information at the different interfaces of the logistics process.

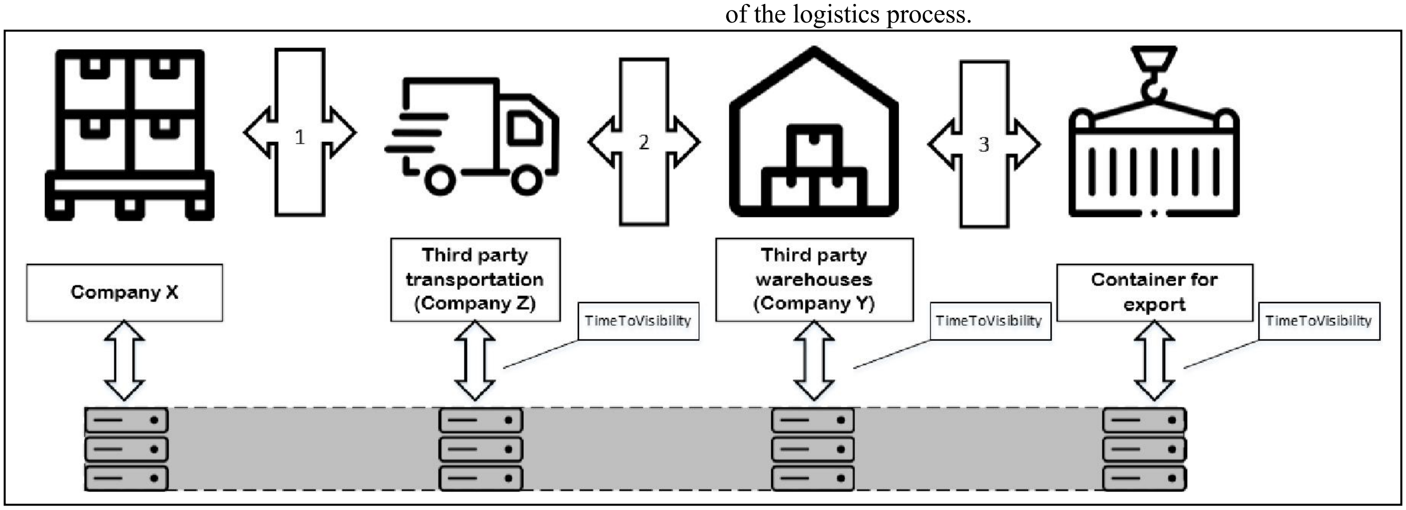

Fig. 2. Use-case concept model without blockchain technology.

The research problem can be viewed in terms of the use-case concept models in Figs. 1 and 2.

B. *Literature research – part II*

The existing scientific knowledge base must be considered in the design of the solution to ensure research rigour. In contrast to the Literature Research - Part I focussing on problem identification and understanding of the problem environment, this part is focusing on relevant scientific publications [22]. Further, the scientific solutions development is studied for the research questions.

1) Simulation modelling

Modelling is used to resolve real-world problems and can be applied when experimenting or prototyping with real systems is not possible or too expensive. A model can be used to determine an optimal solution before implementation [3]. Simulation has been used for a long time to address supply chain management issues by illustrating the effect of different system configurations [1]. Simulation models have the potential to be very useful for understanding the interactions in a complex supply chain between several components. Other techniques for experimentation are required to test and analyse systems in an industry where real testing and experimentation can be very disruptive, capital intensive, and time consuming [16]. Simulation offers the ability to predict the future without changing the current state of operations, and it provides the opportunity to evaluate different strategies.

There are four major paradigms on how to approach systems in simulation modelling, as seen in Fig. 3: dynamic systems, system dynamics, discrete event, and agent-based modelling.

For this study, the discrete event simulation is a good technique to consider to develop the simulation model in the Evaluation phase. The aim of the simulation model is to gain an understanding of the impact of implementing blockchain technology in an outbound logistics process; this is to develop an understanding of well-defined probabilistic behaviour of the global system.

Law [15] suggests a seven-step approach to complete a successful simulation study: Formulate the problem; collect information/data and formulate assumptions; program the model; validate the model; design, conduct, and analyse experiments; document and present results. This approach is followed in Evaluation phase of this study.

2) Blockchain technology evaluation approaches

An extensive review of the literature on the evaluation of blockchain technology is presented in [26]. It was found that blockchain evaluation approaches can be divided into the following classes: queuing models, Markov processes, Markov decision processes, random walks, and emulations.

The blockchain evaluation approaches that are based on analytical modelling and simulation (queuing models, Markov processes, Markov decision processes, random walks) are mostly simplified abstractions of the actual system, focussing on very specific aspects in the system, and provide limited observation of main blockchain evaluation metrics. These approaches are mostly found in academic works and contrast with another field of evaluation, emulation, which is driven by actual implementers.

Most of industry and integrators use an emulation approach to test the performance of private or consortium blockchain-based solutions [26]. Blockchain emulators can provide an overview of actual system operations, resulting in a more in-depth analysis of blockchain system metrics.

Emulation is the best-suited approach to evaluate the process impact that a blockchain solution will have when introduced into an outbound logistics process represented by a specific use case in Fig. 2. The use case is industry-based and the study is focused on understanding the impact that blockchain will have on this system. Simulation and analytics approaches tend to focus on evaluating specific elements of blockchain technology, whereas emulation gives a good indication of overall blockchain performance, especially when considering the performance metrics and measures indicated.

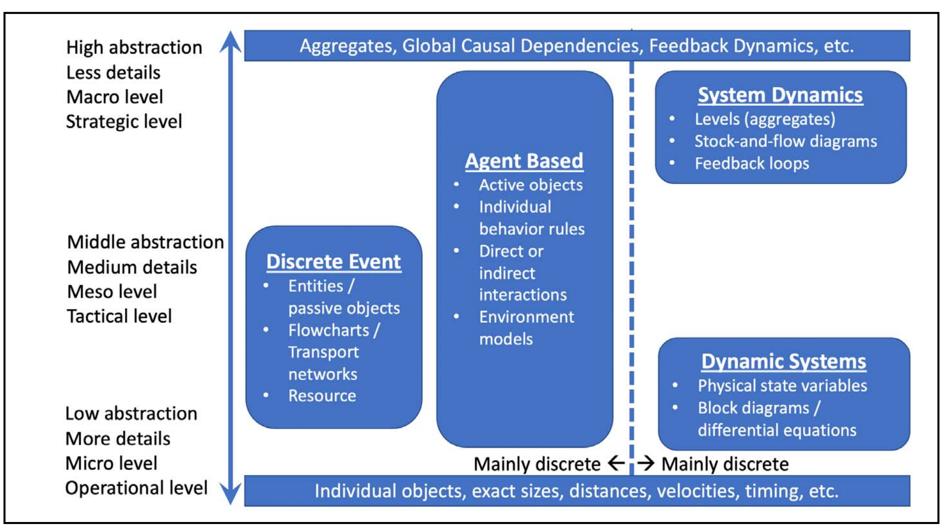

Fig. 3. Simulation modelling approaches, redrawn from [3]

In a permissioned network, the identity of each participant is known and authenticated, so that the blockchain stores who performed which transaction. Extensive access controls form part of such a network to limit who can read and append data, issue transactions, and administer participation in the blockchain network. A permissioned blockchain network is highly suitable for a company application that requires an authenticated participant. Each node in the network can be owned by a different company [29]. For this reason, it is suitable that the blockchain technology that is considered for the specific use case is permissioned.

Of all the permitted emulation approaches identified in [26], it was decided that Hyperledger Fabric is a suitable evaluation environment for the specific industry use case in Fig. 2. It is licensed open source, still actively developed, it has significant community support, many resources are available, and is widely adopted with many existing industry implementations.

3) Hyperledger Fabric

a) Background

Hyperledger Fabric is an open source implementation of a distributed ledger platform to run smart contracts in a modular architecture [28].

In a public blockchain, like Bitcoin, anyone can join the network, which introduces risk. The Bitcoin network mitigates this by using an approach called proof-of-work, making it computationally expensive for a peer to propose a new block of transactions. This leads to inferior performance, where the time to confirm a transaction can take 10 minutes or more, thus achieving a maximum of 4 transactions per second [8].

In a private network, all participants are listed and bound by contractual obligations to act correctly. This results in the use of more efficient consensus protocols, for example, Practical Byzantine Fault Tolerance (PBFT) [6]. PBFT works on the assumption that less than one third of the peers are faulty (f) [28]. This means that the network requires $n = 3f + 1$ peers to tolerate faulty peers, and $2f + 1$ peers must agree on the block of transactions [6].

Hyperledger Fabric is developed to advance blockchain technology and offer a robust solution of highly scalable data storage technology. Due to its flexibility and power, Hyperledger Fabric is evolving to become the most popular framework used by corporates and medium-sized companies [21]. Hyperledger Fabric is a private blockchain and one of the various projects within the Hyperledger blockchain platform system. It was designed to develop private blockchains in a single company or a group of companies that are aligned and link to each other's blockchain systems [21]. Hyperledger fabric does not rely on proof-of-work that involves mining or reliance on cryptocurrency, and it is attractive for enterprises interested in adopting a new form of business-to-business transaction networking, not a whole new currency [21].

The key features of Hyperledger Fabric's architecture are [21]:

- *Privacy:* All computers in the network are identified. This makes it attractive for many industries for whom it is crucial in maintaining data privacy.
- *Channels:* The ability to partition ledgers into different channels. Network members can create separate sets of transactions that are not visible to the larger network. Sensitive data can be kept separate from nodes that do not require access.
- *Scalability:* For larger companies, the scalable network is very attractive. The number of nodes that participate can be scaled, but the system still has the ability to process large amounts of data with a smaller amount of resources.
- *Modularity:* Different components can be added or implemented at different times. Some of the components are optional.

b) System architecture

Hyperledger Fabric intends to convey high degrees of privacy, versatility, adaptability, and scalability [17]. The different Hyperledger Fabric components are:

- Nodes (peers).
- Distributed ledger.
- Certificate Authority.

Peers represent organisations and members, and they play an integral role in the blockchain network: they host instances of ledgers and smart contracts [21]. When a transaction occurs, it is first validated by the majority of network members (represented as endorser peers) or a channel within the network. This is the consensus process. Peers also take on additional roles within the transaction workflow. They provide infrastructure for the movement and processing of data within a channel, and roles include orderer peers and endorser peers. Orderer peers ensure that all peers within a channel have the same version of the updated ledger. They also construct the blocks after the endorsement of transactions and enter the record into them. These peers are collectively known as ordering service and mail out the new blocks to each peer in the channel to update their ledgers. Endorser peers play the endorser role, they either ratify a transaction as valid and accept it to be added to the edger, or refuse it [17][21].

The distributed ledger is what makes blockchain technology unique, and it is also what Hyperledger Fabric is centred around. Within the ledger, record is kept of every transaction that had taken place, including all the relevant details like when it occurred, between whom, for, how much, what it was for and any other detail that is required. The data in the ledger are also protected through immutability, the ledger cannot be modified. The ledger consists of the blocks of data, the most critical components being an ID, the current has of the integrated transaction and the hash of the previous block [17][21].

The Hyperledger Certificate Authority plays the role of the membership service provider for the Hyperledger Fabric. It handles the registration, certification, and regulation of network members. Certificate authorities play a central role in making Hyperledger Fabric a permissioned blockchain [17][21].

c) Transaction flow

Hyperledger Fabric validates the data before they are submitted to the chain. The transaction flow consists of five steps [21][29]:

1. Creation of transaction proposal: A transaction begins with the inception of it by a network peer. A proposal is created by the peer within a client application that is connected to the network (software development kit of a programming language).
2. Endorsement of transaction: From the client application (SDK) the proposal is then submitted to endorsing peers, this occurs within the channel that the transaction is taking place, for endorsement. The endorsing peers execute the proposal (a function defined in the chaincode) and return a positive or negative response. The results and responses from the chaincode are returned back to the client.
3. Submission to orderer peers: Once endorsed and returned, the transaction is submitted to the ordering service (or the combined group of peers which uses consensus to order the transaction onto a block within the ledger).
4. Commitment of transaction: Once ordered, the stored transaction block is sent to all peers that are part of the channel. This is the final validation step before making changes to the ledger. More than one transaction can be stored within a block.
5. Submission to the ledger: When the transaction(s) within the block sent back to the peers is ratified and finalised, the block is written into the ledger.

d) Performance

Thakkar et al. [29] conducted an in-depth study of the throughput and latency characteristic of a Hyperledger Fabric system. They studied in-depth the rate at which transactions are committed to the ledger (throughput) and the time it takes from the application sending the proposal to the transaction being committed (latency) of the system with varying configurations and parameters.

It was observed that when the transaction arrival rate increases, the throughput increases linearly until it reaches the saturation point of around 140 transactions per second [29]. With an increase in block size, latency also increases [29].

The Hyperledger Fabric performance data that was generated in [29] by emulation can be used as input to the simulation for the model in Fig. 2. The data can be used to represent the performance of a Hyperledger Fabric in the outbound logistics use case during the Evaluation phase.

VI. Evaluation

A. Refined research question

The first research question in Section II and sub-questions are answered through the discussions in part I of the literature review in section IV.B.

The second research question is evaluated in the remainder of this section.

Phase I and II literature studies indicate that a blockchain solution could have a positive impact on the supply chain environment, especially outbound logistics systems. The effect it has on process parameters, e.g. time to reach visibility, is not well understood.

The literature also indicated that a permissioned blockchain solution, specifically Hyperledger Fabric, will be suitable for an industry-based use case.

The second question is refined to the following:

- What will the process impacts be if a Hyperledger Fabric blockchain solution is introduced in the use case outbound logistics process?

B. Simulation model

1) Aim

A simulation model provides the opportunity to evaluate the impact of implementing a Hyperledger Fabric blockchain solution without spending large amounts of capital on a blockchain system implementation that might not be beneficial to industry.

The aim of the simulation model is to gain an understanding of the impact of implementing blockchain technology in an outbound logistics process; this is to develop an understanding of well-defined probabilistic behaviour of the global system. The study does not focus on the local interactions between agents and the impact it has on the global system, for which agent-based modelling would be better suited.

Fig. 1 is a conceptual model of the current outbound logistics process, and Fig. 2 is a conceptual model showing a distributed ledger shared among all parties in the process with an implementation of blockchain technology. These conceptual models are evaluated with a simulation of the impact that a blockchain solution will have in this use case.

TimeToVisibility has not yet been quantified in the literature for outbound logistics. The simulation-model results provide insight into the *TimeToVisibility* for the use case with and without a blockchain technology implementation.

For this study, the discrete event simulation technique was selected to develop the simulation model. The simulation model was developed using the approach suggested in [15].

2) Problem formulation

Company X's primary concern in the current system in Fig. 1 is that it has no immediate information or transparency over its product once it has left its warehouse. The model that was developed explicitly focused on simulating the time it takes to gain an accurate view of inventory levels at the different interfaces in the outbound logistics process – this means that the model attempts to understand how long it takes from the inception of the request to a validated answer.

Currently, Company X must contact Company Y to gain insight on inventory levels (product types, damaged inventory, packed containers). This is an informal process, and Company

X is dependent on a response from Company Y for the information it seeks. To receive a response can take anywhere from 5 minutes to a few hours as a Company Y employee needs to gather the relevant information from the information systems and reply to the Company X request either via email or a telephone call.

Implementing a blockchain technology solution, specifically Hyperledger Fabric, in the above system, results in all the process parties having access to the same data source, as indicated in Fig. 2. The developed simulation model explicitly on simulating the time it takes to gain an accurate view of inventory levels at the different interfaces in the outbound logistics process, i.e., how long it takes from the inception of the request to a validated answer.

The key parameter that was selected to measure Hyperledger Fabric performance in the specific use case is *TimeToVisibility*. The *TimeToVisibility* for processes in Fig. 1 and 2 was simulated and compared to answer the refined research question in Section VI.B.

3) Data collection and assumptions

Stochasticity (an element of randomness) was introduced into the system by sampling the parameter *TimeToVisibility* from distributions for the different interfaces in Figs. 1 and 2.

a) TimeToVisibility for the use case without Hyperledger Fabric (Fig. 1)

Time-to-visibility will differ for the different stages of the process because different parties are involved at each interface. Currently, little data captured about precisely how long it takes to gain information. By engaging with expert stakeholders, a minimum, maximum and most likely value of *TimeToVisibility* could be identified [11]. A triangular distribution is also a good model for a skewed distribution [11] which is the case in this situation: *TimeToVisibility* is for most of the time a few minutes, but there are extreme cases when it can take several hours. Triangular distributions were constructed for each process party and sampled in the simulation model runs to determine the *TimeToVisibility* for the logistics process without a Hyperledger Fabric implementation.

TABLE I. *TIMETOVISIBILITY* ASSUMPTIONS FOR PROCESS PARTIES (WITHOUT HYPERLEDGER FABRIC)

	***TimeToVisibility* (minutes)**			**Distribution**
	Min	***Max***	***Most likely***	
Company Z	1	10	3	TRIA(1;10;3)
Company Y: warehouse	5	180	30	TRIA(5;180;30)
Company Y: export	5	120	25	TRIA(5;120;25)

In the current operations, without a Hyperledger Fabric implementation, Company X must submit a request to Company Z and Company Y to obtain information on inventory. The total *TimeToVisibility* per day is a function of the number of information requests and how long each of the requests takes to be fulfilled. The time assumed to fulfil requests is listed in TABLE I. The assumptions for the number of requests per day are stated in TABLE II.

TABLE II. REQUESTS FOR INFORMATION PER DAY ASSUMPTIONS FOR PROCESS PARTIES (WITHOUT HYPERLEDGER FABRIC)

	Number of requests per day			**Distribution**
	Min	***Max***	***Most likely***	
Company Z	1	4	2	TRIA(1;4;2)
Company Y: warehouse	1	4	2	TRIA(1;4;2)
Company Y: export	0	3	1	TRIA(0;3;1)

It was assumed that

Total *TimeToVisibility* per day (without Hyperledger Fabric) =
TimeToVisibility for all Company Z requests +
TimeToVisibility for all Company Y warehouse requests +
TimeToVisibility for all Company Y export requests

b) TimeToVisibility for use case with Hyperledger Fabric (Fig. 2)

To determine the impact that a Hyperledger Fabric blockchain solution would have in this specific use case, data from Hyperledger Fabric emulation studies were used to configure sampling distributions for *TimeToVisibility*. In a Hyperledger Fabric solution, all network peers have access to the same ledger. *TimeToVisibility* was assumed to be the time it takes to update the ledger with the latest transaction data, i.e. the system latency. Data from the Hyperledger Fabric performance study completed in [29] was used to configure triangular distributions for *TimeToVisibility*. It was assumed that the time it takes to update the ledger is the same for all the parties involved.

TABLE III. *TIMETOVISIBILITY* ASSUMPTIONS FOR PROCESS PARTIES (WITH HYPERLEDGER FABRIC)

	***TimeToVisibility* (minutes)**			**Distribution**
	Min	***Max***	***Most likely***	
Company Z	0.04	0.4	0.25	TRIA(0.04; 0.4; 0.25)
Company Y: warehouse	0.04	0.4	0.25	TRIA(0.04; 0.4; 0.25)
Company Y: export	0.04	0.4	0.25	TRIA(0.04; 0.4; 0.25)

When a Hyperledger Fabric solution is implemented in the logistics process, the total *TimeToVisibility* is determined by the number of transactions that occur and the time it takes to update them the distributed ledger. The assumed time it takes to update to the ledger is indicated in TABLE III. The assumptions for the number of transactions per day are stated in TABLE IV. The number of information requests is not applicable to this scenario, as all the process parties have access to the same information source and theoretically they can obtain information as often as they want.

TABLE IV. REQUESTS FOR INFORMATION PER DAY ASSUMPTIONS FOR PROCESS PARTIES (WITH HYPERLEDGER FABRIC)

	Number of requests per day			**Distribution**
	Min	***Max***	***Most likely***	
Company Z	0	15	10	TRIA(0;15;10)
Company Y: warehouse	0	15	10	TRIA(0;15;10)
Company Y: export	0	10	5	TRIA(0;10;5)

It was assumed that

Total *TimeToVisibility* per day (with Hyperledger Fabric) =
TimeToVisibility for all Company Z transactions +
TimeToVisibility for all Company Y transactions +
TimeToVisibility for all Company Y transactions

c) Time period

The model was simulated for a period of 1 year (365 days).

4) Programming the model

To study the time it takes Company X to gain insight about its inventory levels in the system, a stochastic discrete event simulation was developed in R. Simulation allows "what if?" scenarios to be tested and improves system understanding.

In a stochastic model, behaviour cannot be entirely predicted; there is an element of randomness that produces many different outcomes under diverse conditions [14]. This is appropriate as *TimeToInfo* is not deterministic, which means that for a particular set of inputs, the model will produce the exact same set of results [14]. Company X can request information, and in one instance *TimeToInfo* will be a few minutes, and another day it can take up to an hour.

Discrete event simulation refers to a simulation of a system that has abrupt, i.e., discrete, changes. Between consecutive events, it is assumed that no changes occur and the simulation can jump to the next event. An example would be a queueing system; when a new job arrives, the queueing system increases by 1 [7].

R is a programming language and environment for statistical computing and graphics. It provides a wide variety of statistical and graphical techniques and is highly extensible. R is an integrated suite of software facilities for data manipulation, calculation, and graphical display [24].

5) 5.2.6. Validating the model

The stochastic simulation model was run for five replications to ensure that it is stochastically sound and to stabilise variation in the stochastic results. Two measures were used to investigate this: visual inspection and the median value of the replications. There were no process data available to compare the model output, so it did not allow for other validation techniques.

C. Summarizing results

The results of the simulation runs are shown in TABLE V below. The table shows the average total *TimeToVisibility* for the current process compared to the case where a Hyperledger Fabric solution was implemented. This serves as an indication that the implementation of a Hyperledger Fabric blockchain solution will have a significant impact on the time it takes Company X to gain insight and transparency on inventory throughout the outbound logistics process. Company X can expect to see an improvement of around 97% on the total time it takes to reach full process visibility. The simulation results indicate that the hypothesis "implementation of a Hyperledger Fabric blockchain solution in outbound logistics operations will be beneficial" can be accepted. The total time it takes to reach full process visibility per day is reduced from around 250 minutes to below 6 minutes.

Two scenarios were evaluated to investigate the sensitivity of the process:

- Improved current process: It was assumed that the *TimeToVisibility* in the current process improves significantly and is reduced by half of what it is currently (scenario 1).
- Worse Hyperledger Fabric performance: It was assumed that *TimeToVisibility* in the process supported by Hyperledger Fabric is doubled (scenario 2).

TABLE V. SIMULATION RESULTS

	Average total *TimeToVisibility* (minutes)				
	Rep1	***Rep2***	***Rep3***	***Rep4***	***Rep5***
Current process	252.58	246.58	257.55	244.70	252.96
Hyperledger Fabric implementation	5.72	5.90	5.85	5.88	5.81
% difference	97.7%	97.6%	97.7%	97.6%	97.7%

The simulation results of the two scenarios are shown in TABLE VI and VII below.

It can be concluded that even with a much improved current process or a Hyperledger Fabric solution that performs worse than expected, the total *TimeToVisibility* is still significantly improved with a Hyperledger Fabric solution. Company X can expect to see an improvement of around 95% on the total time it takes to reach full process visibility even if the current process is improved significantly or Hyperledger Fabric does not perform as well as expected.

TABLE VI. SIMULATION RESULTS FOR SCENARIO 1

	Average total *TimeToVisibility* (minutes)				
	Rep1	***Rep2***	***Rep3***	***Rep4***	***Rep5***
Current process	129.49	124.09	125.86	126.26	127.51
Hyperledger Fabric implementation	5.86	5.92	5.82	5.81	5.89
% difference	95.5%	95.2%	95.4%	95.4%	95.4%

TABLE VII. SIMULATION RESULTS FOR SCENARIO 2

	Average total *TimeToVisibility* (minutes)				
	Rep1	***Rep2***	***Rep3***	***Rep4***	***Rep5***
Current process	252.39	252.37	245.41	254.71	252.17
Hyperledger Fabric implementation	11.95	11.66	11.64	11.89	11.94
% difference	95.3%	95.4%	95.3%	95.3%	95.3%

VII. CONCLUSION

The goal of this research study was achieved to investigate the potential applications of blockchain technology, the features of blockchain technology, and the advantages and disadvantages of blockchain technology were answered by means of an extensive literature study for outgoing logistics as part of the supply chain. The literature study showed that there is not much knowledge about the impact of the process of implementing a blockchain solution in a logistics process. The time it takes to reach full visibility in such a process that is supported by blockchain technology has not been analysed or quantified yet. The way in which implementing a blockchain solution would influence a logistics process and the effect it has on process parameters, such as the time to reach visibility, is not discussed in the literature. The *TimeToVisibility* parameter was selected to study the impact of a blockchain implementation and measure its performance in the outbound logistics process. This parameter was also highlighted as an improvement area in the use case logistics process.

The impact of a blockchain technology solution was identified for a specific use case of an outbound logistics process in the industry and a simulation was developed to conduct scenario testing. From the literature study, it could be concluded that a Hyperledger Fabric blockchain solution would be suitable for the specific use case. It is permissioned, open-source, and still actively expanded and developed, it has significant community support, many resources are available, it is widely adopted, and many industry implementations already exist. A stochastic discrete event simulation model was developed in R to evaluate the impact that a Hyperledger Fabric blockchain solution will have on the selected use case. The model that was developed explicitly on simulating the time it takes to gain an accurate view of inventory levels at the different interfaces in the outbound logistics process, the total *TimeToVisibility* per day.

The outcome of the simulation study indicated that implementing a Hyperledger Fabric blockchain solution in this outbound logistics use case will have a significant impact on the time it takes to gain insights and transparency on inventory throughout the outbound logistics process. It can be expected that the total *TimeToVisibility* per day is reduced from around 250 minutes to less than 6 minutes when implementing a Hyperledger Fabric solution.

A. Contributions of the study

This study provides evidence that making use of a blockchain solution in an outbound logistics process can have a significant impact on information availability and transparency. It also shows that a blockchain solution can support horizontal integration of parties in an outbound logistics process, which is in line with the principles of Industry 4.0. By means of a simulation study, the time it takes to reach visibility in a specific outbound logistics process is quantified for a current process as well as a Hyperledger Fabric implementation. The time to reach process visibility (*TimeToVisibility*) has been identified through expert interviews as a critical parameter to measure blockchain technology performance for the specific use case discussed in this paper.

B. Recommendations for further research

This study did not investigate the resources required and cost associated with such a technology implementation. Although a significant benefit can be derived from implementing Hyperledger Fabric in an outbound logistics process, the cost should not outweigh it. There is room for further investigation.

Furthermore, the implementation of smart contracts and the appropriate blockchain protocols to enable solutions to scale for enterprise applications are also topics for further investigation.

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