A new blockchain system design to improve the supply chain of engineering, procurement and construction (EPC) companies – a case study in the oil and gas sector

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A new blockchain system design to improve the supply chain of engineering, procurement and construction (EPC) companies – a case study in the oil and gas sector

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Abstract

Purpose – This paper aims to propose a new blockchain system design to improve engineering, procurement and construction (EPC) companies' supply chain for constructing oil and gas infrastructure, by mitigating cost and time inefficiencies.

Design/methodology/approach – A case study analyses the supply chain of a sample EPC company. First, a literature review is conducted to explore the subject in academic literature. Second, information flows are mapped using responsible, accountable, consulted and informed analysis and cross-functional process mapping. Third, inefficiencies are identified. Fourth, the root causes of the inefficiencies are pinpointed using fishbone and five-times-why analysis. Fifth, a comparison is made between the linear and the blockchain information system via force-field analysis. Sixth, a specific blockchain system design is identified based on three external expert interviews. Finally, the new system is designed and a cost-benefit analysis is conducted.

Findings – Major cost and time inefficiencies in oil and gas infrastructure developments are caused by a poor information flow in the supply chain. The new blockchain system design is a feasible solution, reducing cost inefficiencies by 12.4% and operation lead-times by 36.5%.

Research limitations/implications – The confidentiality of the sample EPC company's information represents a limitation.

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Originality/value – The research introduces a new blockchain system design, reducing cost and time inefficiencies in the project-development supply chain, including implementation processes.

Keywords System design, Blockchain, IoT, Smart contract, EPC company, Oil and gas

Paper type Research paper

1. Introduction

Engineering, procurement and construction (EPC) companies have a complex supply chain for developing oil and gas infrastructure (Joshi *et al.*, 2017). Multiple stakeholders from all over the world are involved in this chain (Saad *et al.*, 2014), communicating and performing transactions in a linear supply chain model (Sharma *et al.*, 2016). This multiplicity of stakeholders causes inefficiencies (Gammelgaard *et al.*, 2019). In this linear model, information and resources flow from one party to another along a chain. The main problems are lack of communication, insufficient information quality and loss of data (Gammelgaard *et al.*, 2019), especially when external subcontractors are involved. In this context, this chain is incapable of channelling the flow of information efficiently among the involved parties (Sharma *et al.*, 2016). Thus, companies miscommunicate with their subcontractors, thereby causing delays and extra costs (Sharma *et al.*, 2016). These costs can mount up (Lu *et al.*, 2019) and firms can lose millions of dollars (Huslig, 2014). Currently, EPC companies operate a linear supply chain entailing major inefficiencies. Therefore, our main research question is how to improve EPC companies' supply chain for developing oil and gas infrastructure to reduce costs and increase efficiency.

To mitigate EPC companies' inefficiencies, this research aims to find an alternative system design by reviewing the academic literature, interviewing external expert system developers and assessing the findings in a sample company. In Section 2, the literature review reveals the possible solutions to the problems in EPC companies' linear supply chain, and Section 3 explains the research methodology. Section 4 focuses on the case study of the EPC company, McDermott and summarizes the research findings. This is followed by the conclusion in Section 5.

2. Literature review

A literature review is conducted in order to explore the academic literature on the supply chain for oil and gas infrastructure, the problems of information flows in supply chains and new information system designs. The resultant information leads to a further exploration of distributed ledger technology and blockchain, the role of blockchain in supply chains, blockchain in combination with the Internet of Things (IoT) and Smart Contracts, smart supply chains, and finally concerns about implementing blockchain. The literature search is performed in academic databases, and only peer-reviewed sources are considered. For the literature search, the following terms are used: linear supply chain, system design, distributed ledger, blockchain, IoT, Smart Contracts, smart supply chain and blockchain implementation. The literature review underpins the rest of the article and the case study relies heavily on the theory explored here.

2.1 Oil and gas supply chain

The oil and gas industry supply chain is complex (Chima and Hills, 2007; Huslig, 2014; Joshi *et al.*, 2017; Saad *et al.*, 2014; Sepehri, 2013; Sharma *et al.*, 2016). This complexity occurs mainly in operations such as procurement, logistics and material management (Chima and Hills, 2007; Huslig, 2014; Saad *et al.*, 2014). Procurement includes dealing with many manufacturers and service providers worldwide to source a wide range of goods and services for projects (Chima and Hills, 2007; Huslig, 2014). Also, logistic managers frequently deal with freight forwarders to dispatch an immense array of goods to project sites (Saad *et al.*, 2014). Furthermore, material managers supervise complicated, repetitive tasks of material handling and inventory control (Chima and Hills, 2007).

The supply chain department is responsible for these activities, linking thousands of upstream suppliers/service providers and hundreds of downstream requesting departments (Sharma *et al.*, 2016). To manage these activities, oil and gas companies use a traditional linear supply chain model (Sharma *et al.*, 2016), in which entities such as equipment, information and finances flow from one party to the next through the entire chain (Gammelgaard *et al.*, 2019; Saad *et al.*, 2014; Sharma *et al.*, 2016). Any issue on a project's supply chain can cause millions of dollars of losses (Huslig, 2014).

2.2 Problems of information flows in supply chains

The diversity of stakeholders and the complexity in the linear supply chain leads to miscommunication and loss of information (Gammelgaard *et al.*, 2019). Furthermore, the poor data handling system in this chain causes human errors and data leakage (Martínez-Rojas *et al.*, 2015). These problems create inefficiencies in the chain (Casado-Vara *et al.*, 2018; Gonzálvez-Gallego *et al.*, 2015). Inefficiencies in the oil and gas industry's supply chain are relatively high (Lu *et al.*, 2019) and lead to financial losses up to 20% of operational budgets (Gausdal *et al.*, 2018). As the traditional linear supply chain cannot manage the information and avoid inefficiencies, a new innovative information system architecture is needed (Joshi *et al.*, 2017; Sharma *et al.*, 2016; Farahmand and Farahmand, 2019; Sarrakh *et al.*, 2019).

2.3 Towards a new information system design

A new information system should be fully integrated to ensure the accessibility and visibility of information to the stakeholders in the supply chain (Chima and Hills, 2007; Dudley *et al.*, 2017; Saad *et al.*, 2014). This way, stakeholders can easily access the shared data and validate the information (Asprion *et al.*, 2019), regardless of their location (Lu and Xu, 2017). Such a system enhances collaboration, improves the efficiency of the supply chain (Kache and Seuring, 2017) and eliminates information loss (Dietz *et al.*, 2019). Moreover, it needs to be smart in order to decrease human interaction, thus preventing human errors (Kharlamov and Parry, 2018; Sarrakh *et al.*, 2019). Furthermore, a new system should be secured against data leakage (Dudley *et al.*, 2017). A system with these characteristics would revolutionize the flow of information, goods, services and finance in the supply chain (Lu and Xu, 2017). A new smart, integrated, efficient and secure information system in the supply chain of oil and gas construction projects would play an essential role in mitigating inefficiencies (Gallacher and Champion, 2019). Recent research suggests that information systems such as the distributed ledger and blockchain can cope with the existing challenges. Korpela *et al.* (2017) specify that, among other technologies such as private cloud and public cloud, the distributed ledger and blockchain systems are the most efficient solutions, as they facilitate benefits in terms of efficiency and visibility for complex supply chains.

2.4 Distributed ledger and blockchain

A distributed ledger is a specific model for synchronizing and sharing information between multiple parties, with no centralized data storage (Asprion *et al.*, 2019). It facilitates communication and verification of transaction information stored immutably in the system (Babich and Hilary, 2019). Gammelgaard *et al.* (2019) emphasize that, in a distributed ledger, the information is conveyed between the links in the supply chain independent of the parties' relation and location. The authors specify that such capability enhances supply chain integration while minimizing the frictions of communicators and human errors. They indicate that global supply chains using a distributed ledger significantly mitigate the communication inefficiencies inherent in the traditional system. Therefore, a distributed ledger as a decentralized, integrated, immutable information system architecture could mitigate the traditional supply chain's inefficiencies. Blockchain is the most developed form of distributed ledger, with various specific characteristics (Babich and Hilary, 2019). It is a digital platform for the distributed ledger system where participants can access the shared information database with total visibility (Abeyratne and Monfared, 2016). Blockchain records transactions in blocks and shares them in a distributed network of participants who validate the transactions (Perboli *et al.*, 2018). After validation, the transaction is linked to the previously validated block in the blockchain database (Perboli *et al.*, 2018). Each block has the transaction information, a link to the previous block and a time tag, making blockchain a reliable (Cui *et al.*, 2019), integrated, time-stamped ledger (Gammelgaard *et al.*, 2019). To keep the information in the blocks secure from leakage and modification, blockchain uses a hash algorithm and transforms the information into a specific code (Vyas *et al.*, 2019). A hash acts as a digital signature for the block (Vyas *et al.*, 2019), making blockchain immutable (Gammelgaard *et al.*, 2019). Moreover, in blockchain, validated information cannot be overwritten or deleted (Cui *et al.*, 2019). Any change becomes a new block, validated by participants and added to the chain (Debabrata and Albert, 2018). Thus, the information in this immutable ledger is reliable and easy to audit (Gammelgaard *et al.*, 2019).

2.5 Blockchain in supply chains

Blockchain creates various opportunities in organizations' supply chains and makes them more efficient (Kshetri, 2018; Debabrata and Albert, 2018; Gammelgaard *et al.*, 2019; Perboli *et al.*, 2018; Azzi *et al.*, 2019; Casado-Vara *et al.*, 2018; Vyas *et al.*, 2019). Decentralized communication in blockchain eliminates trusted third persons in the supply chain, thereby allowing faster and more reliable communication (Casado-Vara *et al.*, 2018; Azzi *et al.*, 2019). Moreover, blockchain improves shipment monitoring and speeds up operations in a transparent way (Min, 2019). Blockchain's visibility and traceability enable stakeholders to become more accountable and responsible (Kshetri, 2018), thus improving collaboration and dependability and reducing human errors (Kshetri, 2018; Debabrata and Albert, 2018). Real-time data validation in blockchain-based supply chains ensures the responsible parties' on-time involvement to verify information during the entire operation (Kshetri, 2018). Furthermore, blockchain's exclusive security provides the safe delivery of information over the entire chain and eliminates information loss and data leakage (Vyas *et al.*, 2019). Such an integrated, trustworthy chain helps to reduce costs and time inefficiencies (Debabrata and Albert, 2018; Kshetri, 2018; Azzi *et al.*, 2019). For instance, the implementation of blockchain in Maersk's supply chain shows a 15% cost reduction in shipped goods' value Gausdal *et al.* (2018) and a 40% time reduction (Linnet *et al.*, 2018). Lu *et al.* (2019) state that blockchain is new for the oil and gas industry and its implementation is still experimental. The researchers identify some well-known European oil and gas companies, such as Shell and BP, which have started promoting blockchain in their organizations. Blockchain can reduce costs and lead-time and improve transparency, data security and efficiency in oil and gas companies' supply chains (Lu *et al.*, 2019; Dudley *et al.*, 2017; Gausdal *et al.*, 2018). For instance, Abu Dhabi National Oil Company (ADNOC) expects a 1 billion dollar cost-saving and a 30% time reduction by using blockchain in its drilling projects' supply chain (Gammelgaard *et al.*, 2019).

2.6 Blockchain and the internet of things

A digitalized blockchain platform requires an automated digitalized data collection tool. The most suitable solution is the IoT, a set of electronic devices and applications that automatically collect data, thus facilitating communication between the physical and the digital world (Witkowski, 2017). IoT uses electronic devices such as sensors, radio frequency identification (RFID) and global processing systems (GPS). Using these technologies provides data about the location and the condition of goods (Korpela *et al.*, 2017). Furthermore, IoT, as an application, transfers information from various databases to the blockchain platform (Vyas *et al.*, 2019). IoT assists blockchain-enabled supply chains to automatically collect data from the network of participants in the supply chain and transfer them to the shared, immutable ledger immediately (Gammelgaard *et al.*, 2019). Therefore, such a system automizes data collection, reduces transaction time in the supply chain and, by eliminating human interactions, eliminates human errors in processes (Francisco and Swanson, 2018; Korpela *et al.*, 2017; Bahga and Madisetti, 2016).

2.7 Blockchain and smart contracts

Blockchain uses Smart Contracts to automate the decision-making process based on data collected on IoT devices (Vyas *et al.*, 2019). A Smart Contract is a digitalized contract between parties that automatically enforces the agreed contractual terms without the participation of external parties (Casino *et al.*, 2018). A Smart Contract translates contractual clauses into computer codes with no intervention by third-party participants (Lu *et al.*, 2019). For example, a Smart Contract can be a multi-signature agreement in which a transaction can be shared only by having a specific number of participants' signatures (Vyas *et al.*, 2019). Therefore, blockchain-based systems supported with a Smart Contract automate data processing, reduce time, simplify complex processes, improve efficiency in the supply chain and reduce costs (Lu *et al.*, 2019; Chang *et al.*, 2019; Gammelgaard *et al.*, 2019). Research shows that transaction processing is the most valuable functionality (88 %) of the blockchain-based system with a Smart Contract (Korpela *et al.*, 2017).

2.8 Smart supply chain

Integrating blockchain technology, IoT and Smart Contracts creates a smart supply chain with various advantages (Chen *et al.*, 2017; Cui *et al.*, 2019; Yuan and Wang, 2016). Such a chain automates data collection and information validation, avoiding errors of manual communications (Francisco and Swanson, 2018). It creates a fully integrated supply chain in a secure, immutable, distributed ledger in which stakeholders have visibility and accessibility to the shared database (Asprion *et al.*, 2019). Accordingly, it allows companies to increase control over the physical flow of operations and prevents financial losses (Dudley *et al.*, 2017), thus reducing cost and time inefficiencies in the supply chain (Min, 2019). These unique advantages are lacking in traditional systems (Korpela *et al.*, 2017).

2.9 Concerns about implementing blockchain

Although using blockchain is beneficial for the supply chain, there are some concerns in its adoption that companies need to consider (Gammelgaard *et al.*, 2019; Min, 2019; Lu *et al.*, 2019). One of the main concerns is that, in adopting blockchain, all members should set up an initial blockchain architecture (Gammelgaard *et al.*, 2019). Consequently, all participating parties need to collaborate and accept the adoption of this new system (Min, 2019). Meanwhile, firms need to clearly define the legal aspects of the information disclosure in the distributed ledger (Asprion *et al.*, 2019). Using private, permissioned blockchain facilitates more secure and effective integration (Chang *et al.*, 2019). In this case, the blockchain owner can assign different levels of viewing and writing permission for the participants in the shared ledger (Gammelgaard *et al.*, 2019).

In addition, blockchain has a technological scalability limitation, which means that it cannot be used for high-volume transactions (Vyas *et al.*, 2019). Ethereum is a specific blockchain platform that has a new coding concept to overcome this limitation (Casino *et al.*, 2018). Gammelgaard *et al.* (2019) define another risk: the gap between the physical world and digital data collected in the supply chain system. The authors explain that, although blockchain is immutable by its nature, it depends on the reliability of the input data. Furthermore, mistakes in the design of a Smart Contract could lead to severe financial losses (Gallacher and Champion, 2019). Thus, incumbent companies should design Smart Contracts carefully and regularly audit the process at the primary stages of adoption (Lu *et al.*, 2019).

In conclusion, the academic literature suggests that a decentralized data system design could be a suitable alternative to a linear information system – more specifically, a permissioned, private blockchain application combined with IoT and Smart Contracts. The application of blockchain results in smart, efficient and secure supply chains that can mitigate the problems in linear supply chains.

3. Methodology

This paper contains research on improving an EPC company's supply chain. In this section, the methodology is discussed. This applied research examines a specific process in a specific industry, with a qualitative approach using a case study strategy. A case study approach is recommended for the in-depth examination of a complex phenomenon (Verschuren and Doorewaard, 2010). Yin (1994, p.31) defines a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". This research follows Yin's (1994) guidelines about multiple sources and results triangulation by combining theoretical insights with written company sources, internal and external interviews and a validation session. A major challenge of case study research is its generalizability (Yin, 1994). This research is limited to a single case study. A sample company has been chosen while it is unique in its operational strategy, it is a representative of oil and gas company with a linear supply chain causing inefficiencies. However, further research could lead to generalization if the research protocol developed here is applied to comparable cases.

In order to find a solution, a design-oriented approach is used. Design-oriented research commences by defining the problem and identifying the root causes, followed by suggesting a prototype and validating its use (Verschuren and Doorewaard, 2010). It uses a combination of qualitative methods to describe the existing process, identify the bottlenecks in it, find the root cause of problems, propose a new system design, give advice about its implementation, calculate its costs and benefits and validate the results.

The data collection involves desk research by consulting academic literature and company sources and field research by internal and external interviews. The interviews are semi-structured, as this is the most suitable type of interview to explore background and validate contextual data in research (Saunders *et al.*, 2016). The interviewees are given a list of key questions, leaving space for them to give information on topics that are not included. The interview protocol is available for future research. The internal interviews are conducted with seven staff members, a logistics manager, a subcontracts manager, a project subcontract manager, a subcontract engineer and a subcontracts administrator. The selection criteria are that they are the internal experts involved in heavy hauling and lifting (HLH) services and can supply reliable information about the work, the information flow, timing, bottlenecks and inefficiencies. Each staff member is interviewed at least twice for an hour. Subject confidentiality precluded audio recording the interviews; however, they are carefully recorded in writing and the transcripts are validated by the interviewees. The external interviews are conducted with three system developers of well-known blockchain development companies with successful blockchain implementations in the oil and gas sector. The interviews are conducted to validate the solution found from the literature review, to find a suitable information system architecture and to discuss the cost, time and implementing considerations for a new system. Each company is interviewed once for an hour, and these interviews are recorded. The collected data are analysed using content analysis. The final step of the validation is an internal validation session with company experts.

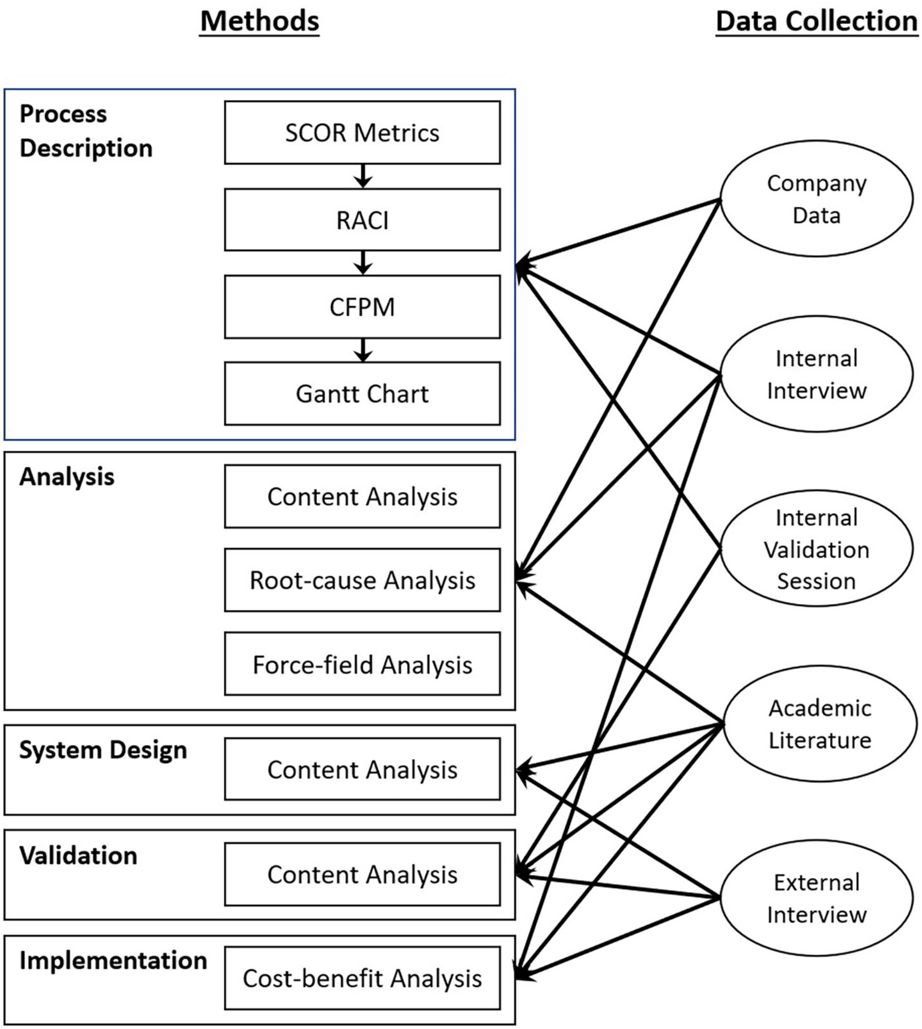


Figure 1.
A visualization of the research protocol

A research protocol, shown in Figure 1, is developed to make the research transparent and repeatable. The research commences with the description of the present processes, using SCOR Metrics, responsible, accountable, consulted and informed (RACI) analysis and cross-functional process mapping (CFPM). Firstly, a supply chain framework, SCOR, is used as a performance evaluation model at the operational level for the information flow of an inter-organizational supply chain in industrial sectors (Estampe *et al.*, 2013). The SCOR model analyses the supply chain on four levels (Gouveia and Costa, 2019). The first level identifies the supply chain scope in six major processes of Plan, Source, Make, Deliver, Return and Enable (Saleheen *et al.*, 2018). The second level is the process categories, which set the processes configuration in standard operation categories, such as engineer-to-order (Bolstorff and Rosenbaum, 2012). In the third level, process elements and the performance criteria for these processes are clarified (Janaki, 2019). Finally, level four is the implementation level, which is not included in SCOR. Firms should define level four processes based on their supply chain and implement solutions to improve their supply chain performance (Bolstorff and Rosenbaum, 2012). In addition, SCOR consists of five performance attributes: reliability, responsiveness, agility, cost and asset (Tripathi *et al.*, 2018). These standard metrics analyse and measure the supply chain configurations (Lemghari *et al.*, 2018), such as total supply chain management cost and order fulfilment cycle time (APICS, 2017). In this research, SCOR is used to analyse and visualize the supply chain.

Secondly, a RACI analysis is performed to identify the responsible, accountable, consulted and informed stakeholders and their activities (Tague, 2005). Thirdly, from the RACI analysis, swim-lane flowcharts are derived by CFPM and a SCOR metrics selection. Then, a Gantt chart is prepared to demonstrate the schedules of activities (Tague, 2005). By combining these methods, an in-detail description is created, which forms a good starting point for further analysis.

Fourthly, the bottlenecks in the system are identified by applying a content analysis to the data derived from the interviews. The root-cause analysis is done by applying a fishbone analysis combined with the five-times-why method, followed by a force-field analysis in order to demonstrate the driving forces of the blockchain system against the restraining forces of the existing system. Force-field analysis is a qualitative method to implement various solutions for a set of specific issues (Tague, 2005). Furthermore, a new system design is proposed, based on the literature study. Consequently, the new system design is validated by the three abovementioned external interviews and an internal validation session at the company. Finally, the cost and time impact are calculated, and a cost-benefit analysis is performed to evaluate the benefits of implementing the new design (Cadle *et al.*, 2014).

4. Case study: the engineering, procurement and construction company McDermott

In this section, after a short introduction to the sample company and the process studied, the process flow is analysed and its bottlenecks and their root causes are identified. Based on these analyses, a new system design is proposed, its impacts on the supply chain are assessed, and finally the costs and benefits of the conceptual implementation are assessed.

4.1 The sample company: McDermott

McDermott International Inc. (McDermott) is a global contractor in designing, manufacturing and building end-to-end infrastructure to process and transform crude oil and natural gas into other products. McDermott has an engineer-to-order business strategy, whereby it engineers a highly customized oil, gas, petrochemical and energy infrastructure based on customers' exclusive orders. The company operates in 54 countries with offices in North, Central and South America; Europe, Middle East and Africa; Asia Pacific.

McDermott has a linear supply chain model where the information and resources flow from upstream resources to the downstream customer. The company uses information and various resources such as upstream materials, finance and human resources for midstream engineering, procurement, construction and installation services. Engineering consists of designing the infrastructure and procurement includes purchasing materials, services provision, goods dispatch, material management and delivery to the on-site construction team. The construction and installation teams build the project infrastructure at the project site, according to the project plan. In this process, McDermott needs a variety of service providers. Information flows between McDermott's internal stakeholders and various external stakeholders such as suppliers and service providers. They communicate regularly at each stage to ensure full compliance with the customer's requirements. Finally, the developed infrastructure is tested and handed over to the downstream customer. All the activities have to be done according to the project's defined time plan, in compliance with the allocated budget. McDermott experiences cost and time inefficiencies caused by problems in the information flow between the company and subcontractors. For instance, the company identifies major financial losses and medium delays in HLH services. Thus, this research focuses on cost and time inefficiencies in this company's HLH services.

4.2 Analysis of the existing process system design

HLH services include lifting and hauling heavy equipment from the port to the delivery point at the project site. In HLH services, eight stakeholders are identified, including internal and external parties. The internal parties are procurement, logistics, subcontracts and the on-site construction team and the external parties are the manufacturer, freight forwarder, civil subcontractor and HLH subcontractor. The research aims to assess two supply chain variables, costs and time, in the HLH services supply chain. Costs are the expenses incurred operating supply chain processes, and time relates to responsiveness as the speed of performing the supply chain process (APICS, 2017). This research studies the delivery process in the order fulfilment of heavy lift equipment. Thus, according to SCOR, cost is Cost to Deliver (CO.2.4) and time is Deliver Cycle Time (RS.2.3) in the Engineer-to-Order Product process (sD3). The selected metrics are listed in Table 1.

Regarding the SCOR framework, HLH services involve Plan Deliver (sP4) and Deliver (D) processes of order fulfilment in the Engineering-to-Order (ETO) category. In this research, Plan Deliver is called Phase A, which consists of planning and preparation for the delivery of the heavy-lift equipment. This phase starts after procurement orders to the manufacturer to manufacture the equipment. Deliver is called Phase B, which begins from the end of manufacturing, including material collection, shipment, lifting and hauling, up to the delivery of the equipment at the installation point on the construction site. HLH services exclude Source (S), Make (M), Enable (E) processes.

SCOR metrics	Cost	Time
Performance attribute	Cost	Responsiveness
Strategic metric	Total SC Management Cost (CO.1.1)	Order fulfilment cycle time (RS.1.1)
Process	Deliver Engineer-to-Order Product (sD3)	
Diagnostic metric	Cost to Deliver (CO.2.4)	Deliver Cycle Time (RS.2.3)

Table 1. SCOR Metric selection summary

Phases	Activities	Internal stakeholders: Procurement	Internal stakeholders: Logistics	Internal stakeholders: Subcontract	Internal stakeholders: Construction team	External stakeholder: Manufacturer	External stakeholder: Freight forwarder	External stakeholder: HLH subcontractor	External stakeholder: Civil subcontractor
Phase A: Plan Deliver	Providing as-built ISOs/drawings, incl the dimension of the equipment and the saddles	A				R			
	Submitting documents to procurement	A				R			
	Submitting the information to logistics	R/A							
	Reviewing/approving the documents from logistics point of view. (How the equipment would be transformed, saddle dimension, and so on)	A	R			I			
	Studying the documents and set relevant HLH resources and issue HLH pre-plan for confirmation of logistics/construction team			I	A			R	
	Confirming HLH plan			I	R/A			I	
	Coordinating with HLH subcontractor for ground study according to confirmed HLH plan		R						
	Studying the ground protection area of hauling route according to the confirmed plan		A	I				R	
	Coordinating/deploying the construction team for ground protection whereever needed			R	R/A				
	Performing ground protection services			I	A			I	R
Phase B: Deliver	Providing actual packing list, packing specification, equipment configuration, material readiness date and load out schedule	A				R			
	Submitting the documents/information to procurement	A				R			
	Matching the information of packing list and export documents with the PO of the equipment	R/A							
	Submitting the documents/information to logistics	R/A							
	Submitting documents to freight forwarder and HLH subcontractor		R/A				I	I	
	Verifying the actual documents, information		A				R	R	
	Inspecting the cargo	R/A	I						
	Coordinating with freight forwarder		R/A				I		
	Collecting the cargo and deliver to the ship	A	I			R	I		
	Dispatching the goods, report delivery schedule of the cargo, submit the shipping documents to logistics		A				R		
	Submitting shipping delivery schedule to HLH subcontractor		R					I	
	Preparing HLH plan		I	I	A			R	I
	Reviewing the HLH plan considering the actual delivery schedule and re-plan HLH services accordingly		R	I	A			R	
	Custom clearance		A				R		
	Notifying about the material readiness for HLH services		R/A				I	I	
	Notifying HLH subcontractor about material arrival		A	I				I	
	Coordinating with construction team to define the exact delivery point of equipment delivery		R/A		I			I	
	Confirming delivery point (lay down area-foundation area)		I		R			I	
	Coordinating with HLH subcontractor to execute HLH services of the equipment		R/A	I				I	
	Deploying HLH resources, execute HLH services and deliver the equipment to lay down area/foundation area		A	I	I			R	
	Informing construction that material arrived on site		R/A		I				
	Receiving the equipment				R/A				

Figure 2. RACI diagram of HLH services

To describe the existing system process design of the HLH services, company data are combined with interviews with company experts. First, a RACI analysis is performed on the data collected to identify stakeholders' roles and activities in both phases (Figure 2). The RACI diagram is used as a starting point to map the Phase A swim-lane diagram (Figure 3) and validated by internal experts. Each activity in this diagram is coded according to its phase and sequence. For example, A1 represents the first Phase A activity, "Provide As-built ISO/ Drawings of equipment". Further, a Gantt chart (Figure 4) is prepared to demonstrate the duration of Phase A. With the same approach, the Phase B swim-lane diagram and the Gantt chart are prepared. The results show that Phase A, Plan Deliver, takes 49 days (Figure 4) and Phase B, Deliver, takes 50 days.

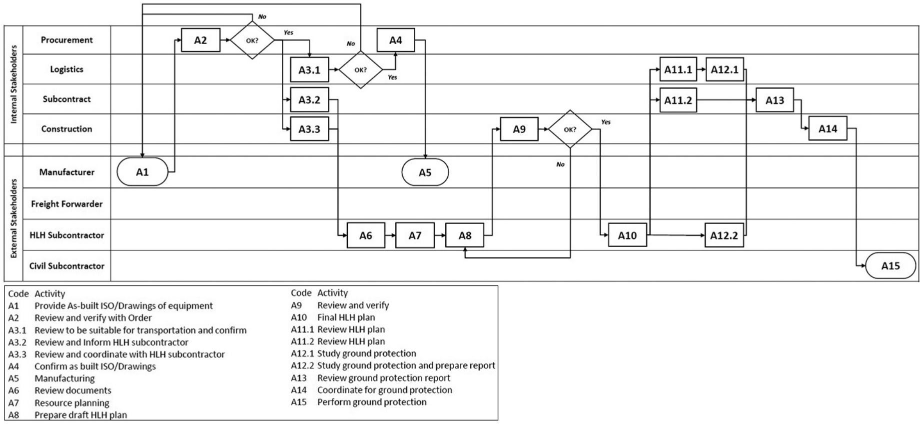


Figure 3. Swim-lane diagram of HLH services – Phase A

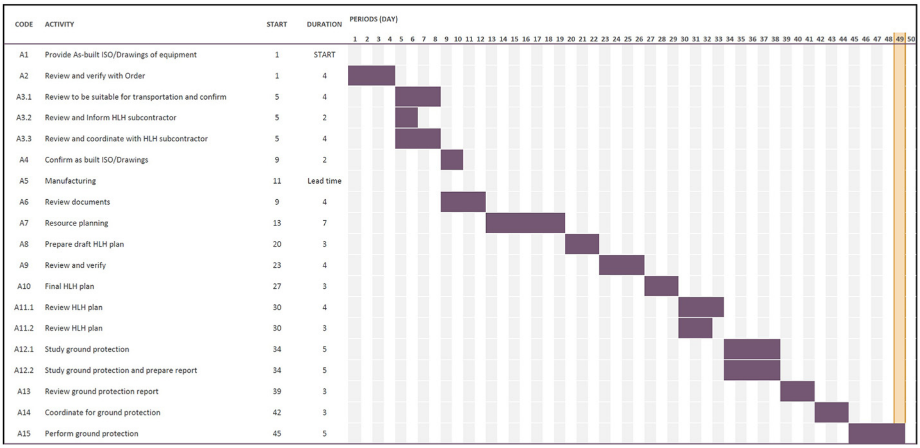


Figure 4. Gantt chart of HLH services – Phase A

4.3 Bottlenecks in the system

The bottlenecks in the process are identified by a combination of company data, desk research and interviews with the logistics manager, project subcontracts manager and subcontracts administration. Five bottlenecks are found in the system. First, logistics, subcontracts and construction teams are not involved in the plan deliver process. In this case, the logistics, freight forwarder and HLH subcontractor do not get the chance to review and verify the equipment configuration before manufacturing. Consequently, the HLH planning and ground protection are not executed in the Plan Deliver process and postponed to the Deliver process. This increases the time of the Deliver process, which delays the HLH services and causes further bottlenecks in the Deliver process. As verified by company data, the logistics manager, project subcontracts manager and subcontracts administration, bottleneck 1 is the main cause of inefficiency confirmed by the logistic manager.

Secondly, there are many changes in the heavy-lift equipment delivery schedule. In the second bottleneck, these changes are not communicated to the logistics team and HLH subcontractor before the cargo arrives at the port. Accordingly, the HLH subcontractor does not expect equipment to arrive, and the HLH services' resources are not available to lift and haul the equipment. Resource planning and allocation is a time-consuming process and causes demurrage costs. The analysis of this bottleneck is verified by company data, the project subcontracts manager and the subcontracts administration.

The third bottleneck is that the HLH subcontractor does not verify equipment specification in the Plan Deliver process; this is the consequence of the non-involvement of stakeholders in bottleneck 1. The HLH subcontractor inspects the equipment specification after the cargo arrives at the port and finds that there are not enough latching points installed on it for safe hauling and lifting. Therefore, the HLH subcontractor has to install additional latching points. For this extra service, the subcontractor has to make an extra order (change order), which causes delays and consequently demurrage costs. This bottleneck is verified by company data, the logistics manager, project subcontracts manager and subcontracts administration.

The fourth bottleneck is caused by unexpected differences in the packing configurations and a lack of communication about it in the Plan Deliver process. Thus, the lifting and hauling resources have to be reallocated, the HLH plan has to be changed and the ground protection has to be repeated. In turn, this causes congestion in the port, time loss, extra demurrage costs and another extra order (change order). This bottleneck is verified by company data, logistics manager, project subcontracts manager and subcontracts administration.

The fifth bottleneck is the fact that the company's systems and database are not integrated. Non-integrated systems make it difficult to extract information for the supervision of HLH activities. Consequently, extracting data manually from various databases and preparing integrated spreadsheets causes unnecessary delays. This bottleneck is verified by company data and the project subcontracts manager. Furthermore, the sample company's vice president of engineering states that the oil and gas companies generally have a major amount of data spread over various databases, thereby creating inefficiencies (Blum, 2019). The description, the effect of the bottlenecks and the verifying sources are summarized in Table 2, and their positions are shown in the swim-lane diagrams in Figures 5 and 6. The company has calculated the total amount of cost inefficiencies as 12.4% of the total order cost.

4.4 Root-cause analysis

A combination of fishbone and five-times-why diagrams is used in this research to identify the root causes of the problem. The causes are divided into four branches: the late involvement of stakeholders, non-communicated changes of delivery schedule with non-integrated systems, non-verified equipment specification and non-communicated changes in packing configuration that lead to cost and time inefficiencies. The five-times-why diagram is used to identify the network of problems and the relationship between the causes. The five-times-why analysis shows that the cost and time inefficiencies in HLH services are caused by cargo congestion at the port, causing high demurrage costs and delays. The subcontractor's resources are not ready for the unexpected arrival, and the equipment lifting points are not suitable for HLH services. These issues arise because of the non-involvement of relevant stakeholders in the early stages

Bottleneck	Description	Effects	Verified by
1	Non-involvement of stakeholders in Plan Deliver process	• Delay in Deliver process • Further issues	• Company data • Logistics manager • Project subcontracts manager • Subcontracts admin
2	Non-communicated changes of delivery schedule in Deliver process	• Cost inefficiency • Time inefficiency	• Company data • Project subcontracts manager • Subcontracts admin
3	Not-verified equipment specification in the Plan Deliver process	• Change order • Demurrage costs • Delay in Deliver process	• Company data • Logistics manager • Project subcontracts manager • Subcontracts admin
4	Non-communicated changes in packing of the equipment	• Change order • Delay in Deliver process	• Company data • Logistics manager • Project subcontracts manager • Subcontracts admin
5	Non-integrated system and databases	• Time inefficiency	• Company data • Project subcontracts manager • Subcontracts admin • Desk research

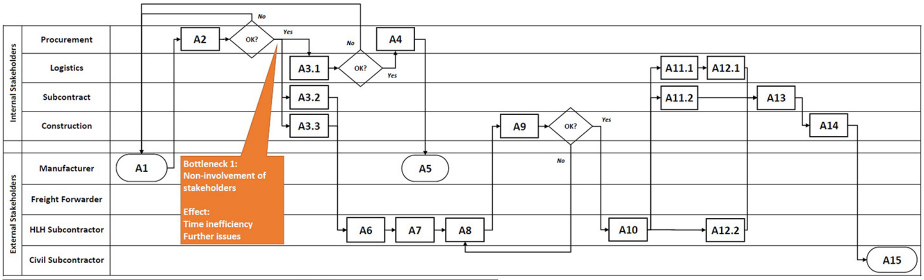
Table 2. Bottlenecks – summary

through a lack of communication. The final result reveals that poor information flow in the Plan Deliver and Deliver processes of HLH services is the root cause of inefficiencies.

4.5 Force-field analysis

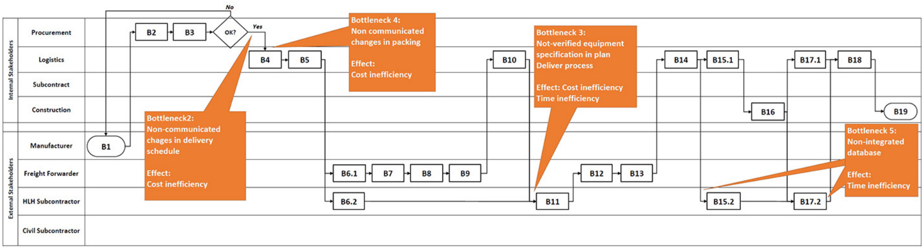
The data collected from the interviews with the external system developers and from the literature review are combined for the force-field analysis, shown in Figure 7. As seen in the diagram, the driving forces of the smart supply chain with distributed information system architecture using blockchain, IoT and Smart Contract in the left column work against the restraining forces of the traditional supply chain with linear information system architecture in the right column.

All interviewees confirm that the blockchain-enabled distributed information system in the left column could reduce the cost and time inefficiencies in McDermott's HLH services. Moreover, the literature review shows that a distributed ledger using blockchain, IoT and Smart Contracts mitigates cost and time inefficiencies in the supply chain. Such a system automates data collection and decision making, thereby speeding up processes (Witkowski,



Code	Activity	Code	Activity
A1	Provide As-built ISO/Drawings of equipment	A9	Review and verify
A2	Review and verify with Order	A10	Final HLH plan
A3.1	Review to be suitable for transportation and confirm	A11.1	Review HLH plan
A3.2	Review and Inform HLH subcontractor	A11.2	Review HLH plan
A3.3	Review and coordinate with HLH subcontractor	A12.1	Study ground protection
A4	Confirm as built ISO/Drawings	A12.2	Study ground protection and prepare report
A5	Manufacturing	A13	Review ground protection report
A6	Review documents	A14	Coordinate for ground protection
A7	Resource planning	A15	Perform ground protection
A8	Prepare draft HLH plan		

Figure 5.
Bottleneck – Phase A



Code	Activity	Code	Activity
B1	Provide Actual packing list, equipment configuration, delivery schedule	B11	Ready for HLH services
B2	Review and verify with Order	B12	Custom clearance
B3	Inspect the equipment and prepare report	B13	Material readiness notification
B4	Review documents	B14	Notifying / coordinating for HLH services
B5	Coordinate for Shipping/Hauling	B15.1	Request for equipment delivery point
B6.1	Verify documents and information	B15.2	Get ready for HLH services
B6.2	Verify documents and information	B16	Define delivery point
B7	Collect the goods from Manufacturer FOB basis	B17.1	Proceed with HLH services
B8	Ship the goods and deliver to CFR Oman port	B17.2	Perform HLH services
B9	Report delivery schedule	B18	Notify construction about material delivery
B10	Coordinate for HLH works	B19	End process, receive equipment

Figure 6.
Bottlenecks – Phase B

2017; Korpela *et al.*, 2017; Gammelgaard *et al.*, 2019; Bahga and Madisetti, 2016; Francisco and Swanson, 2018; Vyas *et al.*, 2019). It also eliminates intermediate transactions, making communication faster and more reliable (Casino *et al.*, 2018; Lu *et al.*, 2019; Azzi *et al.*, 2019; Casado-Vara *et al.*, 2018; Vyas *et al.*, 2019). Therefore, it pushes against the restraining forces of the traditional supply chain and reduces time and cost inefficiencies in the chain (Chang *et al.*, 2019; Gammelgaard *et al.*, 2019; Lu *et al.*, 2019; Azzi *et al.*, 2019; Casado-Vara *et al.*, 2018; Kshetri, 2018; Perboli *et al.*, 2018; Debabrata and Albert, 2018; Dudley *et al.*, 2017; Gausdal *et al.*, 2018; Min, 2019; Vyas *et al.*, 2019).

Furthermore, the literature review reveals that a distributed ledger using blockchain, IoT and Smart Contracts creates visibility, traceability and immutability in the supply chain (Abeyratne and Monfared, 2016; Cui *et al.*, 2019; Gammelgaard *et al.*, 2019; Dudley *et al.*, 2017; Gausdal *et al.*, 2018; Lu *et al.*, 2019). Accordingly, the system enhances communication, ensures on-time verification and improves stakeholder accountability (Babich and Hilary, 2019; Kshetri, 2018; Debabrata and Albert, 2018; Bahga and Madisetti, 2016; Korpela *et al.*, 2017; Francisco and Swanson, 2018). It also ensures the integration of information in the system (Gammelgaard *et al.*, 2019; Azzi *et al.*, 2019; Asprion *et al.*, 2019; Vyas *et al.*, 2019). Such a system drives against the restraining forces of the traditional supply chain to

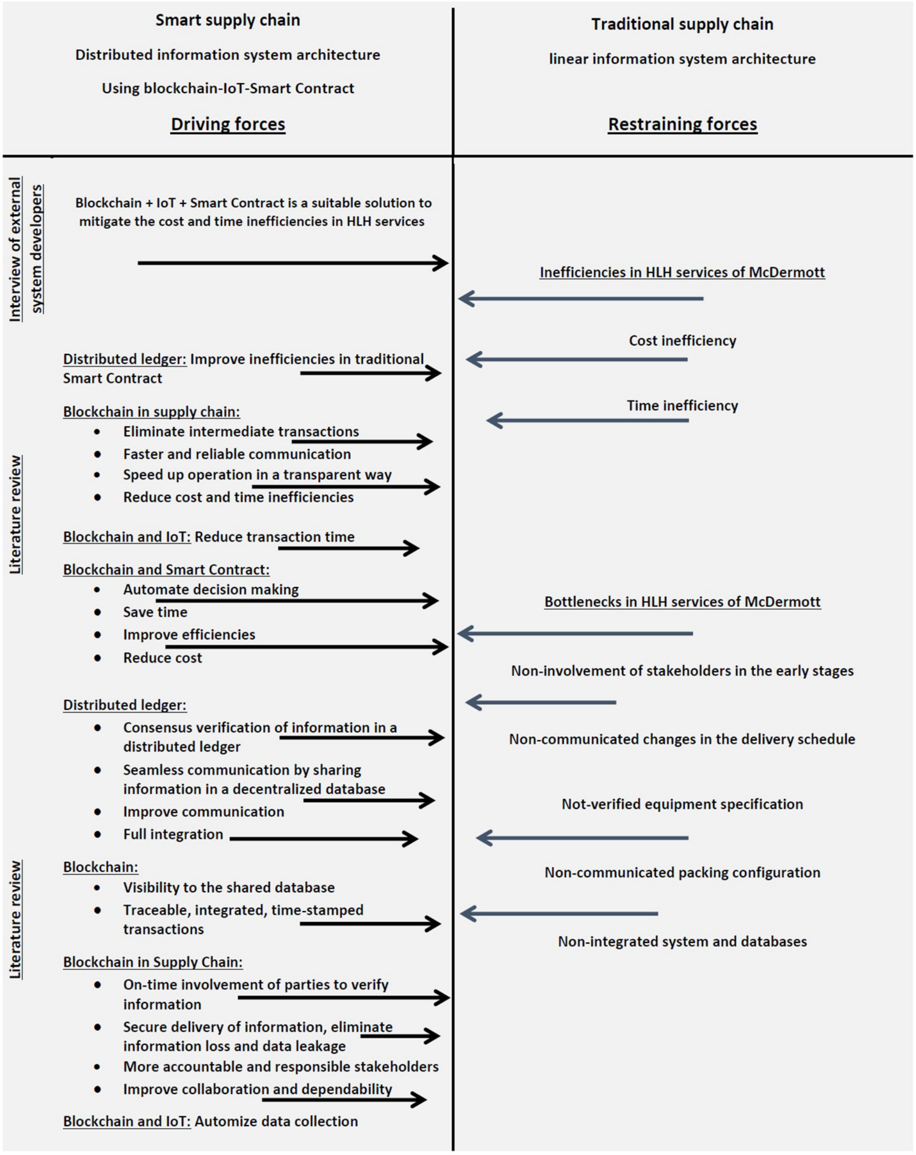


Figure 7. Force-field analysis diagram applied to McDermott

eliminate the bottlenecks in McDermott. Therefore, the distributed information system architecture using blockchain, IoT and Smart Contracts is a suitable system for McDermott.

4.6 Towards a suitable blockchain system design

Figure 8 demonstrates a suitable blockchain-based information system design. The outline of this blockchain architecture is extracted from the literature, and its specific structure is obtained through interviews with system developers. For this purpose, three 1-hour

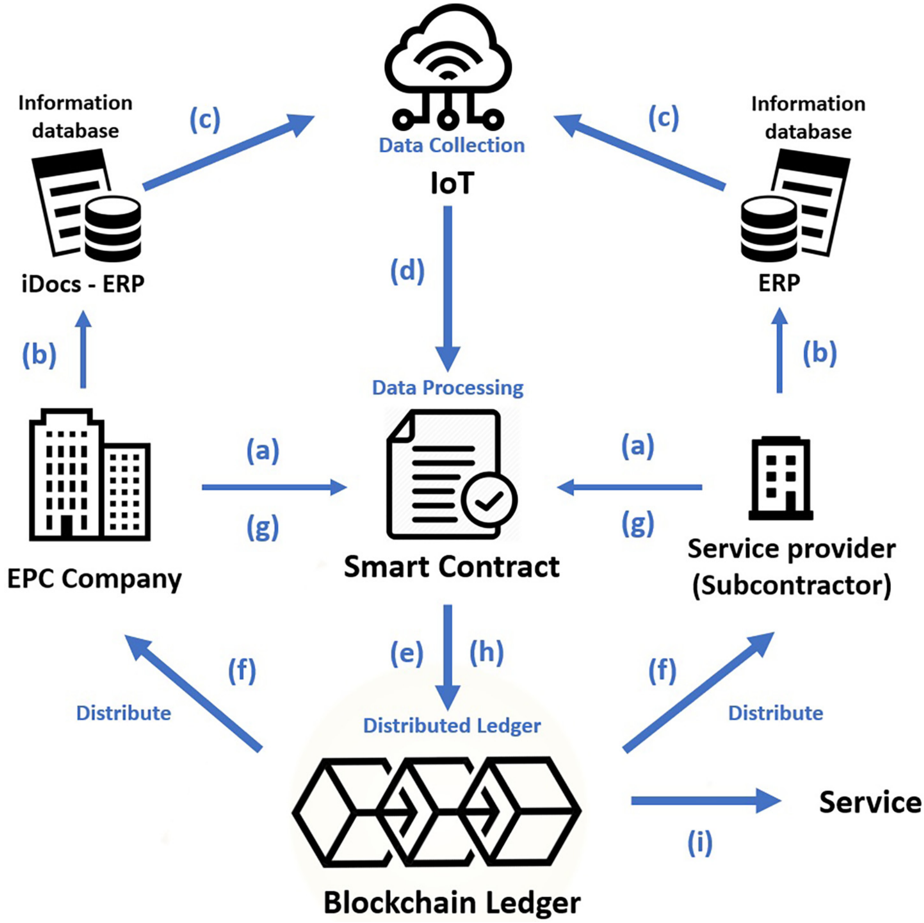


Figure 8.
Suitable blockchain-based information system design obtained from interviews

interviews are conducted separately with three reputable blockchain system developers. These companies have successful experience in setting up blockchain-based systems for subcontracting services in the oil and gas industry with credible information about a suitable system design, as well as implementation time and costs. Each interviewed company confirms that a blockchain based-system design could mitigate inefficiencies in the sample company's HLH services.

In this blockchain-based system design, initially (a), the EPC company and the subcontractor translate the contractual clauses into a Smart Contract and legalize the cooperation terms in a distributed ledger. Accordingly, they agree to share part of their information databases (b). IoT, as an application, automatically collects the added information in databases (c) and brings them into the Smart Contract (d). The Smart Contract verifies the information automatically with the pre-set clauses and creates a block in a distributed ledger (e). Immediately, the ledger distributes the block among the participants (f) who validate the information (g). Afterwards, the information is added to the immutable blockchain ledger (h), which results in the service provider performing the relevant service (i).

In this model, automatic IoT data collection (b, c, d) eliminates the process of reporting and notifying other parties. The Smart Contract automatically verifies the information with the contractual clauses. This automated process removes the activity of Procurement and Subcontracts in verifying the data with the contract and purchased order (PO). Similarly, blockchain instantly distributes the block in the ledger for validation (f), thereby removing the time-consuming activity of manual submission of information to stakeholders. This automation method provides smooth data integration, which prevents miscommunication, human interaction and human error in the supply chain. By having visibility and timed-tagged transactions in an immutable ledger, the parties become more accountable and dependable to validate the information and perform services (Kshetri, 2018). Finally, after adding the block to the ledger (h), the system notifies the service provider (i) to perform the service. Thus, services and activities are performed only after validation, ensuring that stakeholders are not ignored before the services in the supply chain are processed.

This blockchain-based information system design is a new, smart, integrated, immutable system architecture with various effects on the information and workflow in HLH services. The automation of data collection eliminates reporting and notifying activities. Also, automated verification of the Smart Contract with an instant distribution of information removes intermediate manual activities, such as matching the received information with the contract and reporting the activity's progress. Moreover, immutable storage ensures integration in the system. Finally, notifying stakeholders, after consensus validation of the data, eliminates non-involvement and manual coordination activities. The effects of the new system design are summarized in Table 3.

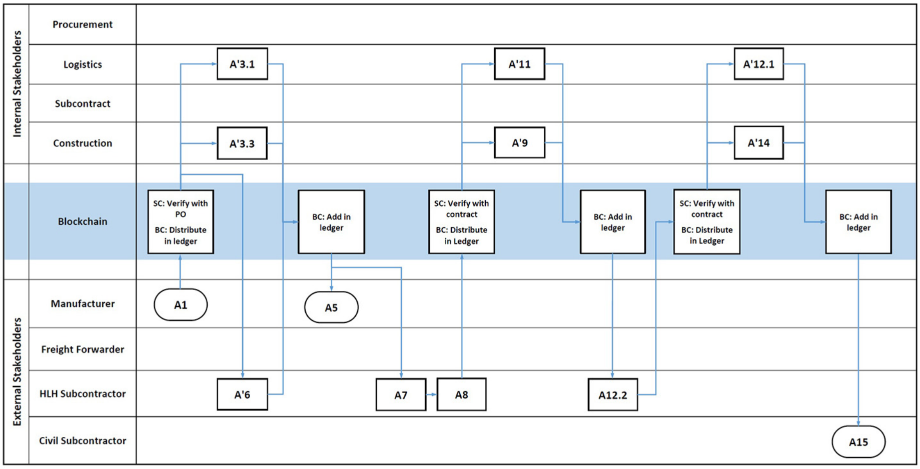
Process in the blockchain-base system	The effect in supply chain process in McDermott's HLH services
Automatic data collection by IoT	• Eliminating reporting • Eliminating notifying • Reduction of human interaction and human error
Automatic data verification by Smart Contract	• Eliminating reviewing and verifying data with contract/order • Eliminating matching and confirming data • Eliminating the intermediate activities • Reduction of human interaction and human error
Instant distribution among parties for validation	• Eliminating reporting • Eliminating requesting • Eliminating the intermediate activities • Reduction of human interaction and human error
Immutable data storage	• Integration of information and work
Notifying service provider after validation of data	• Eliminating non-involvement of parties • Eliminating coordination activities

Table 3. Blockchain processes and effects on HLH services

Given these effects, the existing HLH services system architecture is redesigned as a new blockchain-based system design. For instance, in Phase A, the new system design does not change activity A1. So, the process starts with the manufacturer, who provides the drawings. As soon as the manufacturer enters the drawings in the shared information database, IoT collects the information and Smart Contract verifies it with the PO. In this way, there is no need for Procurement and Subcontracts to verify the information with the PO and contracts. Therefore, A2 and A3.2 are eliminated from the activities. Instantly, blockchain distributes information in the ledger between logistics and construction. Accordingly, the review, inform and coordination activities in A3.1 and A3.3 change to reviewing and validating the data. Because of the blockchain architecture's distributed nature, the HLH subcontractor is involved in the verification of the information at the same time as logistics and construction. Thus, the HLH subcontractor reviews and validates data parallel with the other parties and A6 is removed from the swim-lane. Once the parties have reviewed and validated the information, the system adds data to the blockchain ledger. Accordingly, the system notifies the manufacturer automatically to start manufacturing (A5), without the need for intervening Procurement in A4. The system also notifies the HLH subcontractor to begin resource planning (A7) automatically. With this approach, the existing Phase A swim-lane (Figure 3) is redesigned as a new blockchain-based swim-lane (Figure 9), and the new Gantt chart is prepared (Figure 10) based on the duration of remaining activities. The same concept applies for Phase B, and the final result shows that, in the new system design, Phases A and B of HLH services take 31 and 32 days, respectively.

4.7 Costs and time impact

The blockchain-based system design has a major impact on HLH services. This research evaluates the cost and time improvements. The cost impact is calculated, considering the eliminated cost of inefficiencies in HLH services. As identified in section 4.3, McDermott's



Code	Activity	Code	Activity
A1	Provide As-built ISO/Drawings of equipment	A'9	Review and validate HLH plan
A'3.1	Review and validate informaiton	A'11	Review and validate HLH plan
A'3.3	Review and validate informaiotn	A'12.1	Review and validate ground protection
A5	Manufacturing	A12.2	Study ground protection and prepare report
A'6	Review and validate information	A'14	Review and validate ground protection
A7	Resource planning	A15	Perform ground protection
A8	Prepare draft HLH plan	BC	Blockchain
		SC	Smart Contract

Figure 9.
Swim-lane diagram in Phase A in blockchain-based system design

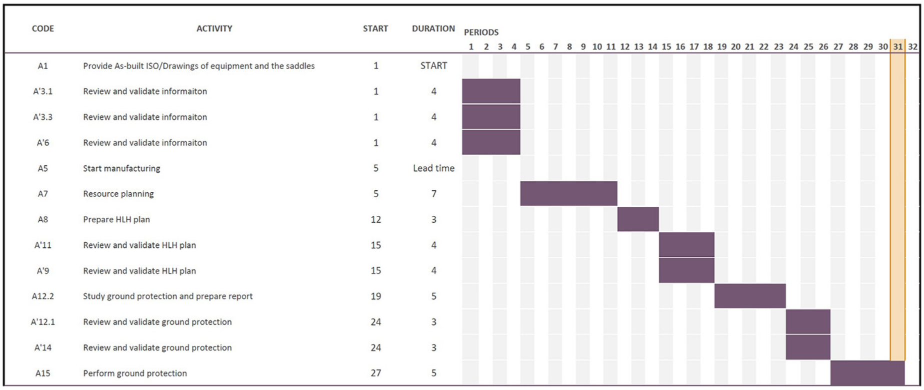


Figure 10. Gantt chart of blockchain-based system design – Phase A

existing system architecture has created five bottlenecks. The cost impacts of these bottlenecks are high demurrage costs and two change orders for installing latching points and restudying the hauling route. Similarly, based on the force-field analysis in section 4.5, blockchain ensures the elimination of these bottlenecks in McDermott's HLH services. Consequently, the blockchain-based system eliminates the demurrage cost and two change orders, creating a 12.4% cost inefficiency reduction. Accordingly, the cost reduction for HLH services reduces SCOR's Cost to Deliver (CO.2.4) metric, leading to a decrease in McDermott's Cost (CO) performance metric.

The time impact is measured by evaluating the time difference between the duration of HLH services in the existing system and in the blockchain-based system. The duration of Phase A is reduced by 37% and the duration of Phase B by 36%. The total time impact of using blockchain architecture is a 36.5% time reduction in a project's HLH services (Table 4), thereby reducing SCOR's Deliver Cycle Time (RS.2.3) metric. Thus, it increases the speed and improves the Responsiveness (RE) performance metric in McDermott's supply chain.

The lead-time reduction and elimination of activities also reduce the project's labour costs. Calculating labour costs requires additional interviews and extra research. Because of the time limitation on the research, evaluating the exact reduction in labour costs is excluded from this research.

The calculations measure the reductions by introducing the solution in McDermott's HLH services. Figure 11 illustrates the reduction by comparing the costs and time between the existing system and the new blockchain-based system. It shows that, compared with the existing architecture, the blockchain architecture reduces costs by 12.4% and time by 36.5%. Therefore, this solution mitigates the cost and time inefficiencies in McDermott's HLH services.

Phases of HLH services	Existing system Duration of service (days)	Blockchain-based system Duration of services (days)	Reduction amount(%)
Phase A – Plan Deliver	49	31	37%
Phase B – Deliver	50	32	36%
Total – HLH services	99	63	36.5%

Table 4. Time reduction by a blockchain-based system

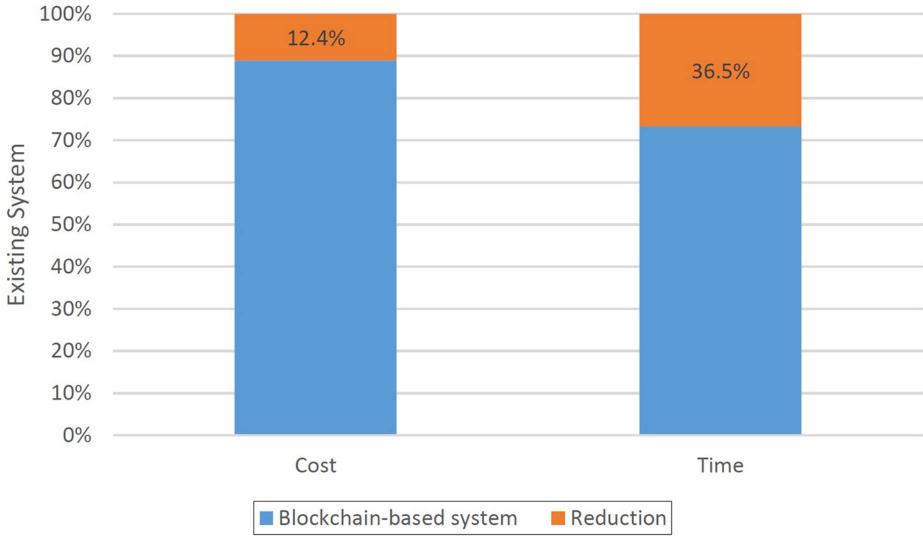


Figure 11.
Cost-time reduction diagram

4.8 Cost-benefit analysis

The cost-benefit analysis evaluates the costs and benefits of the new system architecture along with the timing of implementation in order to evaluate the feasibility of implementing the blockchain-based system design. Costs include the costs of developing blockchain and the service charge for the ledger. Information collected from three blockchain developers clarifies that blockchain development consists of three main steps. Firstly, the blockchain developer establishes the scope of services and the transactions between participants and makes swim-lane diagrams. Secondly, an IoT is created and a Smart Contract is developed. During this step, the required data, acquisition automation, coding the Smart Contract and executing it are completed. It is also important to check whether the participant's databases are mature digitalized databases compatible with the IoT application. Lastly, the system is launched in the ledger. This step includes testing the transactions, Smart Contracts, approving processes and recording the blocks on the blockchain ledger; all stakeholders must participate actively in this step for a successful blockchain development and launch.

According to the interviews, the total development cost of the blockchain is approximately US Dollars (US$) 370,000, and development takes between 12 and 25 weeks. The service charge for using a blockchain ledger depends on the number of transactions and varies from US$0.5 to 1 per transaction. Interviewed developers mentioned that a project like HLH services can involve around 7,000 transactions. Thus, use of the ledger for a single service would cost between US$3,500 and 7,000.

Benefits include direct cost reduction and time reduction. Time reduction relates to the discontinued activities of managers and administration workforces. Thus, the monetary effect of time reduction is calculated as US$5,400, assuming the workforce reduction and daily rates listed in Table 5.

Cost reduction is calculated at US$2.5 million, assuming a 12.4% cost reduction by implementing blockchain in the company with seven projects valued at US$6,700 million. The result of the calculations shows a US$2.1 million total net profit with a positive ROI (Table 6). The outcome excludes the indirect costs and time reductions in HLH services.

Eliminated activities	Duration (days)	Quantity of Managers	Daily rate (US $)	Quantity of Admin	Daily rate (USD)
Review and verify with Order	4	1	100	2	50
Review and Inform HLH subcontractor	2	2	100	2	50
Confirm as built ISO/Drawings	2	1	100	2	50
Review HLH plan	3	2	100	2	50
Review ground protection report	3	2	100	2	50
Inspect the equipment and prepare report	3	1	100	2	50
Coordinate for Shipping/Hauling	5	1	100	2	50
Request for equipment delivery point	1	1	100	2	50
Total calculated reduction (US$)					5400

Table 5. Financial calculation of workforce time reduction

Description	Amount	Remarks
The total development cost for blockchain	370,000 US$	The fixed cost of developing blockchain
The total service cost for blockchain	49,000 US$	For a total of assumed 7 projects; considering a 7,000 US$ service cost per project
The total benefit of cost reduction	2.5 million US$	For a total of assumed 7 projects; considering 12.4% cost reduction for HLH services with 0.3% of the total projects value
The total benefit of time reduction	37,800 US$	For a total of assumed 7 projects, considering a 5,400 US$ cost of workforces in a project
Total cost (Investment)	419,000 US$	
Nett benefit (profit)	2.1 million US$	
ROI	Positive (over 500%)	Net benefit (profit) divided to total cost

Table 6. Costs and benefits summary table

5. Discussion

In this section, the research findings are summarized and the implications of the study are discussed. This section connects the theoretical results with practical future implementation. It also includes a discussion about limitations and future research.

5.1 Summary of the research findings

This research introduces an exclusive blockchain architecture that is suitable for EPC companies as an alternative to their linear supply chain. This architecture can mitigate costs and time inefficiencies in these chains. The research includes a new blockchain system design reducing costs by 12.4% and lead-time by 36.5% in McDermott's HLH services. Thus, McDermott can reduce its operation costs and increase profitability. The new system design can ensure on-time stakeholder involvement and improve communication on a shared platform. In an immutable ledger, it integrates information and avoids data loss. Furthermore, it automates data collection and data processing and reduces human errors. It eliminates intermediate activities and enhances stakeholder accountability. Therefore, the new blockchain system design provides the opportunity to remove waste from the supply chain and improve efficiency in developing projects.

Three well-known system developer companies are interviewed, and all confirm that the blockchain-based system design is a solution for mitigating inefficiencies in McDermott's HLH services. Also, the study outcome was presented in a verification session to the sample company in February 2020. The attendees, including the global subcontract manager, project subcontract manager, engineering manager, supply chain manager, validated the results, indicating that the solution provided can mitigate the inefficiencies in HLH services.

Although only limited research has been performed on blockchain implementation in the oil and gas industry (Kshetri, 2018), some companies started with it in the past couple of years. For instance, the Oil and Gas Blockchain consortium awarded a contract to Data Gumbo to implement blockchain, aiming for automation, cost and time reduction and elimination of human interactions in subcontracting water hauling services (*BusinessWire*, 2019b). Furthermore, Data Gumbo partnered with Atlas RFID, using blockchain and RFID to automate the construction supply chain (Heiskanen, 2020). Equinor and Saudi Aramco, two major oil, gas and energy providers, invested US$6 million in blockchain (*BusinessWire*, 2019a), and Royal Dutch Shell invested in blockchain for energy trading (Edie, 2019). Recently, TOTAL, a French oil and gas company, announced blockchain as an innovative solution for verifying equipment certificates, increasing traceability and security in the supply chain and eliminating the risk of fraud (TOTAL, 2020).

To our knowledge, this is the first case study to assess a blockchain-based system design for mitigating supply chain management inefficiencies of an EPC company in the oil and gas industry. One limitation is that the cost and time effects of the introduced blockchain design were tested theoretically. Future studies could test the result via simulation. This research studied blockchain-based system design only in a sample company's HLH services, but it is advised to examine other services in other organizations. Thus, the generalizability of the findings to other EPC companies, and to other services in projects, should be tested in future research.

5.2 Research implications

Despite its limitations, this research points to various interesting implications and future research directions. Recent findings show that the information flow in a linear supply chain creates inefficiencies, especially in international development projects with multiple stakeholders. As suggested by the result of this research, using a blockchain-based design reduces costs and time inefficiencies in the supply chain. Global supply chains could mitigate the communication inefficiencies of their linear systems by using distributed blockchain-based information systems instead (Gammelgaard *et al.*, 2019). Various studies reveal that blockchain reduces costs and lead-times by improving transparency and efficiency in the supply chain of oil and gas companies (Lu *et al.*, 2019; Dudley *et al.*, 2017; Gausdal *et al.*, 2018). The result of this research proves theoretically that costs and time are reduced in the sample company's supply chain. Therefore, a challenge for future supply chain research is to examine supply chain improvements by simulating the blockchain system design. Based on the results of this paper, we strongly recommend EPC companies to scrutinize their linear supply chain using our methodology, as we have shown that they can reduce time and cost inefficiencies. Furthermore, their research can improve the knowledge about EPC supply chain systems which are essential in this dynamic market.

6. Conclusion

This paper presents research on the supply chain of McDermott International, a global contractor designing, manufacturing and building end-to-end infrastructure to process and transform crude oil and natural gas into other products. McDermott has an engineer-to-order business strategy, whereby it engineers a highly customized oil, gas, petrochemical and energy infrastructure on customers' exclusive orders. The company's linear supply chain creates inefficiencies in complex operations. In this research, McDermott's supply chain is described with a combination of SCOR, RACI and CFPM, and the lead-times are visualized by Gantt charts. Consequently, five bottlenecks are identified in the process: firstly, non-involvement of required parties; secondly, uncommunicated changes; thirdly, unverified specifications; fourthly, unexpected differences in the packing configurations; and fifthly, the lack of communication between different databases. The root-cause analysis reveals that all these bottlenecks are caused by poor communication flows.

Based on academic literature, it is found that a decentralized data system design is a suitable alternative to a linear information system, more specifically, a permissioned, private blockchain-based system, in combination with an IoT and Smart Contracts. Applying blockchain, IoT and Smart Contracts results in smart, efficient and secure supply chains. Blockchain-based supply chains can mitigate the problems arising in linear supply chains, as long as they are designed and implemented considering the challenges of technological blockchain adoption, scalability and risks of implementing Smart Contracts. This is further confirmed by force-field analysis.

A specific system design is proposed, the outline of which is derived from academic literature, and its exclusive structure obtained through interviews with system developers. In this model, first, the EPC company and the subcontractor need to translate the contractual clauses into a Smart Contract and legalize the cooperation terms in a distributed ledger. Furthermore, they need to agree to share part of their information databases. In the process, IoT, as an application, automatically collects the added information in databases and brings them into the Smart Contract. The Smart Contract verifies the information automatically with the pre-set clauses and creates a block in a distributed ledger. Immediately, the ledger distributes the block among the participants who validate the information. Afterwards, the information is added to the immutable blockchain ledger, resulting in the service provider performing the relevant service. This design fully fulfils the company's functional requirements, and its future implementation by McDermott is suitable, as shown in the description of the new system design.

It is advised to implement blockchain in three steps: defining the scope of services by swim-lane diagrams, developing an IoT application and a Smart Contract, and launching the system in the blockchain ledger. The latter step consists of testing the transactions, Smart Contracts, approving processes, and recording the blocks in the blockchain ledger. The costs of the process are estimated at US$370,000. The total blockchain development time varies between 12 and 25 weeks. It has not yet been implemented, but the managers agreed in the validation session that this is the correct way to proceed.

The cost-benefit analysis shows that the system design is feasible and can reduce costs by 12.4% and the lead-time by 36.5% in McDermott's HLH services. Accordingly, McDermott can reduce its operating costs and increase profitability when developing infrastructure projects. These results are validated by three system developers, a validation session in McDermott, and two other cases – ADNOC Gammelgaard *et al.* (2019) and Maersk (Gausdal *et al.*, 2018; Linnet *et al.*, 2018). From this evidence and our findings, it can be concluded that this system design can be beneficial to more companies in more industries suffering from an inefficient linear supply chain.

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