Building up Supply Chain Resilience: Blockchain Technology in the Oil and Gas Industry

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ABSTRACT

In 2020, The Oil and Gas industry was heavily disrupted by COVID-19. The industry is usually well prepared to face external disruptions, yet the novelty and global reach of COVID-19 surprised the industry and disturbed its supply chains. The solution revolves around technology adoption in their supply chains. This study aims to determine the resilience of the supply chains can be enhanced by new technologies. Specifically, it investigates the use of blockchain as a solution to SC problems in the Oil and Gas industry through a three-themed literature review. The first studies and reports on the reluctant adoption of technologies by companies in the industry. The second investigates the way blockchain could salvage the supply chains. The third compares the risks of implementing blockchain or not. The results show that if the big players accept to implement blockchain, it can enhance resilience of the supply chains and dimmish the risks.

Keywords

COVID-19, Blockchain, Supply Chain, Oil and Gas, Resilience.

INTRODUCTION

The worldwide COVID-19 pandemic has disturbed the health of citizens whilst impacting the business world as well. Supply chains (SC), from all over the world, are disturbed due to various measures such as the implementation of lockdowns, closed factories, unreliable demand patterns or even borders closing. As the world endeavours to halt the progression of the virus, many organizations realize the need to rethink and reorganize their SC to enhance its resilience. The purpose is not only to solve current challenges, but to respond to new shifts and unexpected peaks in demand and supply. One of the catalysator of this restructuration is technology.

Within the oil and gas (O&G) industry, the global demand significantly dropped since the beginning of the new coronavirus crisis. This lower demand, in combination with a full inventory, has led to a sharp decline in oil prices. This industry is strongly impacted by external influences such as market volatility and geopolitical risks as a result of the pandemic (Barbosa et al., 2020). Therefore, Barbosa et al. (2020) advise companies within this sector to investigate how networks can be built as such that they are more flexible to scale up and down volumes if needed.

This research paper focuses on the following three information management aspects: 1. IT governance, 2. Cybersecurity and 3. Business Process Integration. The three aspects will be analysed in the context of transports and logistics within the O&G industry. The moderating effect of Information Technology on the supply chain resilience of O&G companies before and after the corona crisis will be especially investigated.

RESEARCH

Objective

The Oil and Gas (O&G) industry is never short on external disruptions (Luft & Korin, 2003). In this century alone, it has learnt to contend with unstable political and economic environments, criminal activities such as piracy and cyber-terrorism, and even natural catastrophes (Vakhshouri, 2011). Nonetheless, it has never before encountered a pandemic which does not stop at frontiers nor respect treaties**.** The industry is moving into uncharted waters and, as such, is looking to keep itself afloat. In light of this, the present paper is seeking to investigate the use of Information Technology and especially blockchain technology to enhance the resilience and, consequently, the viability of Supply Chain Management (SCM) in O&G companies. The following issues will be expounded for the purpose of drafting practical recommendations.

In the first instance, we will ponder on the cause of the adoption reluctance in Oil and Gas companies and how to facilitate the implementation of new technology. Then we will design an implementation strategy of the blockchain technology as an IT solution to the COVID-19 disruption. Finally, we will investigate the indirect influence of the COVID-19 pandemic on the cyber-security threats encountered by O&G companies, and the use of blockchain as a solution.

In essence: How can the resilience of the Supply Chain in Oil and Gas companies be enhanced by the adoption and subsequent implementation of blockchain in a time of crisis?

Approach

The diagram below, Figure 1, demonstrates the method followed in this report. The first step is a selective literature review on the Oil and Gas (O&G) industry and on technology adoption with a focus on blockchain technology. In addition, this literature review will also investigate the notion of Resilience in Supply Chain Management (SCM) and how IT solutions can enhance it. The data and sources of this paper are twofold. First, academic papers and other energy industry related reports, whether white papers or consultancy's owned reports, are used to enhance the knowledge in the O&G sector and on SCM. Second, through benchmarking, the concept of resilience from previous disruptive events is dissected.

Following the literature review, the next step is to analyse O&G firms, their current disruption and IT solution through three different lenses. IT Governance (ITG), the first lens, allows us to investigate the reluctance of O&G to implement new technologies and how to dimmish it. The second lens, Business Process Integration (BPI), enables us to understand the implications of a successful blockchain implementation. The last lens, Cyber-security, and Risk Management studies the threats indirectly triggered by the emergence of the pandemic and the use of blockchain as a technological solution.

Finally, throughout the discussion, we review our findings in both the literature review and the analysis to draft recommendations for O&G firms. Those recommendations focus on the elaboration of a resilient supply chain through, notably, the adoption of blockchain in the SC.

THE INDUSTRY AND BLOCKCHAIN

Logistics and transportation are used to optimize an organization's production procedures by connecting separate activities, from raw material handling to delivery to the final consumer (Tseng, Yue & Taylor, 2005). The final product consumed by the end-user flows in the supply chain (SC) through value-adding entities (Yusuf et al.,2014). Energy SCs consist of complex networks of

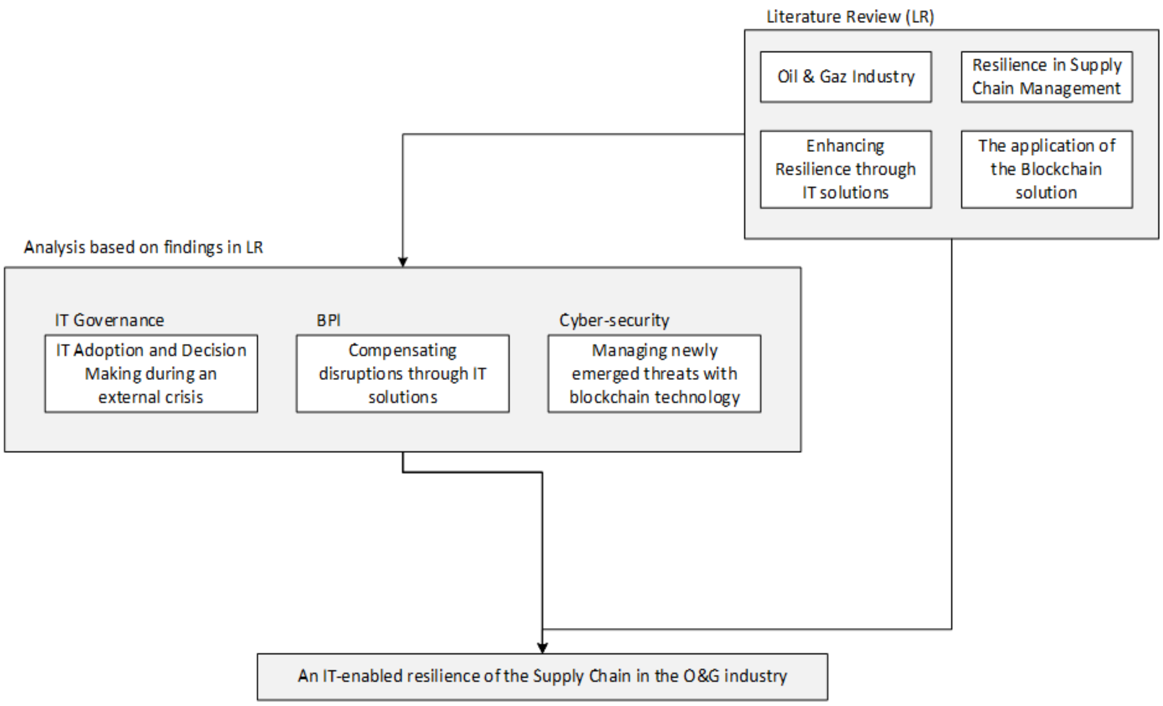

Figure 1. Modelized Approach on how Information Technology can enhance SCM Resilience through Digital Transformation

interlinked companies, producing, distributing, and exchanging energy resources and carriers (Halldorsson & Svanberg, 2013). These characteristics render energy SCs vulnerable to disruptive events such as natural catastrophes, demand risks or world-wide pandemics (Emenike & Falcone, 2020).

The petroleum industry is divided into three businesses: upstream, midstream, and downstream. An upstream business encompasses the exploration, development, and production. Midstream businesses consist of tankers and pipelines carrying crude oil to refineries, whereas downstream business comprises the refining, marketing, and distribution of the final product. Transportation plays a significant role especially in midstream business. In this sector there are large oil companies, which operate within several parts of the SC, as well as smaller companies, which are specialized in one of the elements mentioned below (Credle, et al., 2009). These three businesses within the industry are integrated and major operators are in the power position effecting on supply chain optimization and value creation. However, the trend has shifted from retaining operations in-house to a greater level of outsourcing and integration (Yusuf, et al., 2014).

British Petroleum (2019), an O&G company, goes against the other sectors, by arguing that the energy transportation faced massive changes enabled by new technologies even before COVID-19. In fact, recently, academia has pursued the companies' interests by discovering new opportunities brought by new technologies such as blockchain, artificial intelligence, or even cloud computing in the O&G industry (Lu et al., 2019). As an emerging trend, Mohammadpoor & Torabi (2018) stated that the utilization of Big Data analytics enables the improvement of shipping and transportation performance, as well as decreasing greenhouse gas emissions in the O&G industry. The pipeline is a crucial part of O&G transportation with two million miles worldwide. Nowadays, those pipelines are evolving towards intelligent integrated systems which produce a massive amount of data, thus, enabling pipeline threat monitoring, risk management, and context awareness (Lu, Guo, Azimi & Huang, 2019a).

Even though the industry is already implementing various technological solutions, blockchain is a relatively new technology in the O&G industry since the administrative and managerial operations are conducted in a traditional way (Perrons, 2014). According to Samuel & Lakhanpal (2018), blockchain is based on the distributed ledger technology (DLT), which allows a SC network to share information and be updated of any transaction taking place. All the transactions are in linked blocks which carry the address of the previous block (Infosys, 2018). This facilitates both transaction tracking and that every transaction is digitally signed and timestamped. To the contrary of a traditional database, data modification within the blockchain is challenging due to combination of asymmetric cryptography and decentralized structure (Samuel & Lakhanpal, 2018). Blockchain technology improves tamper-resistance, authenticity verification, accountability, robustness, reliability, and smart contract management (Liang et al., 2018).

ANALYSIS

The Oil and Gas industry versus Technology

This subsection focuses on the information technology governance of O&G industry. The O&G firms are giants with feet of clay. They are cautious in adopting new ways and are known for having sound contingencies against unexpected threats (Deane, Ragsdale, Rakes, & Rees, 2009). Nonetheless, the efficiency of said contingencies depends on the governance of the giants to enact timely decisions.

The Oil and Gas Industry's resistance against new technology

The O&G industry, as a traditional sector, does not possess the reputation of an early- adopter of new technologies, it is considered to be a fast-follower alluding to the necessity for companies to be the second to master the new technologies (Daneshy & Donnelly, 2004; Perrons, 2014). A fast follower, while accepting some risks, will outsource the implementation of a new technology by either buying the solution or partnering directly with a vendor (OGA, 2018). This strategy simultaneously lowers the cost of early adoption and the risk of an immature application by entrusting the risk to the early adopters.

Roberts and Flin (2020) suggest that this reluctance can be explained by a lack of ownership and leadership when it comes to handling IT investment. Such psychological factors affect both decision-makers and the organizational structure of the firm (Roberts & Flin, 2019; OGA, 2018). The lack of technical information available to the decision-makers hinders their investment in IT as they cannot accurately measure the risks and added value of a new technology (Roberts and Flin, 2019). This leads decision-makers to struggle to elaborate a clear strategy (Bargach & Hirsch, 2005). Consequently, the decision-making process is long, with its integration taking between 10-15 years, and its outcome is dependent on the credibility of said technology in the sector (Noke, Perrons & Hughes, 2008; Perrons, 2014).

Business Continuity Plan: business as usual during an external crisis

However, O&G firms cannot afford this timeframe when confronted to external disruptions. Hence the existence according to best practices of a business continuity plan (BCP) to initiate a return to business-as-usual (Smith, 2003). As per the nature of their operations, the industry is well-versed in implementation of a BPC (Faertes, 2015). Nonetheless, due to the unprecedented pandemic, in term of scale and impact, the whole industry was affected. The use of blockchain as a solution, to support both shared information and structure amongst the actors, reduces uncertainty (Nærland, Müller-Bloch, Beck, & Palmund, 2017). Consequently, the BPC needs to include the implementation of a new technology in a risk-adverse industry during a crisis.

IT Governance: the cornerstone to resilience

In order to facilitate the return to business-as-usual in a disrupted environment, we propose Figure 2, the IT Governance Arrangement Matrix (GAM), as a foundation for O&G companies to support their adoption of blockchain and therefore enhance the resilience of their supply chain.

Domain / Style	IT Principles		IT Infrastructure Strategies		IT Architecture		Business Application Needs		IT Investment and Prioritization	
	Input	Decision	Input	Decision	Input	Decision	Input	Decision	Input	Decision
Business Monarchy	X	X						X		X
IT Monarchy				X		X				
Feudal					X		X			
Federal										
Duopoly			X						X	
Anarchy										

Figure 2. Recommended Governance Arrangement Matrix for O&G companies during a crisis

<u>IT Principles:</u>

In a time-sensitive setting, decision-making must be swift and final to avoid confusion and miscommunication. Therefore, a business-monarchy governance with technical insight and knowledge will shorten the decision-making time whilst still sustaining the long-term objective (Roberts & Flin, 2020). Furthermore, as the military saying goes, order, counter-order, disorder. This idiom, from an O&G industry perspective, reinforces the need for a firm to have, in crisis, one voice that is dictating the strategy.

<u>IT Infrastructure Strategies:</u>

Weil and Ross (2004) define the infrastructure strategy as coordinated shared IT services laying the cornerstone of the IT department within the firm. As such, during a crisis, the C-Level should communicate with the IT executives in order to establish a clear application of both the IT principles and the crisis-specific business needs.

<u>IT Architecture:</u>

The IT architecture, as reminded by Salavati (2007), needs to be flexible, agile, and reactive to the changes in the business models. COVID-19 differs from other externalities through its global, yet heterogenous effects on O&G companies. Thus, the architecture of IT needs to be suited geographically, while also being able to circonvend the policies of its region. The logical governance style is then letting a Feudal system be the responsible for the inputs whilst the IT department makes the decision.

<u>Business Application Needs:</u>

The business application needs of different business units and different offices vary during a crisis period. Indeed, they vary because of different policies, different political agreements or even because some regions are less implicated in the external disruption. Thus, each region and business should be able to communicate their expectations and needs for the business executives to make a fully informed decision about the reason behind an IT application. In addition, early engagement of the users and of the seniors will encourage adoption of the solution. (Sætren & Laumann, 2015; Roberts & Flin, 2020)

<u>IT Investment and prioritization:</u>

The control of the IT investment and prioritization requires an overview of the solution needed by the IT department. Consequently, the IT and business units' leaders should be heard as they need to collaborate in evaluating the possible outcome of an IT solution. The final decision should lie in the hands of the business monarchy to save valuable time and create a sense of order and cohesion within the firm (Weil & Ross, 2004).

Transparency and Traceability through Blockchain in SCM

In the past, supply chains have learned to strengthen their resilience when disrupted by disasters, whether natural or not (Ivanov, 2020). Resilience refers to the ability to withstand a disruption and recover performance. Due to the disruptions caused by COVID-19, this newfound resilience in SC was put to a test. One of the occurring problems in oil SCs, brought to light by the pandemic was ensuring timely coordinated receipt of information.

However, these information flow problems are not unheard of in SCs. Indeed, Hull (2002) mentioned the "bullwhip" information distortion and information friction in the crude oil SC as the major information flow problems. The bullwhip information distortion is the phenomenon of information being gradually distorted along the SC while information friction refers to the miscoordination of processes, resulting in for example missed transportation connections (Saraeiana, Shirazib, & Motamenia, 2018). Global SC are highly reliant on transportation, and thus, due to long cycle times they can be blocked in the case of a disruption within the SC (Hull, 2002), such as COVID-19. Therefore, the challenge in the O&G SC is to organize information flows within business processes in a way, that is timely, transparent, and agile (Mendling et al., 2018).

This paper investigates the implementation of blockchain in the O&G SC. As stated by Little (2020), the implementation of blockchain technology in the transportation information flow will increase traceability, security, automatization, and speed. Additionally, it could improve the transparency and traceability within a SC through the use of immutable data documentation, a distributed storage/ledger, and controlled user access (Abeyratne & Monfared, 2016).

This chapter focusses on the management of business processes in the SC, because SCs are comprised of complex intertwined business processes (BP) which require management to deliver a valuable output for customers (Saraeiana et al., 2018). More specifically, it focusses on the BP management, modelled in BPMN, before (Figure 4) and after (Figure 5) the implementation of blockchain. The models are based on the case of Alaskan crude oil (Hull, 2002) and on the research of Samuel & Lakhanpal (2018), Mendling, et al. (2018) and Abeyratne & Monfared (2016). The O&G SC before COVID-19 has an approximate duration of two months from the start to the end. Actors in this diagram include: 1) the producer who extracts the O&G, 2) the transporter who transports and stores the crude oil from the producer, 3) the refinery who refines the crude oil, into for example kerosine, and selling it to the market, 4) the distributor and 5) the market including, for instance, service stations, industry and ships among others.

The main blockages that can occur in the model are in transport and distribution (Hull, 2002). The disruption of COVID-19 caused both lower capacity and physical restrictions, which resulted in increased price of transport and a potential inability to deliver as planned.

The objective of blockchain in this use case is to store and share immutable data easily and safely. The initial implementer of the blockchain will also initially be the owner of the digital core (Holdowsky & Killmeyer, 2019), which in this case can be assumed to be the oil refinery. The data can be accessed through a user interface, accessible through a private key. Ownership data, location data and product specific data can be stored in blocks to build a product profile and each transformation is timestamped (Abeyratne & Monfared, 2016). The initial product profile is created by the producer and saved as a block. When the transporter changes the product data, instead of changing the previous information, an additional block is added. In this manner the history and therefore transparency of the process is contained. However, not every actor can view all previous blocks. In the user interface of for example the customer, the customer can see a product profile (Figure 3). Indeed, it also clearly displays that the customer does not have access to for example the producer's product data.

Therefore, the benefits of the blockchain adoption are transparency and traceability. The transparency is indicated by the distributed storage and the embedded smart contracts, enabling blockchain to govern BPM. The traceability is enforced by the timestamping of all actions in the blockchain. Additional benefits of blockchain include, reduction of cycle time, because of process efficiency (Hull, 2002) and lower dependency on workers, like project and transport contract trackers (Samuel & Lakhanpal, 2018).

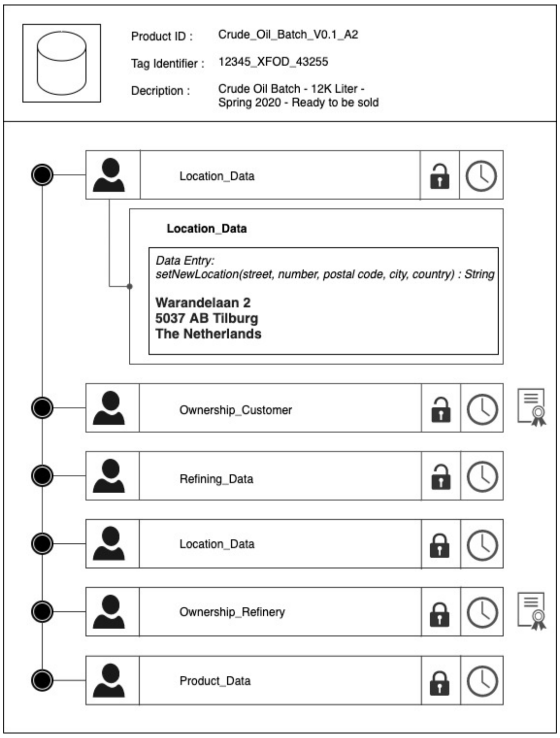

Figure 3. Product Profile Customer-View

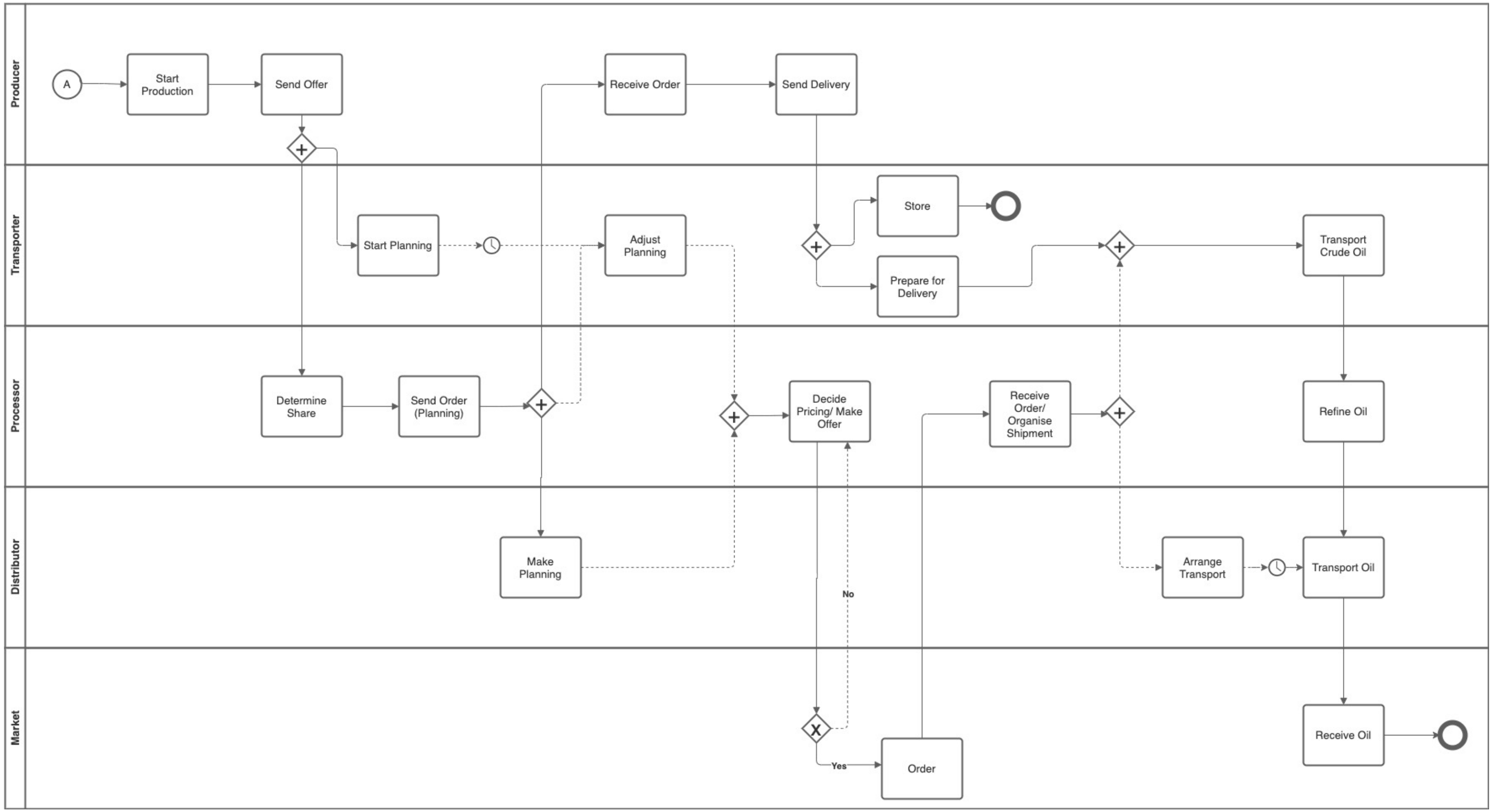

Figure 4. BPMN O&G SC before Blockchain Implementation

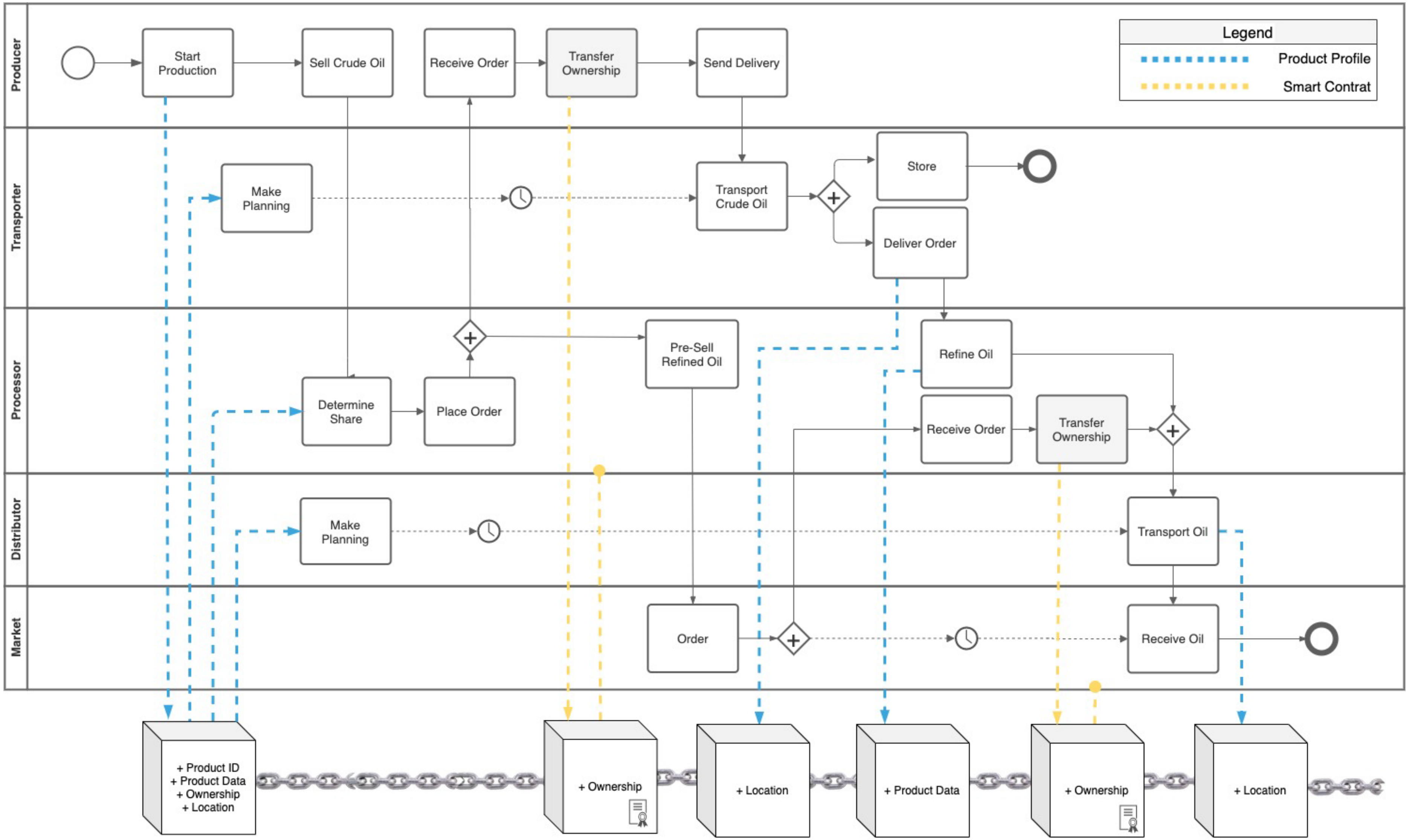

Figure 5. BPMN O&G SC with blockchain enhancement

Analysing the potential advantages and risk in the supply chain

To get a deeper understanding of information sharing's gains and threats regarding the Oil and Gas (O&G) SC, this paper explores two scenarios: 1) Do nothing, and 2) Implement a decentralized ledger database, specifically the blockchain technology.

Scenario 1: Do nothing

A centralized ledger database is controlled by one entity. The traditional ledger comprises various technologies and can be analysed or monitored at a central location, as seen in Figure 5 (Preveral, Trihoreau, & Petit, 2014). Alibaba Cloud is its one example (Yang et al., 2020). The cloud technology allows the O&G SC to handle threats, from third-parties with trusted access through given credentials, to the company's data. Understanding the internal and external threats helps monitor data breaches and improves visibility (PWC, 2016).

According to Preveral et al. (2014) and Vogels (2019), the system incurs a massive maintenance and a long transaction time and a high integration cost. Nevertheless, its authenticity can be verified by external audits, although the transactions can be tampered by the ledger service providers (LSP). A strong trust is therefore required (Yang, et al, 2020).

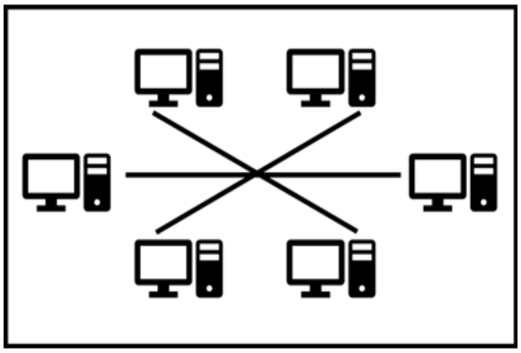

Figure 7. Decentralized database

Scenario 2: Distributed Ledger Database, Blockchain

The distributed ledger database allows data to be stored in different locations and computers, globally and locally (Chowdhury, Colman, Kabir, Han & Sarda, 2018; TradeIX, 2018). Participants can easily manage the database, making processes transparent (Firdhous, 2011).

One of the newest platforms is blockchain, a globally shared database with no need for intermediaries. Its implementation cost is generally smaller than the whole IT investment and a higher ROI can be anticipated (Mingaleva, Shironina, & Buzmakov, 2020). All transactions are time-stamped and recorded in blocks, linked together by a hash function. The system is transparent and immutable through the use of the consensus mechanism creating greater trust (Ajao et al., 2019; Chowdhury et al, 2018; Jayachandran, 2017; Liang et al., 2018). The traceability quality increases the confidentiality, integrity, and availability of the whole SC (Liang et al., 2018). With its decentralized nature, the transactions are difficult to tampered and the energy assets can become digital (Yang et al., 2020).

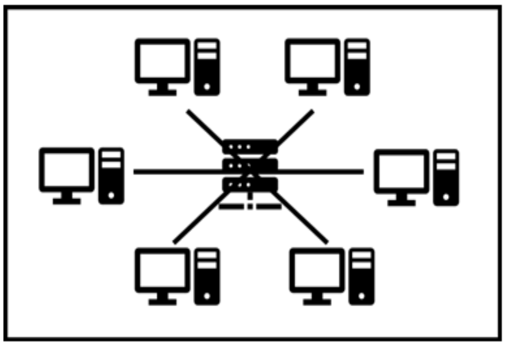

Figure 6. Centralized Database

Risk analysis

Due to the complex nature of O&G SC, there are a significant amount of reasons, objectives, and methods of cyber-attacks. The most common ones are data leakage, data tampering, malicious code, and social engineering (Nasir, Sultan, Nefti-Meziani, & Manzoor, 2015).

Scenario 1 relies on a central authority enabling a single point of vulnerability if the central authority were to be compromised, the whole SC network can be damaged (Sultan, Ruhi, & Lakhani, 2018). On the contrary, in blockchain technology, if one or several blocks were to be hacked, the other blocks could provide a secure backup and overwrite the hacked version, thus decreasing the likelihood of a massive data leakage (Xu, 2016). The consequences of a data leakage have a major impact on the business and its reputation (Nasir et al., 2015).

A Centralized database renders an O&G SC network vulnerable to information falsification and data tampering when all the transactions are not properly identified and tracked (Ajao et al., 2019). Blockchain technology is considered tamperproof due to fact that the integrity of the blocks is verified through consensus model (Sultan et al., 2018). As many economies are driven by the O&G industry as it generates a substantial income, data tampering and falsification could result into notable financial and reputation losses (Ajao et al., 2019).

One of the most typical ways of attacking an O&G SC network in Scenario 1 is to send a malicious code within a phishing email to users having access to the network (Liang et al., 2018). Although a blockchain prevents multiple types of malicious attacks on a global level, it remains vulnerable to the injection of a malicious code at a single user level (Signorini, Ponteocorvi, Kanoun, & Di Pietro, 2018). Malicious attack can paralyze the SC network and lead to extreme high financial losses, as did, for instance, the case Shamoon-1 (Hussain & Skinner, 2020).

In Scenario 1, the other common way of attacking the database is social engineering: attackers are manipulating SC authorized members into unintentionally handing over to the attackers an access to the network (Gallegos-Segovia et al., 2017). Similarly, Weber, Schütz, Fertig and Müller (2020) proved that social engineers successfully lure private keys from their targets in the blockchain cryptocurrency environment.

The following tables are constructed according the guidelines created by Refsdal, Solhaug, & Stolen, (2015). Table 1 represents the levels of likelihood and consequences of the potential threats described above in the context of both scenarios. Table 2 represents the risks in the matrix form. In the Scenario 2, the implementation of blockchain is decreasing the likelihood of each risk.

Table 2 Risk Matrix Likelihood and Impact

Scenario	Risk	Likelihood (1-5)	Impact (1-5)	Overall Risk (1-25)
Scenario 1: Do nothing, centralized database	R1 Data leakage	Possible (3)	Moderate (3)	9
	R2 Information falsification Data tampering	Possible (3)	Major (4)	12
	R3 Malicious code	Likely (4)	Critical (5)	20
	R4 Social engineering: access	Likely (4)	Major (4)	16
Scenario 2: Decentralized ledger database, blockchain	R5 Data leakage	Unlikely (2)	Moderate (3)	6
	R6 Information falsification/Data tampering	Rare (1)	Major (4)	4
	R7 Malicious code	Rare (1)	Critical (5)	5
	R8 Social engineering: access	Unlikely (2)	Moderate (3)	6

Discussion

This paper aimed to explore how the resilience of the SC in O&G companies can be enhanced by the adoption and subsequent implementation of blockchain in a time of crisis.

The results show that the implementation and success of the blockchain technology rest on the market leaders' shoulders. Indeed, the adoption of new technology in the market depends on the big players (Daneshy & Donnelly, 2004) which depends on their inhouse IT, its governance of IT and on the service providers marketing. Nonetheless, their usual reluctance to adopt changes is upset by the novel external disruption that is COVID-19. Indeed, caught unaware, the O&G companies must change their governance paradigm to secure their SC.

Furthermore, another finding of this report states the need for the O&G companies to consider blockchain as a solution for this crisis and the future ones. Thus, O&G industry's long-term orientation would be satisfied and less reluctant to invest in new technology. In order to better convince them of the gains achieved, especially in terms of resilience of the SC, this paper offers a modelled implementation of blockchain. The operational vulnerabilities pre-COVID-19 shown, high dependency on transport and on present workforce, among others, can be solved and later avoided by the blockchain technology.

Nevertheless, implementing a recent technology is never without risks and an industry as risk-adverse as the Oil and Gas will require in depth opportunity cost analyses and risks assessments. The preliminary risk assessment exacted in this paper convey that blockchain is not without cyber-security focused risks. However, through the comparison of the option of doing nothing and the option of using blockchain, it appears that using the common centralized database standard presents higher risks than a decentralized digital ledger. Blockchain-focused risks have in general a lower likelihood due to the high financial cost and the substantial computing power needed. In addition, blockchain has the benefits of also increasing transparency, trust, and efficiency. Therefore, those three factors and an enhanced security should convince the companies in the need of its implementation to be more resilient against new external disruptions.

Table 1. Risk Matrix

		Likelihood				
		Rare	**Unlikely**	**Possible**	**Likely**	**Certain**
Consequence	**Critical**	7			3	
	Major	6		2	4	
	Moderate		5,8		1	
	Minor					
	Insignificant					

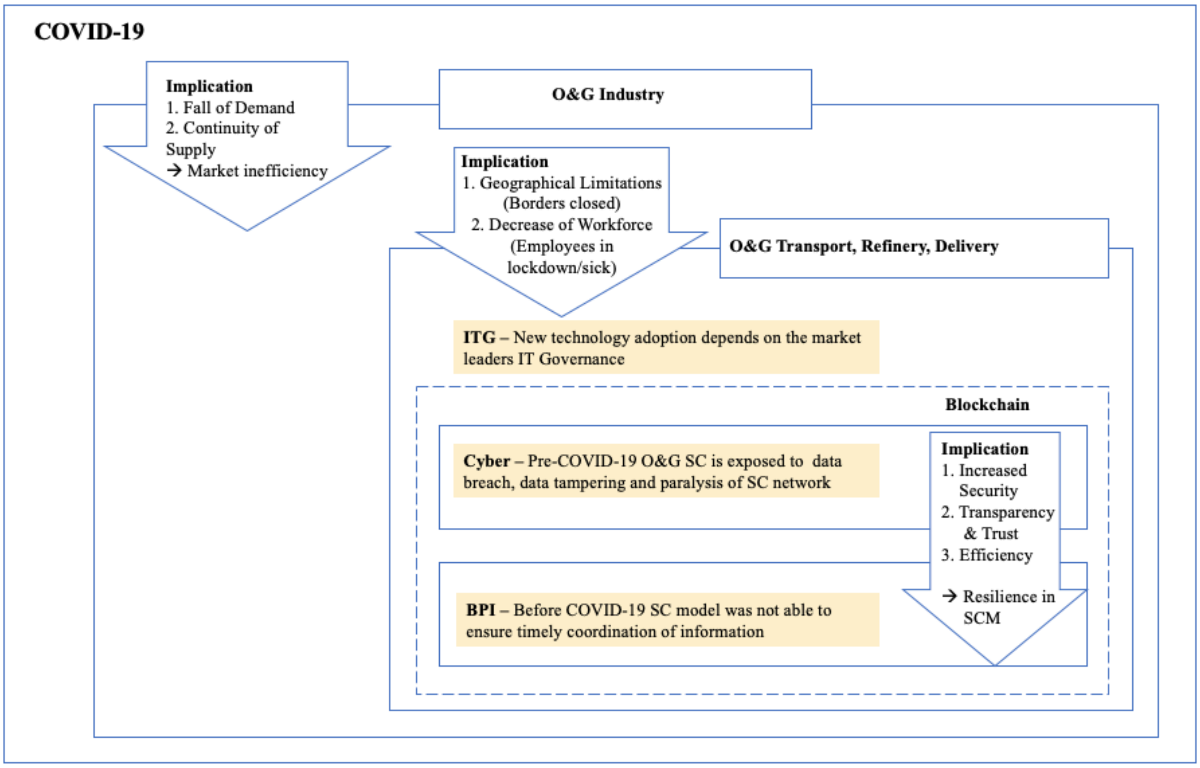

Figure 8. Overview and Cross-Examination of the findings

However, the O&G industry, made of giants with feet of clay, is known for its slow adoption of new technologies, thus, slowing down its digital transformation. Consequently, the industry's transformation and the possible effects brought will not occur in a short-term perspective. A shift of the whole industry is more likely to be the main reason for long-term implications in the market, rather than an external disruption such as COVID-19. The pandemic has highlighted vulnerabilities in the SC which can now be better addressed. Indeed, one noteworthy discovery of the research is that COVID-19 is not the main reason for the need of becoming more resilient.

Conclusion

As the O&G industry is accustomed to external disruptions, their main challenge is to deal with the aftermath. Therefore, the O&G must use blockchain as a solution to overcome the perceived threats against the Supply Chain. This report advises the firms in the O&G industry to implement the following steps to dimmish the influence of external disruptions on the SC. The first step in this endeavour is to shift from the fast follower paradigm of the industry to a technology abled company through a modified governance model. The second step is to implement the blockchain technology to simultaneously create transparency and heighten the efficiency of the SC by making it faster, reliable, and trustworthy. The last step is to prevent the realization of the detected risks by designing blockchain solutions.

This report suffers from some limitations. Indeed, it appeared, through the literature review, that the main challenges of the O&G were revealed by the pandemic. Thus, the paper is not able to fully measure its impact. Another limitation is the timeframe in which it was realized: the pandemic is still ongoing, and as such, we could only make assumptions on a world post-COVID-19. Further studies need to be conducted to investigate more closely some of the following issues. First, academic research needs to focus on the concrete threats of COVID-19 on the cybersecurity of the O&G industry. Second, they need to explore whether the BPC sufficiently prepared the O&G industry to confront this external disruption. Last, the opportunity and financial cost of blockchain in the O&G industry should be investigated and calculated.

References

Abeyratne, S., & Monfared, R. (2016). Blockchain ready manufacturing supply chain using distributed ledger. *International Journal of Research in Engineering and Technology*, *5*(9), 1-10.

Ajao, L., Agajo, J., Adedokun, E. A., & Karngong, L. (2019). Crypto Hash Algorithm-Based Blockchain Technology for Managing

Decentralized Ledger Database in Oil and Gas Industry. *Multidisciplinary Scientific Journal, 2*, 300-325.

Barbosa, F., Bresciani, G., Nyquist, S., & Yanosek, K. (2020). *Oil and gas after COVID-19: The day of reckoning or a new age of opportunity?* Retrieved from McKinsey: https://www.mckinsey.com/industries/oil-and-gas/our-insights/oil-and-gas-after-covid-19-the-day-of-reckoning-or-a-new-age-of-opportunity

Bargach, S., & Hirsch, M. J. (2005). Role of Incentives and compensation models and Culture of Oil and Gas Industry in Technology Acceptance. In S. o. Engineers (Ed.), *SPE Annual Technical Conference and Exhibition*, (pp. 10-12). Dallas.

(2019). *BP Energy Outlook.* BP p.l.c.

Credle, R., Akibola, V., Karna, V., Pannerselvam, D., Pillai, R., & Prasad, S. (2009). *Discovering the Business Value Patterns of Chemical and Petroleum Integrated Information Framework.* An IBM Redbooks publication.

Daneshy, A., & Donnelly. (2004). . A JPT roundtable: the funding and uptake of new upstream technology. *Journal of Petroleum Technology, 56*(6), 28-30.

Deane, J. K., Ragsdale, C. T., Rakes, T. R., & Rees, L. P. (2009). Managing supply chain risk and disruption from IT security incidents. *Operations Management Research, 2*(1), 4-12.

Emenike, S. N., & Falcone, G. (2020). A review on energy supply chain resilience through optimization. *Renewable and Sustainable Energy Reviews , 134*.

Faertes, D. (2015). Reliability of supply chains and business continuity management. *Procedia Computer Science, 55*, 1400-1409.

Firdhous, M. (2011). Implementation of Security in Distributed Systems – A Comparative Study. *International Journal of Computer Information Systems*.

Gallegos-Segovia, P. L., Bravo-Torres, J. F., Larios-Rosillo, V. M., Vintimilla-Tapia, P. E., Yuquilima-ALbarado, I. F., & Jara-Saltos, J. D. (2017). Social engineering as an attack vector for ransomware. Pucon, Chile: IEEE.

Halldorsson, A., & Svanberg, M. (2013). Energy resources: Trajectories for supply chain management. *Supply Chain Management, 18*(1), 66-73.

Holdowsky, J., & Killmeyer, J. (2019). *From siloed to distributed Blockchain enables the digital supply network.* Deloitte.

Hull, B. (2002). A structure for supply-chain information flows and its application to the Alaskan crude oil supply chain. *Logistics Information Management, 15*(1), 8-23.

Hussain, A., & Skinner, G. (2020). Analysis and Findings of Social Engineering Industry Experts Explorative Interviews: Perspectives on Measures, Tools, and Solutions. *IEEE Access, 8*, 67321-67329.

Infosys. (2018). *Oil and Gas Industry - Blockchain, the Disruptive Force of the 21st Century.* Retrieved from Infosys: https://www.infosys.com/industries/oil-and-gas/features-opinions/Documents/blockchain-disruptive-force.pdf

Ivanov, D. (2020). Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. *Transportation Research Part E: Logistics and Transportation Review, 136*.

Ivanov, D. (2020). Viable supply chain model: integrating agility, resilience and sustainability perspectives—lessons from and thinking beyond the COVID-19 pandemic. *Annals of Operations Research*.

Jayachandran, P. (2017). *IBM Blockchain Blog.* Retrieved from https://www.ibm.com/blogs/blockchain/2017/05/the-difference-between-public-and-private-blockchain/

Liang, X., Shetty, S., Tosh, D., Ji, Y., & Li, D. (2018). Towards a Reliable and Accountable Cyber Supply Chain in Energy Delivery System Using Blockchain. Springer, Cham.

Lu, H., Guo, L., Azimi, M., & Huang, K. (2019). Oil and Gas 4.0 era: A systematic review and outlook. *Computer in Industry, 111*, 68-90.

Lu, H., Huang, K., Azimi, M., & Guo, L. (2019a). Blockchain Technology in the Oil and Gas Industry: A Review of Applications, Opportunities, Challenges, and Risks. *IEEE Access, 7*, 41426-41444.

Luft, G., & Korin, A. (2003). Terror's next target. .

The Journal of International Security Affairs, 6, 95-101.

Mendling, J., Weber, I., Aalst, W., Brocke, J., Cabanillas, C., Daniel, F., . . . La Rosa, M. (2018). Blockchains for Business Process Management - Challenges and Opportunities. *ACM Transactions on Management Information Systems*(9), 17.

Mingaleva, Z., Shironina, E., & Buzmakov, D. (2020). Implementation of Digitization and Blockchain Methods in the Oil and Gas Sector. *Integrated Science in Digital Age 2020* (pp. 149-153). Kep, Cambodia: Springer.

Mohammadpoor, M., & Torabi, F. (2018). Big Data analytics in oil and gas industry: An emerging trend. *Petroleum*.

Nærland, K., Müller-Bloch, C., Beck, R., & Palmund, S. (2017). Blockchain to Rule the Waves-Nascent Design Principles for Reducing Risk and Uncertainty in Decentralized Environments. *ICIS*.

Nasir, M. A., Sultan, S., Nefti-Meziani, S., & Manzoor, U. (2015). Potential cyber-attacks against global oil supply chain. *International Conference on Cyber Situational Awareness, Data Analytics and Assessment (CyberSA)* (pp. 1-7). London: IEEE.

Noke, H., Perrons, R. K., & Hughes, M. (2008). Strategic dalliances as an enabler for discontinuous innovation in slow clockspeed industries: evidence from the oil and gas industry. *R&d Management, 38*(2), 129-139.

OGA. (2018). *Technology Insights.* Retrieved from https://www.ogauthority.co.uk/media/4776/a5-technology-insights-online-v2.pdf

Perrons, R. K. (2014). How innovation and R&D happen in the upstream oil & gas industry: Insights from a global survey. *Journal of Petroleum Science and Engineering, 124*, 301-312.

Preveral, A., Trihoreau, A., & Petit, N. (2014). Geographically-Distributed Databases: A Big Data Technology for Production Analysis in the Oil & Gas Industry. *SPE Intelligent Energy Conference and Exhibition.* Utrecht: Society of Petroleum Engineers.

PwC. (2016). *Turnaround and Transformation in Cybersecurity: Oil and Gas.* Retrieved from https://www.pwc.com/gx/en/consulting-services/information-security-survey/assets/2016-oil%20and%20gas.pdf

Refsdal, A., Solhaug, B., & Stolen, K. (2015). *Cyber-Risk Management.* Oslo: SpringerBriefs in Computer Science.

Roberts, R., & Flin, R. (2020). Unlocking the Potential: Understanding the Psychological Factors That Influence Technology Adoption in the Upstream Oil and Gas Industry. *SPE Journal*.

Sætren, G. B., & Laumann, K. (2015). Effects of trust in high-risk organizations during technological changes. *Cognition, Technology & Work, 17*(1), 131-144.

Salavati, S. (2007). IT Governance & Management: An ability to be more efficient and competitive.

Samuel, R., & Lakhanpal, V. (2018). Implementing Blockchain Technology in Oil and Gas Industry: A Review. *DOI: 10.2118/191750-MS* (pp. 1-13). Texas: SPE Annual Technical Conference and Exhibition.

Saraeiana, S., Shirazib, B., & Motamenia, H. (2018). Towards an extended BPMS prototype: Open challenges of BPM to flexible and robust orchestrate of uncertain processes. *Computer Standards & Interfaces, 57*, 1-19.

Signorini, M., Ponteocorvi, M., Kanoun, W., & Di Pietro, R. (2018). BAD: Blockchain Anomaly Detection.

Smith, D. (2003). Business continuity and crisis management. *Management Quarterly, 44*(1), 27-33.

Sultan, K., Ruhi, U., & Lakhani, R. (2018). Conceptualizing Blockchains: Characteristics and Applications. *11th IADIS International Conference Information Systems 2018*, (pp. 49-57).

TradeIX. (2018). *The Difference Between Blockchain and Distributed Ledger Technology.* Retrieved from https://tradeix.com/distributed-ledger-technology

Tseng, Y.-y., Yue, W. L., & Taylor, M. A. (2005). The role of transportions in logistic chains. *Proceedings of the Eastern Asia Society for Transportation Studies*, 1657 - 1672.

Vakhshouri, S. (2011). Measuring the effect of political instability in middle East and North Africa on global energy security. *USAEE Working Paper No. 30*.

Vogels, W. (2019). *Amazon Web Services BrandVoice: Increasing Access to Blockchain and Ledger Databases*. Retrieved from Forbes: https://www.forbes.com/sites/amazonwebservices/2019/06/24/increasing-access-to-blockchain-and-ledger-databases

Weber, K., Schütz, A., Fertig, T., & Müller, N. H. (2020). Exploiting the Human Factor: Social Engineering Attacks on Cryptocurrency Users. *Learning and Collaboration Technologies. Human and Technology Ecosystems. HCII 2020* (pp. 650-668). Springer, Cham.

Weil, P., & Ross, J. W. (2004). *IT Governance, How Top Performers. Manage IT Decision Rights for Superior Results.*

Xu, J. J. (2016). Are blockchains immune to all malicious attacks? *Financial Innovation*.

Yang, X., Zhang, Y., Wang, S., Yu, B., Li, F., Li, Y., & Yan, W. (2020). LedgerDB: A Centralized Ledger Database for Universal Audit and Verification. *Proceedings of the VLDB Endowment*.

Yusuf, Y. Y., Gunasekaran, A., Musa, A., Dauda, M., El-Berishy, N. M., & Cang, S. (2014). A relational study of supply chain agility, competitiveness and business performance in the oil and gas industry. *Int. J. Production Economics*, *147*, 531-543.