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Blockchain in Supply Chain Management: A Review of the Capability Maturity Model

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Abstract. With the growing popularity of cryptocurrencies, Blockchain systems have found a new audience within the business environment. The decentralized ledger technology that allows the creation of verifiable transactions has extraordinary applications within business. In this paper the authors have attempted to identify the core benefits of using Blockchain technology to improve Supply Chain Management (SCM). With industry 4.0 transformation in its preliminary stages, a discussion on how Blockchain systems can benefit SCM is important. Like any other information system, Blockchain implementation is not just limited to infrastructure changes but also requires organisational wide changes to reap the benefits of the new system. The inherent technological issues associated with Blockchain are preventing many organizations from adopting Blockchain systems at a large scale. The authors have presented a model to guide the implementation of the Blockchain based systems using the industry accepted Capability Maturity Model (CMM) as the reference.

Keywords: Blockchain, Supply Chain Management, Capability Maturity Model, Information System Implementation.

1 Introduction

The Global Supply Chain Forum (GSCF) defines supply chain management as “the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders” [1]. Chief among the issues faced in supply chain management is the issue of business process links as they have a significant impact on the performance of the supply chain [1]. To achieve a truly integrated supply chain, commitment from all the members is essential.

To create an integrated supply chain, the buying organization has to invite its business partners into their organization. This goes beyond just sharing information about the products and requirements thereby including business partners into buying organization’s operational activities. This integration does come with a challenge since there is limited reciprocity from the business partners. The business partners are provided

extensive information about the inner workings of the buying organization while they can choose to remain firewalled. This is a unique problem since the objectives of both parties may not be always in line.

Additionally the creation of such an integrated supply chain often puts the buying organization at the risk of being held since there is an overwhelming reliance on the partners [2]. The sheer complexity of managing business partners through the entire supply chain is compounded by the limited willingness to create an integrated supply chain process [3].

The contemporary literature identifies various methods to implement and sustain an integrated supply chain. There is consensus that supply chain integration requires both managerial and technical solutions [4–6]. To improve the supply chain performance, contemporary organizations have been looking at technology driven solutions and they found varying amount of success.

Introduction of cyber-physical system in production and operations environment with the aim of interconnecting human beings and machines in a globally accessible network is referred to as “industry 4.0”. The technologies involved in industry 4.0 include “Advanced Robotics, Artificial Intelligence, Hi-Tech Sensors, Cloud Computing, Internet of Things (IoT), Data Capture and Analytics, Digital Fabrication, Mobile Devices, Software As A Service and Blockchain” [7]. Supply chain 4.0 is the application of the above mentioned technologies in SCM to improve performance and customer satisfaction [8].

Supply chain 4.0 creates a disruption in the traditional supply chain environment which requires organizations to radically rethink and redesign their business functions That leads to leads to potential cost reduction in various domains of supply chain (7,8). The supply chain 4.0 benefits have been achieved thus far on the traditional business intelligence infrastructure. The tradition infrastructure relies on centralized data repositories which connects all the partners of the supply chain. However centralized system could be easily manipulated by anyone rendering the data untrustworthy. With the use of Blockchain in an organization can create a decentralized platform for recording transactions that cannot be manipulated.

The supply chain 4.0 benefits have been achieved thus far on the traditional business intelligence infrastructure. The tradition infrastructure relies on centralized data repositories which connects all the partners of the supply chain. However, centralized system could be easily manipulated by anyone rendering the data untrustworthy. With the use of Blockchain in an organization can create a decentralized platform for recording transactions that cannot be manipulated.

There is also an issue of transparency which needs to be addressed. The question of “how much can I actually trust the information coming from my supply chain partner?” is a difficult question for any organization to answer. One of the solutions to such a conundrum is the use of modern technology such as Blockchain. The transparency that the Blockchain systems provide will enable organizations to improve the supply chain. Many organizations are now looking at Blockchain to ensure the validity of the information being shared across organizations. Recently Walmart had implemented Blockchain based systems in collaboration with IBM to track the movement of produce from Chinese farms to their shelves [9].

2 Blockchain Technology and Supply Chain Management

The last two decades of technological innovations in the area of peer-to-peer (P2P) networks and cryptography has led to the development of the Blockchain. The fundamental technological principle of Blockchain is the distributed, encrypted database, which cannot be reversed and is incorruptible. The following three technological concepts form the underpinnings of Blockchain technology; Decentralized Databases, Blockchain, Proof of Work/Stake [10]. Bitcoin was the first system to utilize the Blockchain data structure and has become the blueprint for future Blockchain implementations.

The starting point of the Blockchain is the concept of Distributed Ledger Technology in which each participant of the P2P network has access to a shared ledger. This provides a secure environment to perform transactions without relying on a third-party service provider [11]. Every transaction performed in the network uses public key encryption and digital signatures to validate the transaction.

The process of validation of the transaction is based on decentralized consensus. Instead of the traditional centralized consensus which was built based on database rules; authority and trust of ensuring validity of a transaction is moved to the decentralized network. Each node in the network is enabled to record transactions continuously and sequentially in a public "block" creating a unique "chain". Each successive block contains the unique fingerprint of the previous block in an encrypted format (hash). This combination of cryptography and Blockchain system removes the need for a centralized intermediary for authentication of transactions [12].

In order to ensure the validity of information being created by the nodes, Blockchain can use the network security protocol called "proof of work". This protocol essentially prevents attackers from creating transactions which are not authenticated. This protocol uses computational power from all the nodes to solve a complex mathematical function which serves as the prerequisite for the Proof of Work scheme. Proof of Stake scheme serves as an alternative to Proof of Work scheme which revolves around the entities that holds stake within the network. In certain conditions a hybrid of both the schemes can also be used to authenticate the transactions [10].

Contemporary literature is littered with examples of how Blockchain systems can be used to create a digital platform where authenticated transactions and records could be created [13]. We can classify the areas in which Blockchain has been implemented into 10 overall themes namely "Finance, Citizenship Services, Integrity Verification, E-Governance, IoT, Healthcare, Privacy & Security, Business, Education and Data management"[14]. The Estonian government has created a Blockchain based e-residency program [15]. In the Indian context, the Government of Andhra Pradesh has launched an ambitious scheme to use Blockchain technology to manage land records and streamlining vehicle registrations [16]. The impact of Blockchain technology on financial services industry beyond cryptocurrencies [17, 18]. Blockchain could modernize the utilities grid to create a new era of decentralized power [19]. The Blockchain based sharing services can benefit smart cities as well [20]. Blockchain can also be considered as a general-purpose technology i.e. it can be used to create a platform without a powerful intermediary wherein the privacy risk and censorship risk is drastically reduced

thereby reducing the cost of networking [21, 22]. In all the above examples, the traditional centralized intermediary based authentication is replaced with Blockchain. In all cases the authors have identified that the ability to create transaction which are authenticated increases the transparency of the transaction and the underlying service as well. In creating the transparency in transactional systems, the Blockchain has business value in record keeping of static information and maintaining a registry of tradeable information [23].

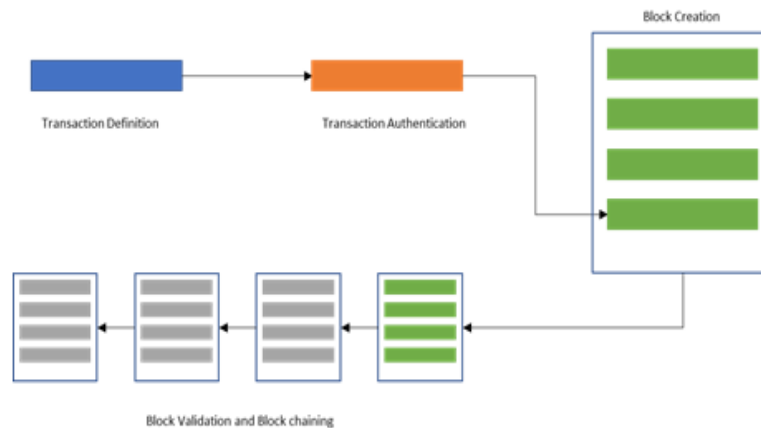


Fig. 1. Blockchain Process

The Blockchain based systems are able to ease paperwork processing, identify counterfeit products, facilitate origin tracking thereby transforming enterprise supply chains [24, 25]. The container logistics company A.P. Moller – Maersk is using a Blockchain based system to reduce the paperwork and associated cost for container shipment [26]. The Blockchain enabled supply chain have the potential to improve the strategic performance dimensions including Risk reduction, Sustainability and Flexibility [27, 28].

The following studies have shown the potential benefits of using Blockchain to improve supply chain management. The first study, explains the use of Blockchain system in Pharma supply chain [29]. In their work, the authors were able to present the case of a start-up that uses IoT sensor devices to leverage Blockchain technology to bring about the benefits of fraud detection and identity management. The second study, detailed the utilization and development of RFID based Blockchain system to build agri-food supply chain traceability [30]. A similar conceptual study was conducted that detailed how Blockchain system could be used to modernize the halal supply chain [31]. All three studies look into the different parts of the supply chain's transparency issue. The benefits of Blockchain technology are not limited to transparency alone but also include durability, immutability and process integrity [32]. For example, use of Blockchain makes it much more difficult for illicit or counterfeit products to enter an otherwise legitimate supply chain [33, 34]. Having a transparent supply chain enables an organization to plan better. In a typical supply chain, multiple parties are involved and this generates extensive amounts of documentation. Small error in the paper documents may

result in delays or hold up of payments. Blockchain eliminates this chance of an error thereby reducing the extra price of verification which is required for paper-based systems. Blockchain based systems can also reduce the procure-to-pay gaps with the use of smart contracts. This validated data storage provides organizations ability to create better data analysis platforms which can reduce the inventory cost by better forecasting.

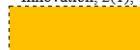
One of the critical challenges involved in the implementation of Blockchain systems is the cost. As discussed before Blockchain systems require complete overhaul ng of the IT infrastructure which is expensive [35]. The second challenge is with the technology itself; the network-based validation reduces the throughput of Blockchain transactions as well as latency. With the current setup of Blockchain achieving the performance parameters of centrally controlled systems is extremely difficult [36]. The regulatory uncertainty is definitely a challenge within the Indian context as the India Government has recently decided not to recognize cryptocurrencies which is based on Blockchain. The fact that Blockchain implementation involves multiple business partners is a barrier to the implementation of the project. Combined with the lack of acceptance within the industry driven primarily by the uncertainty of benefits makes the implementation project extremely challenging [24]. Even with these challenges the benefit of creating a transparent supply chain is pushing major players in the market to adopt Blockchain as a viable alternative to traditional information systems.

3 The Capability Maturity Model for implementing Blockchain

The Capability Maturity Model for Blockchain implementation has four categories and their corresponding maturity levels [37] and the authors have added a fifth category namely “Skills”.to the existing model.

	Initial (stage 1)	Repeatable (stage 2)	Defined (stage 3)	Managed (stage 4)	Optimizing (stage 5)
Network		Network load	Reliability	Network Design	
Information systems	<ul style="list-style-type: none"> Architecture Upgrading Integration 	<ul style="list-style-type: none"> Storage Scalability Maintenance 		Business Efficiency	Strategic convergence
Computing methodologies	Standardization	Computational anxiety			
Security and Privacy	<ul style="list-style-type: none"> Authentication Node Security 	Security Management System	Privacy	<ul style="list-style-type: none"> Data security Transaction security 	Enterprise security integration
Skills		Training and development	Competency Development	Competency Integration	Continuous capability improvement

Source: Adapted from Wang, H., Chen, K., & Xu, D. (2016). A maturity model for blockchain adoption. *Financial Innovation*, 2(1), 12.



Added by the authors to the existing model

Fig. 2. Capability Maturity Model for Blockchain implementation

First of the categories is network; with the Blockchain, organizations will have to transform their existing centralized networks to enable peer to peer communication. Additionally, along ensuring the reliability of the network and load management it is important to ensure that proper hybrid network is designed. It is impractical to replace the entire client- server architecture with the P2P architecture. So, while designing the network there should be synergy with the operations of the organization [38–40].

Second category is the information systems wherein both technical and managerial considerations are required. The chief among the technical considerations is the requirement of upgrading the infrastructure which includes the computer systems, interfaces and storage. There is also requirement that Blockchain system should not be standalone which requires extensive integration across the legacy systems. While considering adoption of Blockchain based information systems it's important for an organization to understand the business requirement. Therefore, the information technology strategy and organizational strategy should have a convergence as well[41–44].

Third category deals with the computing methodologies. With Blockchain, generating standards that are acceptable across companies is a challenge [35]. The computational complexity involved in managing a complex Blockchain is not just limited to the volume and the speed it extends to ensuring data accuracy as well.

Fourth category is the security and privacy. Using a public Blockchain would render confidential information at risk of exposure. The complexity of securing all the nodes in the network is also extensive [45–47]. Like any information system the security of the network is dependent on the security of each device [48]. At the same time a technological solutions alone are insufficient in creating a resilient environment therefore it requires an enterprise level integration of active, passive and recovery mechanisms [49].

Fifth category in the proposed model is Skills. With the complete redesign of the supply chain environment the employees within all the participating organizations have to develop new skills to leverage the benefits of Blockchain. Improved cross functional communication and leadership skills would strengthen the collaboration between the relevant parties and prepare the organization for the digital transformation which is required. CMM for People (P- CMM) created by the Software Engineering Institute of United States Carnegie Mellon university is designed to judge the maturity of enterprise human resource processes [50]. Using the P-CMM as a reference we have identified the maturity levels for the development of the skills required in implementing and maintaining Blockchain based systems. The starting stage is having the requisite training for employees and there after identifying the competencies required and thereby ensuring that competencies are mapped and continues improved [51]. The updated CMM for Blockchain with additional parameters is represented in Figure 2. For a successful implementation of Blockchain systems, organizations have to display maturity in all categories described above along with a clear business rationale for the implementation.

4 Discussion and future work

Digital transformation of the entire supply chain involves both high complexity as well as high novelty whereas single use systems require far less effort from the organizations

[52]. Blockchain Technology has value in business functions that have been struggling to create a system of recording and validating transactions without an intermediary. Blockchain based systems require an enterprise level transformation for a successful implementation. However, comparison between the approaches used in implementing Blockchain based systems and traditional approaches is challenging [53].

The number of organizations that have implemented Blockchain based systems is limited. Hence an empirical validation of the model will be challenging. However, a case study-based validation of the model may be considered. Also, the CMM proposed in the present study needs to be expanded to include the other management categories as well.

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