Inventory Visibility Scenario to Reduce Safety Stock in Supply Chain Network Using Blockchain Hyperledger Composer

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***Abstract*—Limited inventory visibility in supply chain networks increases stock levels and leads to negative consequences of stock repetition, bullwhip-effect, inventory backlog, and out of stock situations. It is essential to increase the inventory visibility and reduce the safety stock level to exchanged inventory data between supply chain stakeholders to achieve inventory accuracy and efficiency accordingly. This paper presents a technical implementation of inventory visibility scenario to reduce safety stock level in Blockchain-based supply chain network. The proposed inventory visibility scenario provides access to accurate and up to date inventory levels and reduces the safety stock level accordingly. The scenario implemented using Blockchain Hyperledger Composer and tested in Blockchain Hyperledger Composer Bluemix. In the performance evaluation, the inventory visibility scenario compared to Cloud-based and traditional supply chain models in terms of reducing the safety stock level. Scenario results show improved inventory visibility and significant reduction in inventory safety stock compared to other models. This reduction prevents negative consequences of stock repetition, bullwhip-effect, inventory backlog, and out of stock situations which helps in efficient inventory management and hence improves supply chain performance.**

Keywords—Supply Chain Management, Supply Chain Visibility, Blockchain, Smart Contact, Inventory Visibility

I. Introduction

It is widely agreed on the necessity of sharing inventory information within supply chain networks [1, 2]. As suppliers need to access an accurate and up to date inventory levels and sales information [3]. Inventory data are exchanged between supply chain stakeholders in a limited, delayed, and inefficient manner [4]. The importance of sharing inventory information came from preventing stock repetition, the out of stock situation [5], reducing total stock level [6], and stock cost [7]. Bullwhip-effect is another important consequence of limited inventory visibility [8]. Since un planed change in supply and demand leads to an in-accurate forecasting [9]. Moreover, product visibility and the ability to track products significantly reduce the inventory cost [7].

Current supply chain traditional information systems are able to track information from a single source and on an as-needed basis [10]. Nevertheless, the emergent technologies such as: Internet of Things (IoT), Radio Frequency Identification (RFID), NFC tags, and Electronic Data Interchange (EDI), ERP systems have some issues that deemed to be difficult to adopt which are: the implementation cost in RFID, and IoT infrastructure suitability for small scale industries [7]. It is fundamental for supply chain practitioners to adopt a new technology that exceeds other technologies in term of the limitations of the existing technologies. The author extensively reviews the potential and the most appropriate technology for the poor inventory visibility issue in supply chain. Arguably, it is largely agreed between academia and practitioners that the adoption of Blockchain technology is promising for information sharing and inventory visibility in supply chain [10-12].

Although number of studies addressed the importance of supply chain visibility (including inventory visibility) because it is necessary criteria for competitiveness [13], decision-making [10], performance improvement [2], there is a lack of common effective evaluation metrics to measure supply chain visibility [14, 15]. According to Caridi, Crippa [15],

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quantifying the visibility value is not completely satisfied in the literature. Since some authors in the literature emphasized on measuring the supply chain visibility by the ability of information sharing within the supply chain network. As information sharing provides the necessary access to key decision-making information such scholars as [2, 3, 6, 7, 16].
Another stream of visibility measurement work such as [17] pointed to the inventory visibility as a critical measure for supply chain visibility. Following the same stream with [2, 16, 18-20].
This paper presents a technical implementation of inventory visibility scenario to improve inventory visibility and reduce safety stock level in Blockchain-based supply chain network. The inventory visibility scenario provides access to accurate and up to date inventory levels and reduces the safety stock level accordingly. The scenario implemented using Blockchain Hyperledger Composer and tested in Blockchain Hyperledger Composer Bluemix.

The rest of this paper is organized as follows: section two reviews the extant literature of previous work in the area and motivation of research. Section three explains the design and implementation of the proposed scenario including the technical implementation of the inventory visibility scenario in Blockchain platform. Section four evaluates the performance of the proposed scenario. Finally, section five concludes with the summary of findings.

II. Previous Work and Motivation

Improving inventory visibility is necessary to reduce the safety stock level and the lead times accordingly [21]. The safety stock is the buffer stock that needs to be set up in case of demand uncertainty [22]. This additional inventory quantity "safety stock" is necessary to achieve higher service levels and inventory accuracy [11, 23]. Again, this is in turn leads to an accurate forecasts, demands and decision making process [19]. These factors encourage previous studies to address the limited inventory visibility in the literature. Diniz, Yamaguchi [24] implemented Blockchain in energy supply chain to improve inventory process of greenhouse in energy sector. Energy companies and certificate issuers' activities of buying and selling the purchased data were stored in the Blockchain network. The data declared in the Blockchain network was limited to emissions inventory accounting, data of electric power transactions, and certificates data sold in the market. Longo, Nicoletti [25] proposed a software connector module to link an Ethereum-like Blockchain to enterprise information systems to enable information sharing between supply chain partners. The system focused on sharing demand forecasts and inventory levels information using a simulation model for Blockchain information sharing and non-information sharing. The total costs and profit margin for each supply chain party using Blockchain was calculated; however, results showed that inventory position remained almost the same in Blockchain & non Blockchain scenario. The total cost of using Blockchain was also higher than the non-information sharing scenario. Madhwal and Panfilov [12] developed a decentralized and transparent network of supply chain for aircraft's manufacturing and distribution parts to reduce inventory and performance enhancement quality and proper flow of products in this chain. The model focused on aircraft parts traceability and authenticating aircraft's spare parts. In the inventory visibility, the model registered all details of the products during the production process.

Additionally, inventory visibility addressed in the literature using different approaches e.g. Cachon and Fisher [26] conducted a numerical study to compare the inventory holding cost and the penalty cost of back-orders. They compared the supply chain costs in the traditional information policy and full information policy. The study concluded with cutting lead times and batch size reductions for better inventory management. Kelle and Akbulut [18] proposed a multi-level cooperation framework to minimize the total supply chain system cost through coordinating the safety stock policy which result in cost saving. Duong, Wood [27] Identified the performance metrics of perishable and substitutable products. The study proposed a multi-echelon model to address the suitable inventory policy which enhances inventory management performance. Kim, Ryoo [3] proposed an inter-organizational information system (IOIS) that facilitates information visibility between buyer and supplier. The study argued that IOIS visibility is an influence of supply chain performance. While Zhang, Goh [17] assessed the inventory visibility using a theoretical model. With the ability of inventory visibility numerical measure which helps to improve efficiency and effectiveness of inventory decision making.

The present work is in line with previous studies that contributed to increase inventory visibility using different approaches [28-31]. Inventory visibility in the proposed HCSC-POS model is achieved by the ability to access, share, and manage key inventory information such as inventory levels and safety stock levels using an inventory visibility scenario implemented in Blockchain Hyperledger Composer platform.

III. Blockchain Hyperledger Composer

Blockchain is the core technology of Bitcoin which is a decentralized electronic peer-to-peer network payment system [32]. Blockchain technology is a distributed ledger technology that immutably stores transaction records into a form of chained blocks called Blockchain without the need of any third-party intermediary[33]. Recently, beyond the Bitcoin, this emerging technology is used in many sectors such as in food manufacturing [34], environmental solution [35], energy sector [36] and supply chain [37]. Moreover, in the last few years Blockchain technology has been utilized for non-financial applications [38]. According to Linux Foundation definition, Hyperledger is one of the projects that are run by the Linux Foundation [39]. Hyperledger is an ideal platform to develop Blockchain applications. As it is an open-source platform, rapidly developing and easy to design user-defined chain code

or “smart contracts”. Hyperledger consists of many projects such as Hyperledger Fabric, Hyperledger Sawtooth, Hyperledger Indy, and Hyperledger Composer.
According to the Linux Foundation definition, Hyperledger composer is a one of Hyperledger projects that aims to build Blockchain business networks and develop Blockchain applications in a decentralized ledger platform [39]. Hyperledger Composer is built with JavaScript programming language and consists of modern development tools to build business-centric Blockchain solutions. The key concepts in Hyperledger Composer are: Blockchain State Storage, Connection Profiles, Assets, Participants, Identities, Business Network cards, Transactions, Queries, Events, Access Control, Historian registry.

The Blockchain state storage in Hyperledger composer is the Blockchain state database that stores the current state of the business network components such as participants and assets. The Blockchain uses a consensus mechanism to ensure the same copy of updated ledger and state database among all network peers. The Hyperledger Composer identifies the network participants with identities. Each identity is a digital certificate with a private key that is stored in a business network card. Using the business network cards concept, the network participants are able to connect to a business network in the Hyperledger Fabric runtime. Additionally, business network cards contain the connection profile, identity, and metadata of the business network that is a certain participant is connected to. Transaction, events and queries are defined in the business network definition file. Transactions are the mean of communication between the participants and assets. Events are emitted transactions to show that certain change or update happened in the ledger. While queries are used to retrieve data from the Blockchain network. The access control rules govern the access control of the participants and assets in the business network. The final key concept in Hyperledger Composer is the historian registry. It is a registry that contains the successful transactions records in addition to the participants identities. Generally, the Hyperledger Composer platform is shown in Figure 1.

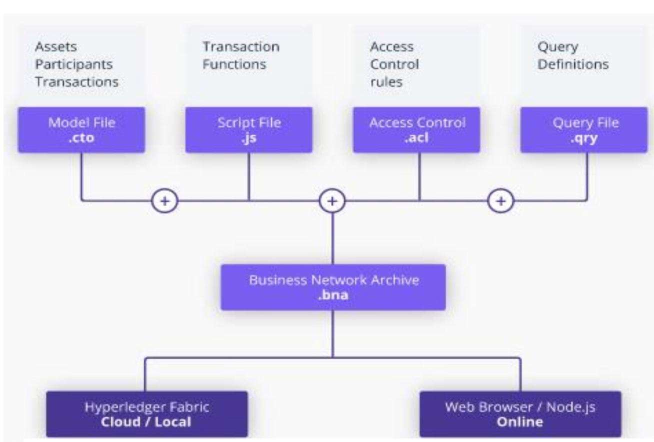

Fig. 1. The Hyperledger Composer platform [40]

The Hyperledger Composer platform is used to identify a business network definition. To model this definition, the business network archive (*.bna) file is generated. This file contains the general files of definitions of the network which are:

- Script file (*js)
- Access control file (.acl)
- Query definition file (*qry)

As shown in Figure 1, the model file (*.cto) contains the assets, participants, transactions, events definitions. While the script file contains the transaction functions (*js). The access control file (.acl) to gain control over participants, assets and certain conditions to assign ownerships and perform different transactions. Other definition files include a query definition file (*qry) which is used to return data about the Blockchain world-state. All the above-mentioned definitions are packed and exported as (.bna) file ready for deployment in Hyperledger Fabric platform.

IV. PROCESS DESIGN AND IMPLEMENTATION

The proposed Inventory visibility scenario provides the ability to share key inventory information such as current inventory levels and safety stock levels. The scenario is part of Blockchain network that consists of four-echelon supply chain trading participants:(Supplier, Manufacturer, Distributor, Retailer) and Customer connected in a permissioned distributed immutable Blockchain ledger and trading on a single product “Commodity”. The Blockchain network components are: (Participant, Asset, Transaction, Event) where:

- Participant: Supplier Manufacturer Distributor Retailer Customer
- Asset: Commodity
- Transaction: viewStock
- Event: 'TrackOrders'

Herein, transaction `ViewStock` calculates and determine the safety stock level of the product in Hyperledger Composer platform. The safety stock is calculated based on the standard safety stocks equation in supply chain inventory theory in [41-44]:

$$SafetyStock = (MaximumDailyUsage \times MaximumLeadTime) - (AverageDailyUsage \times AverageLeadTime) \quad (1)$$

Where: Maximum daily usage is the maximum sales of the product per day. Maximum lead time in days: the maximum time needed for the product to be made and shipped. Average daily usage: the product units been sold per day. Average lead time in days: the time needed for the product to be made and shipped.

The transaction compares safety stock value with stock quantity. If the safety stock level is reached, the transaction automatically notifies the user of reaching safety stock level to place a purchase order for the specified product. Accordingly, the product ownership will be changed to the new owner of the product. The inventory visibility scenario is implemented in Hyperledger Composer using industrial data set that is collected from manufacturing industry located in Sudan. This manufacturing industry was selected based on contacting results with three supply chain industrial experts in the supply chain market. The implementation of the inventory visibility scenario is as follows: Retailer `Loc_R1_0042010` queries the Blockchain about the available stock quantity of product Tweety. Using its tradingSymbol: `M1_TweetyTBC_001`. Transaction ViewStock in Hyperledger Composer calculates the safety stock level of product `M1_TweetyTBC_001` in retailer `Loc_R1_0042010` stock based on `DailySalesUnits, leadtime`, values in the data set as following:

TABLE I. THE SAFETY STOCK PARAMETERS

Retailer Loc_R1_0042010	**Min**	**Max**	**Average**
DailySalesUnits	5000	10000	7500
leadtime	5	8	6.5
DailySalesUnits* leadtime		80000	48750
Safety Stock	**31.250**		

Therefore, the safety stock level is calculated in Hyperledger Composer by the equation:

$$SafetyStock=(10.000*8) - (7500*6.5) = (80000-48750) = 31.250\ unit \quad (2)$$

As shown in Figure 2 and as a result of submitting transaction ViewStock:

- Calculates the safety stock (SafetyStock = 31.250 units).
- Compare product quantity with SafetyStock:
- if (trade.Product.quantity<SafetyStock)
- The condition is TRUE as the current quantity of product M1_TweetyTBC_001 in retailer Loc_R1_0042010 stock is 20.000 units, since (20.000<=31.250) THEN {
- Emit event StockLevels, and notify the product owner by notification message: "Product quantity is less than the safety stock levels ".
- Place purchase order no:PO_002 for product M1_TweetyTBC_001.
- Otherwise, if (trade.Product.quantity>SafetyStock), notification message: "Product quantity within safety stock levels ".

Fig. 2. Product `M1_TweetyTBC_001` quantity is less than safety stock levels

A purchase order no:`PO_002` should be placed for product `M1_TweetyTBC_001`. As manufacturer `M1_001200` is the owner of product Tweety, manufacturer `M1_001200` transfers product `M1_TweetyTBC_001` ownership to retailer `Loc_R1_0042010`.

V. PERFORMANCE EVALUATION

In terms of safety stock levels reduction, the proposed HCSC-POS model exceeds the Cloud, and Traditional model in [29] in terms of reducing the safety stock levels. The safety stock in HCSC-POS model is 0.4746 units when the average daily sales units are 10.05 and the average lead time is 0.02 which is less units compared to the Cloud model safety stock 21.205 units and 52.895 units for the traditional model. This reduction in safety stock units in HCSC-POS model is due to the big reduction in the lead time in the proposed HCSC-POS using Blockchain technology. Lead time in HCSC-POS model is the time between initiating a purchase order and confirming the order in the Blockchain network. Therefore, the lead time is calculated by the time of submitting and committing the purchase order transaction which is approximately equals to 40 minutes. The average delay time in HCSC-POS model is 25 minutes which equals to 0.02 from the day. Therefore, using this value of average lead time (0.02) in HCSC-POS model leads to significant reduction in safety stock units. This means that using HCSC-POS model the safety stock is reduced to less than one unit. Table 2 shows the safety stock levels calculations in each model. While Figure 3 depicts the safety stock levels and its related parameters.

TABLE 2. THE SAFETY STOCK LEVELS IN HCSC-POS MODEL, CLOUD, AND TRADITIONAL MODEL

	Max Daily Sales	Average DS	Max Lead Time	Average LT	Safety Stock
HCSC-POS	22.52	10.05	0.03	0.02	0.4746
Cloud	22.52	10.06	1.5	1.25	21.205
Traditional	22.52	10.05	4	3.7	52.895

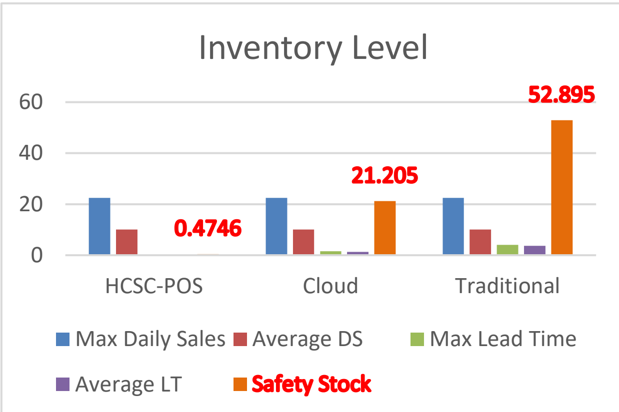

Fig. 3. Comparison of inventory levels in HCSC-POS model, Cloud, and Traditional model

VI. CONCLUSION

Blockchain technology enhances the inventory visibility in supply chain networks by the availability of accurate, up-to-date inventory information to all Blockchain network participants. Inventory visibility is achieved by exchanging inventory data between supply chain stakeholders and the availability of inventory data. Since limited inventory visibility in supply chain networks increases stock levels, lead times and leads to higher stock cost, using Blockchain technology helps in reducing the safety stock level, lead times, and inventory cost accordingly. Improving these features lead to efficient inventory management and improving performance in the supply chain network. This paper presents a technical implementation of inventory visibility scenario to improve inventory visibility and reduce safety stock level in Blockchain-based supply chain network. The inventory visibility scenario provides access to an accurate and up to date inventory levels, comparison of current quantity in stock with the safety stock level. The scenarios implemented and tested in the Blockchain platform Hyperledger Composer. The performance evaluation of the scenario compares the scenario to Cloud-based, and Traditional models and shows proven reduction in safety stock level, efficiency in inventory management, and hence, performance enhancement. The inventory visibility shows significant reduction in the safety stock in the supply chain network using Blockchain technology, however, the proposed scenario is limited to stocks of four-echelon supply chain network. Future research may incorporate more complex and multiple tiers of supply chain networks in multiple industries to implement the proposed safety stock reduction scenario.

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