Blockchain Framework for Textile Supply Chain Management

Improving Transparency, Traceability, and Quality

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Abstract. Modern textile supply chain systems are both large and complicated, with global sources and suppliers feeding into production lines that can span continents. A substantial amount of defects can't be directly traced back to defective batches that entered the supply chain along the way, causing waste and frustration downstream. Traceability is almost impossible due to the number of stages the product goes through and the size of data involved. No single system is globally utilized to record and trace the product throughout the supply chain. By the time the root cause of the issue is discovered, no recourse is possible except to discard the end product, resulting in losses that could reach 40% of the end product value. Communicating quality issues cross-stream is virtually nonexistent due to the challenges in identifying the source and recognizing that the other systems can deal with utilizing it. While traceability is an obvious problem in textile supply chain, transparency is a more impactful issue that is not well addressed. Cross supply chain and lack of transparency exacerbates the problems facing each participant and forces each entity to work locally using the localized information. This approach is fundamentally flawed as it deals with a global problem from a localized point of view. Not all industries are ripe for taking advantage of blockchain technology. Blockchain requires an industry with a complicated and widely distributed supply chain, containing an increased number of middle stages. This cannot apply more than in one of the world's oldest industries, textile.

In this paper, we propose a complete blockchain-based framework for textile quality improvement that enables in near real time, cross chain information sharing with guaranteed authenticity and accuracy allowing quality defective batches to be identified in all systems as soon as they are detected in any few.

Keywords: Blockchain · Supply chain · Textile · Garment chain

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1 Introduction

To have an appreciation of the problem we are addressing, we need first to visit the current status in the textile industry and then provide an understanding of what blockchain technology is.

1.1 Textile Quality

In the textile industry, the low-cost players have forced many manufacturers to compromise on quality to be more cost competitive in the face of global competition. Currently, due to the inefficient quality monitoring systems, the cost of poor quality is at an average of 14% of sales for textile and apparel industries versus to other industries (6.5%) [1]. Several papers [4,6] attained the quality of various products flow in the textile production chain. The evaluation of the quality control principles through the application of statistical quality control, statistical processes control, total quality control, total quality management and Six Sigma are static systems. The dynamic quality control system was suggested but not fully developed.

Traditionally, high variability has been known to result in a substantial loss due to the existence of several nonconforming units in a highly variable process [22]. The On Line Quality Control System comprises with the raw material quality control and process. Control is the target for controlling the level of the quality in the production line [11,17]. Despite the advancements in technology and production-monitoring systems, these quality requirements seem to be a distant task as on-line systems for monitoring the quality of material at different stages of processing have not yet received due importance. One of the key issues for failure that has been identified is the incongruent application of current static control systems in the complex textile production environment [9,18,21,22].

The quality of the final product is a function of the qualities of the sub product that accommodate the complex, dynamic and interactive nature of the textile production environment. Consequently, the single stage control algorithms usually lead to loss of production, material and profit. It was revealed that the total quality of a product is a dynamical function and depends on the transfer function of the sequential process involved in its production [8,21]. To solve this problem, several attempts were successfully made to measure the quality parameters on line, such as trash %, number of neps, sliver evenness, yarn evenness, and real-time fabric inspection [3,4]. Thus, there is a need and requirement for development of new methods for modeling and automated monitoring of key parameters in the textile processing industry to optimize quality of the product, which consequently will improve profits.

1.2 Textile Supply Chain

We can view the textile supply chain in a simple view consisting of two main activities:

Primary Activities. Inbound Logistics - involve relationships with the suppliers and include all the activities required to receive, store, and disseminate inputs. Operations - are all the activities required to transform inputs into outputs (products and services). Outbound Logistics - consist of all the activities required to collect, store, and distribute the output. Marketing and Sales - activities inform buyers about products and services, induce buyers to purchase them, and facilitate their purchase. Service - includes all the activities required to keep the product or service working effectively for the buyer after it is sold and delivered.

Secondary Activities. Procurement - is the acquisition of inputs, or resources, for the firm. Human Resource Management - consists of all the activities involved in recruiting, hiring, training, developing, compensating and (if necessary) dismissing or laying off personnel. Technological Development - pertains to the equipment, hardware, software, procedures and technical knowledge brought to bear in the firm's transformation of inputs into outputs. Infrastructure - serves the company's needs and ties its various parts together. It consists of functions or departments, such as accounting, legal, finance, planning, public affairs, government relations, quality assurance and general management.

Raw Material. The ability to have full transparency into the raw material is critical and can lead to huge impact such as in the case with false advertisement. A case point is that in the week since Indian textile maker Welspun was called out by Target for mislabeling sheets and pillow cases as premium Egyptian cotton products, the company's shares have collapsed. While Target has severed all ties and Walmart and J.C. Penney have announced their own reviews, Bed Bath & Beyond has appointed an independent auditor. A year ago, Welspun, one of the world's largest manufacturers of home textiles, was boasting of a durable competitive advantage over Chinese rivals. The latter, it claimed, had higher labor costs and were dependent on stockpiled Chinese fiber, which tended to lint.

Manufacturing. Communication and coordination are vital in streamlining goals and ensuring timelines are met. Effective coordination will result into successful and smooth order processing. Generally, it has been seen that shipment delay is only the result of poor coordination of merchandisers with another department. Factory buyers largely depend on factory merchandisers. By increasing knowledge sharing, communicating best practices and developing functional coordination platforms, merchandisers can place themselves in a better position to create plans and execute the same as per requirements.

Garments. The dictionary definition of garment is "an article of clothing", however, from a textiles supply chain point of view, garments are the end product of a very long and complicated process. The quality of a single finished garment depends on several quilts of subproducts and materials. This made the second quality and waste in each sector depend on the previous processes [1,11]. Huge efforts and cost are spent on the inspection of the quality of the product in the textile chain, which started with the raw material and is finished by the final garment product. For example, the garment industry inspected all the fabric imported and number of defects which are visually inspected before the purchase. Defect assessment is conducted on between 10%–50% of the produced products where visible flaws such as stains, stitching, incorrect color variations, patterns, sizes, and poor alignment, etc., are tested.

The American Apparel Manufacturers (AAMA) point-grading system for determining fabric quality is the most recommended fabric inspection [13]. The work presented in [14] provides a good example of the garment value chain structure as shown in Fig. 1, demonstrating complicated relations between the different elements of supply chain with each of them having their own quality control system on their product which reacts on the final quality of the final garment [12]. The cost of the quality control in the garment industry varies from 11% up to 39%.

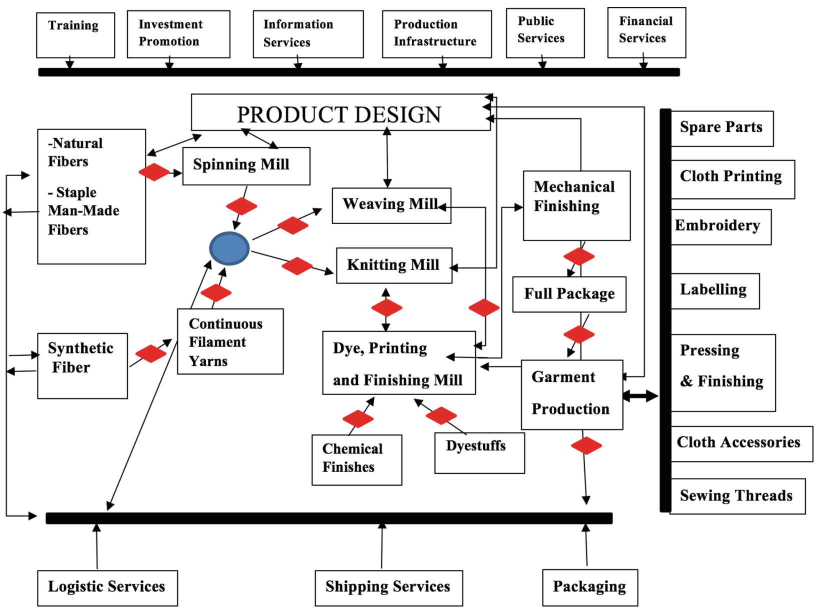

Fig. 1. The garment chain structure.

Fashion. Fighting fake is not the only benefit that blockchain technology can offer the fashion world, it also gives consumers and brands the opportunity to track and display supply chain information [10]. Making this possible is a company called Provenance. They have used blockchain to build a traceability data system that will securely store information that is inherently auditable, unchangeable and open. Their objective is to work towards an open traceability protocol that allows them to tell every product's story using blockchain technology in a way that enables secure traceability of certifications and other information in the supply chains. It answers the question, where does my product come from? As one of the new emerging technologies, blockchain technology is empowering brands to take steps towards greater transparency. Should you ever want to trace the origins, footprint and histories of that cute dress you have your eye on, then blockchain technology will be able to tell you the product's story which leaves us wondering, is fashion ready to be that honest and transparent? They do this by making sure that every physical product comes with a "digital passport" that not only proves the product's authenticity, but also creates an auditable record of the journey the product took. The quality data hub in various points of the quality chain has several types of data about the sub product.

1.3 Blockchain

Blockchain technology is a form of an encrypted distributed ledger, essentially a distributed database of records, or public ledger of all transactions that are shared among participating parties [5,24].

Consensus of a majority of the participants in the system is the main mechanism by which each transaction in the public ledger is verified. Once the transaction is deemed verified, it is then admitted to all the records and can never be erased. The verified transactions are put in a queue to be committed to the next block. The data is secured using a hash function which is any function that can be used to map data of arbitrary size to data of fixed size, more formally defined by Eq. 1, where H is the hash and n is number of bits returned by the hashing function [15].

$$H : K \times M \rightarrow \{0,1\}^n \tag{1}$$

A block consists of the following main parts:

Payload, which contains the actual data to be committed to the blockchain.
Previous Block Hash, the digital fingerprint of the previous block.
Current Block Hash, the current digital fingerprint of the current block payload and the previous block hash.

The main concept of the blockchain can be illustrated in Fig. 2.

The transactions can be traced back to the original first block, commonly called the genesis block. The genesis block is the only block that does not reference an actual previous block hash. Blockchain contains a certain and verifiable record of every single transaction ever made. The first example of a widely used blockchain application is Bitcoin, the decentralized peer-to-peer digital currency. The central hypothesis is that the blockchain provides a system of a distributed consensus in the digital universe, removing the need for trust and transferring it

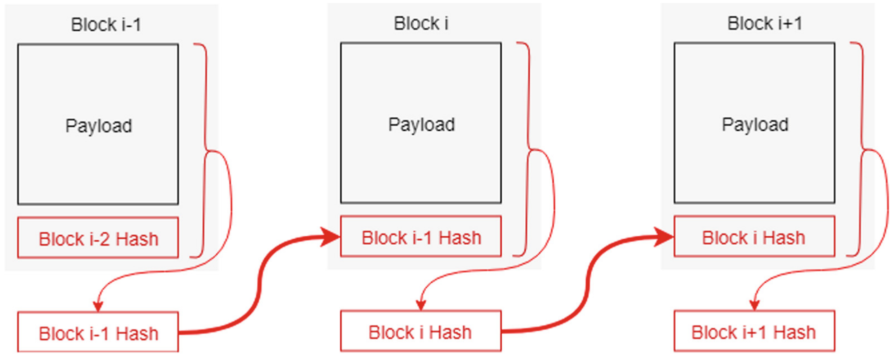

Fig. 2. Conceptual illustration of the blockchain.

to a binding contract, which assures the users that a digital event occurred by creating an irrefutable record in a public ledger [23].

The blockchain can be viewed as a global computing machine with near 100% uptime due to the fact that the contents of the database and ledger are copied across thousands of computers. Thus in case of 99% of the computers running it were taken offline, the records would remain accessible and the network could rebuild itself. The distributed nature of the blockchain also means that a local copy can exist at or near the user. This is a very important practical consideration as many of the textile facilities are located in developing countries with very limited bandwidth. Having a local copy that auto updates reduces potential failure due to Internet bandwidth.

The central feature of the blockchain technology is an immutable ledger [19]. Immutable means that the contents of the payload of each block cannot be changed after it is committed to the chain. This is due to the fact that each block hash is computed based on the payload of the block and the hash of the previous block as shown in Fig. 2. If we want to tamper with block i, we will need to recompute the hash of block i. That will require us to recompute the hash of every and all subsequent blocks as changing one hash will invalidate all subsequent hashes. Now, because the ledger is distributed, we will need to gain control and change the hashes of at least 51% of the entire network. The sheer amount of required effort renders it practically impossible. One model of understanding blockchain is through comparing it to the new application layer for Internet protocols because blockchain can enable both immediate and long-term economic transactions, and more complicated financial contracts. It can be a layer for transactions of different types of assets, currency or financial contracts. Moreover, a registry and inventory system for recording, tracking, monitoring, and transacting of all assets could be managed with blockchain. Consequently, blockchain can be used for any form of asset, including every area of finance, economics, and money [16].

1.4 Blockchain in Textiles

There are many benefits of blockchain. Yet, there is little to no adoption of blockchain technology in the textiles supply chain domain. Blockchain technology presents many features and characteristics that can be useful in textile industry aspects such as: compliance, transparency, tracking, tracing, error reduction, payment processing, and many others [20]. IBM has revealed its intention to lead an "industry-wide collaboration" to create a supply chain and trading ecosystem built on IBM blockchain technology. It will use the Hyperledger Fabric, which provides a foundation for developing blockchain solutions with a modular architecture, pluggable implementations and so-called container technology. There are numerous organizations, processes, systems, and transactions involved from field to fabric. Located at the intersection of agriculture, finance and technology, the Seam with the help of IBM, is in a unique position to introduce blockchain technology to cotton-affiliated companies around the world. In conjunction with IBM, the Seam wishes to create a supply chain and trading ecosystem built on IBM blockchain using the hyperledger fabric. This new technology will be transformational for the cotton industry. There are numerous organizations, processes, systems and transactions involved from field to fabric. The Seam and IBM launched the first cotton industry blockchain consortium.

2 Problem Statement

The problem we address in this work is as wide as it is deep. It deals with an industry that has been in existence for as long as humans started coexisting in large groups. In the following sections, we will go over the main aspects of the problem in the textiles supply chain.

Transparency. The textiles and clothing sectors are a supply chain consisting of many discrete activities as shown in Fig. 3. It is being organized as an integrated production network where the production is sliced into specialized activities and each activity is located where it can contribute the most to the value of the product.

When the location decision of each activity is being made, costs, quality, reliability of delivery, access to quality inputs and transport and transaction costs are important variables. Walmart insisted that suppliers implement information technologies for exchange of sales data and adopt standards for product labeling and methods of material handling. This ensures quick replenishment of apparel, which in turn allows the retailer to offer a broad variety of fashion clothes without holding a large inventory. This approach has spread throughout the industry in the United States as well as elsewhere (and to other industries), shifting the competitive advantage of suppliers from being mainly a question of production costs to becoming a question of costs in combination with lead time and flexibility and quality.

The number of the suppliers in any industrial product increased almost exponentially throughout the chain, which means that the reality of an organization being able to control all aspects and impacts of its supply chain is a goal rather than a certainty. Figure 3 shows that the reality of tracking and influencing suppliers was clearly articulated. This required high transparency throughout the supply chain. Consequently, the success of the enterprise depends on the transparency and the trust between the suppliers within the enterprise.

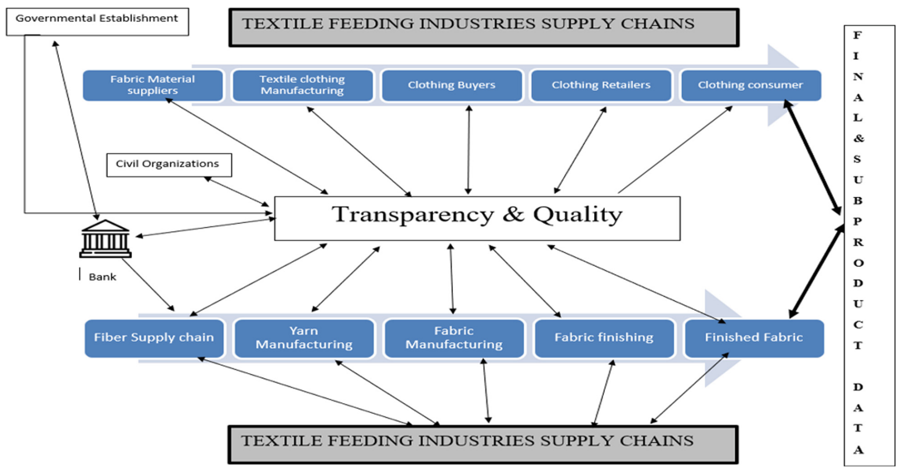

Fig. 3. Conceptual illustration of the textile supply chain.

The results of these long chains, the time required for quick response of the market demands and the cost increased tremendously with instability of the product quality.

We know surprisingly little about most of the products we use every day. Even before reaching the end consumer, goods travel through an often-vast network of retailers, distributors, transporters, storage facilities, and suppliers that participate in design, production, delivery, and sales, yet in almost every case, these journeys remain an unseen dimension of our possessions. The supply chain sector represents billions of dollars in enterprise revenue but is fraught with losses and inefficiencies resulting from risk, fraud or anachronistic manual paperwork delays. The main challenge is setting up technology for farmers, field workers and others to collect data and insert it onto a blockchain. Innovative data entry tools running on ubiquitous smartphones, with backends in the cloud, are expected to allow field workers to input relevant data to a blockchain ledger that tracks all data, making it accessible "in minutes, rather than days", thereby improving supply chain efficiency, identifying bottlenecks and reducing waste.

The bales of cotton arriving at the port and being scanned automatically trigger the smart contract to execute the terms, which would involve transferring the ownership of goods and authorizing payment. This happens because there is a single document agreed on by all parties and that is only completed once a certain action has taken place.

Traceability. Traceability has recently gained considerable attention in the textile industry. Traceability stands for information sharing about a product including the history, specification, and location. With the involvement of globally dispersed actors in the textile supply chain, ensuring appropriate product quality with timely supplies is crucial for surviving in this industry with ever increasing competition.

Quality. Quality is one of the main cost factors in the textile industry. As manufacturers face an increasingly competitive global business environment, they seek opportunities to reduce production costs without negatively affecting product yield or quality. Rising quality requirements are driving up costs and decreasing value added at the plant. The supply chain of the textile product is completed with involvement of worldwide distributer supplier chains as shown in Fig. 6 textile supply chain. The high percentage of quality control cost is related to lack of data about the subproduct and material and processing defects either in the previous operations or in processes defects. All the applied quality control management systems suffer from: late detection of defects, higher cost of defective work, poor access to previous production supervision, second quality being higher, more manpower to maintain quality, and higher manufacturing costs.

One of the early works that related information impacted on the product quality is outlined in [7], where the authors show that in the textile field, the quality of the final product is normally affected by different material and production parameters. They propose a matrix representation of each production process input and required information as well as the importance of the information for the production process. In the case of garments, it is established that the garment quality is determined by different fabric characteristics such as fabric defects, yarn hairiness, color shades variations, sewing defect, etc. Consider n quality characteristics of a certain process, defined as $Y_i (i = 1\, to\, n)$, each Y_i value may be affected by m data value of the previous process parameters defined as $X_j, (j = 1\, to\, m)$. The introduction of the entire set of values of the previous process parameters to predict the entire set of garment characteristics is very complex. Therefore, the identification of the main data affecting the investigated set of Y_i value characteristics would be very useful. To perform this task, a matrix $A(mxn)$ is formed with the variables X_j which are expected to affect properties Y_i. Each coefficient a_i, j will be equal either to 1 when the corresponding parameter X_j is expected to have an effect on the corresponding garment characteristic Y_i or to zero when no effect is to be expected. Matrix $B(n * 1)$ defines the set of yarn characteristics to be predicted. The multiplication of the two matrices (AxB) gives a new matrix C. For the values $c_j > 0$ the corresponding data X_j should be taken as an input data required for this particular process.

The larger the positive value of c_j is, the more significant the effect of the corresponding value X_j is expected to be. The matrices are used to predict the impact on quality of the different required data that defines the quality. In more complex systems, the impact of each information would be adjusted using a learned model [2] (Fig. 4).

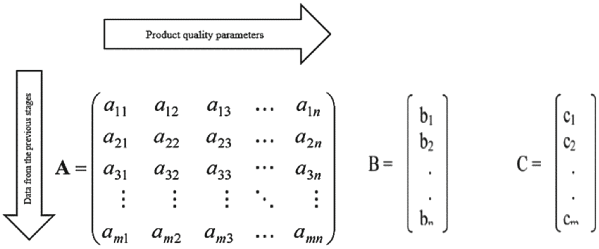

Fig. 4. Matrices used for the presentation and selection of input parameters from one stage to the next.

3 Proposed Framework

Our proposed framework works by adding textile materials information to the blockchain at each point along the supply chain journey. Each atomic unit of raw material will be uniquely identified, as illustrated in Fig. 5. The process starts at the farm with identifying the seeds used. The resulting crop bales will be given a unique number as the first component in the manufacturing process. As raw materials are used in each manufacturing process, the resultant product will be recorded as a transaction on the blockchain. The transactions can identify the processes and machinery used and be traced to the previous manufacturing stage. Each machine or manufacturing unit can be connected directly to the blockchain and is capable of reading previously recorded data pertaining to the material which the manufacturer has acquired. The machinery can update new information regarding only to the material that has been acquired by the manufacturer. Before the machine starts processing the material, the machine would check the reported history by confirmed owners of the same material batch. After processing the material, the machine would automatically post the results to the blockchain. A consensus mechanism is used to evaluate when to flag a batch with a defect.

The framework allows the machine to utilize the information shared by others to automatically stop processing the material and require human override. The proposed framework work flow is illustrated in Fig. 6.

3.1 Machine Chain Interface

One critical change required to enable the framework is to upgrade the current machinery so that it can interface with the blockchain. Most modern textile

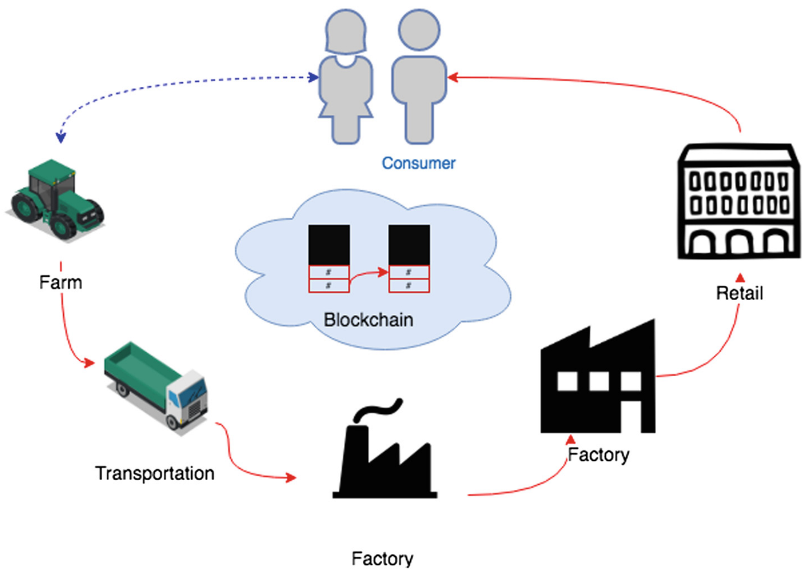

Fig. 5. Matrices used for the presentation and selection of input parameters from one stage to the next.

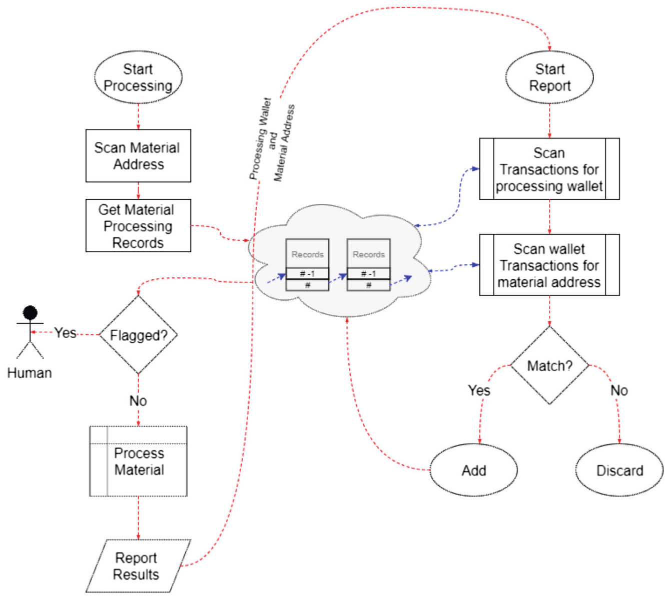

Fig. 6. The proposed framework work flow.

machines are equipped with sensors that can communicate measurement back and allow remote control. The fundamental difference in our model is that each machine will be identified by a wallet in addition to the existing identifier. Using a wallet will enable the chain to track incoming material and the processed output. In addition, due to the ledger architecture, the material will have to be traced back to the initial creation wallet.

3.2 Material Creation

The first step in the framework is to create the material. Only certain actors such as farms and fiber manufacturers would be able to create new materials and record them on the chain. Once the material is created, all the properties are committed to the chain. This way, the material is traceable back to this genesis wallet.

3.3 Manufacturing

The process of manufacturing is mapped to the chain by adding a manufacturer role. A manufacturer can record the purchase of a certain batch of material in conjunction with the material creator. This is represented by a transaction of the material portion. The transaction can be of the entire or partial batch. Once the material is transferred on the chain from the creator to the manufacturer, the manufacturer is now able to record the material processing results. This is a fundamental step in the framework to prevent bad actors from destroying the credibility of competitors. The network will only accept reports from those that have been recorded on the chain to own the material.

3.4 Reporting and Consensus

Any network participant has full access to the entire network. The information is publicly accessible. However, only material owners can report on the processing results of the material. A consensus mechanism requiring certain criteria to be fulfilled before the material is flagged on the chain. The consensus is a critical component to remove errors and outliers from the chain. An example of consensus criteria can be:

- Same material batch
- Similar manufacturing process
- Minimum number of reports
- Defined time in which the reports are recorded.

3.5 Automated Protection

Usually, the action to correct the fault in the textile chain takes place after it occurs. Through the introduction of the concept of automated protection, if the equipment queries the chain to find that the batch about to process is flagged as a bad batch for this process, the equipment will halt the process and notify the attendant to make a decision based on the provided chain data.

4 Evaluation

It is clear that from a traceability and transparency point of view, our proposed workframe provides capabilities that do not exist in the current status quo. To evaluate our proposed workframe from the quality point of view, we need to take into consideration the potential cost waste due to the degradation in product quality as a function of information quality.

We build on the approach proposed in [7] by extending it to different stages in the supply chain as illustrated in Fig. 7. The impact at each stage is computed and then combined with the following stage as shown in Eq. 2.

Fig. 7. Abstract representation of textiles supply chain stages.

$$\text{Quality Impact} = 1 - \prod_{i=1}^{i=n} \left(\frac{Si_i}{Ai_i} \right) \tag{2}$$

where i is the current stage, n the total number of supply chain stages, Si_i the shared information at stage i, while Ai_i is the available information at stage i. Figure 8.

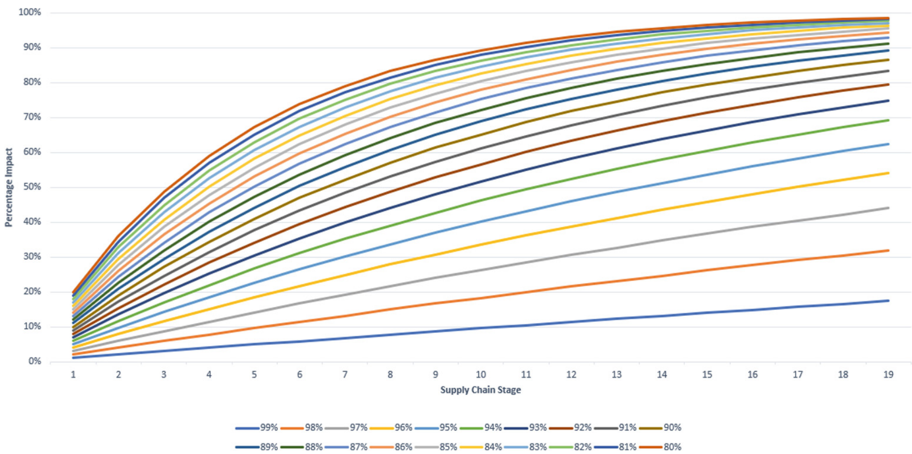

Fig. 8. Potential impact of supply chain stage information on quality.

At every stage, the missing information affects not only the current stage quality, but also the subsequent stages down stream. Our simulation shows that missing information can greatly affect the overall quality of the entire process. Just missing consistently on 20% throughout the supply chain can lead to more than 98% quality degradation by the 10^{th} stage. In contrast, we mapped the information flow in a local garment production line, then assured that all required fabric information is provided in every stage. We observed that second quality products dropped by 26.5%.

5 Conclusion

Most agroindustry corporations believe new technologies of blockchain will be transformational for the cotton industry by making it easier and more secure to trade the commodity. In this work, we proposed a novel approach to solve a huge problem in the textiles supply chain. We presented how this approach will interact with the current status quo and how it will lead to massive improvement in the traceability, transparency and quality of the textile production and end product. Our work combines one of the oldest technologies known to man with the latest cutting edge one. In our further research, we will explore exact parameters for this approach to be adopted as well as the impact on the end user, consumer, and how it can change the social sensibilities of the consumer.

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