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USE OF BLOCK CHAIN IN THE INFORMAL DISTRIBUTED MANUFACTURING INDUSTRY IN KENYA

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Declaration

This research project report is my original work and has not been presented for a degree in any other University.

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This research project report has been submitted for examination with my approval as the University supervisor.

Supervisor Signature: _______________ Date: _____________________

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Abstract

In the last decade, research and development around distributed ledger technology (DLT) has grown exponentially. The financial services industry has been revolutionised by the explosion of cryptocurrencies like Bitcoin and Ethereum. Researchers have taken the principles used in these cryptocurrencies and are using them to develop other DLTs in various fields. This study explores how blockchain can be used to provide traceability, visibility and transparency in the Kenyan informal distributed manufacturing industry.

SOKO, an aggregator of artisans spread all over Nairobi, was the case study used. Purposive and convenience based were the sampling methods used. SOKO supply chain employees and active artisans were the sample population. Interviews and observations were data collection methods used. Content analysis, a qualitative data analysis method, was used to capture emerging and predetermined themes. Google sheets and Dovetail were the tools used for this study.

This paper finds that the use of the immutability and proof of origin features of blockchain greatly enhances traceability within a supply chain. It is imperative that the granular information collected should be intuitive and accessible to all parties to enhance visibility. Amplified traceability and visibility greatly improved transparency and accountability within the SOKO ecosystem. A pivotal recommendation for future research is usage of unit-based tagging technologies e.g barcodes, QR codes or RFID. Combined use of such technologies and blockchain would achieve the highest level of traceability, especially when working with diverse producers who produce similar products.

Key Words: Distributed Ledger Technology (DLT), Blockchain, Distributed Manufacturing, Aggregator, Supply Chain (SC)

Table of Contents

Table of Figures

List of Tables

CHAPTER 1: INTRODUCTION

1.1 Background

While the popularity and growth of Distributed Ledger Technology (DLT), which is popularly known as Blockchain, started after cryptocurrency burst into the limelight, the work to establish the infrastructure began in 1991. Haber & Stornetta 1991, proposed a cryptographically secured chain of blocks whereby no one could tamper with timestamps of documents. A year later an upgrade was made that incorporated Merkle trees to enhance efficiency and therefore allowing the addition of more documents on a single block.

It was 17 years later that the technology gained popularity after Satoshi Nakamoto created the Genesis bitcoin block after proposing the use of peer-to-peer network timestamp transactions by hashing them to create an ongoing continuous chain of hash-based proof-of-work. This would create a record that cannot be changed without redoing the proof-of-work (Nakamoto, 2008). Soon after, the open source code was modified to create better cryptocurrency, and some projects also tried to change the idea of blockchain to be used in other areas apart from P2P money.

Distributed ledger technology can be described as a database shared between computers spread across the globe, creating a decentralized environment rather than a central one. Blockchain is just one type of distributed ledger. The blockchain is a shared database filled with entries that must be confirmed and encrypted. Therefore, blockchain is a distributed ledger, but not a distributed ledger is not a blockchain.

In the last decade, we have seen a large number of applications and cryptocurrencies stemming from the underlying distributed structure. There are several types of DLTs that exist currently, the most famous one being Blockchain, the others are Hash-graph, DAG and Holochain. In the past few years, the world has seen over 2,500 patents filed that are related to blockchain technology, and several billion US dollars invested in blockchain startups (Lenz, 2018).

One of the sectors where Blockchain technology has been widely discussed, most probably because of the Bitcoin hype, is the financial services industry. DLT development in the financial services industry has had the most discussions and popularity due to the notoriety of bitcoin. Banks are also trying out DLT, as evidenced by the Global R3 consortium that is applying Blockchain to trade finance and cross border payments. Startups, organizations and governments have begun exploring implementations in various areas such as energy supply, electronic health records, voting, ownership management , supply chain, etc. (Xu et al, 2017). Some countries such as Sweden have already implemented the use of blockchain in their land registry systems (New York Reuters, 2016). The growth of interest is emphasized by the quick evolution of the ecosystem with companies like IBM and Microsoft Azure offering Blockchain-as-a-Service, which provide easier deployment.

Globally, the manufacturing sector has the most organisations with at-scale deployments, compared to the retail and consumer products industry (Capgemini, 2018). Apple Inc's largest electronic manufacturer, Foxconn, released a blockchain based supply chain finance platform called Chain Finance. This platform guarantees that every transaction carried out can be more transparent, manageable and easily authenticated. Robert Bosch, ZF Friedrichshafen and other automotive manufacturers have created a consortium called the Mobility Open Blockchain Initiative with organisations like Renault, BMW and General motors. The goal of the consortium is to set up compatibility standards between brands for blockchain based services. Looking at their usability and costs of set up, it is clear that the technologies developed so far do not cater for distributed manufacturing in developing countries.

The Kenyan distributed manufacturing sector is largely informal, heavily interconnected, with real time transactions ongoing at every moment. Optimal management needs a frictionless flow of information about the physical flows of materials and goods and the flow of payments within the process (Lenz, 2018). Kenyan manufacturers and aggregators would greatly benefit from cases where smart contracts could address existing processes that are heavily reliant on a lot of paperwork, multiple currencies, and general supply chain visibility.

1.2 Problem Statement

While traditional manufacturing is characterized by centralized manufacturing ((Bamber & Dale, 2000), developing markets such as Africa, Central and South America have missed out on opportunities because the majority of the workforce is distributed. To solve this, a solution like pooling together the resources available has given the markets a chance to enter the global market. Taking the Kenyan agricultural sector as an example, the majority of farmers do not have direct access to the international market. In order to achieve this, farmers have formed cooperatives that allow them to consolidate their produce and make the logistics of getting the produce to the end consumer easier.

While this approach offers a level playing field, it brings its fair share of challenges. The aggregators need to have visibility of data of all their producers, their location as well as any processes that the product being handled goes through.

We are also in the age of the conscious consumer, with customers asking to have more transparency regarding sourcing of their goods and the manufacturing process. Buyers are keen to understand the true value of what they are purchasing or reselling. To satisfy these requests is quite difficult in the existing distributed manufacturing set up. In agriculture, it would require consolidation of data from several cooperatives, logistics companies and processing companies if any were used and tracing all the activities back to their origin.

Some Kenyan startups have developed proprietary technologies that cater for their specific industries, however most of them use the traditional centralized architectures which do not offer the benefits that DLTs do e.g. smart contracts, immutability. On the global stage, technologies have been developed using DLTs that run the Blockchain architecture, however, they are not suitable for the economic and infrastructural needs that the Kenyan distributed manufacturing sector requires.

The intention of this research is to provide a solution that provides transparency, traceability and visibility that the distributed manufacturing industry in Kenya requires that is affordable and utilizes the available infrastructure.

1.3 Objectives

1.3.1 Main Objective

The main objective of this study is to address the lack of transparency in the informal distributed manufacturing industry by developing and implementing systems that provide traceability and visibility in the sector using distributed ledger technology.

1.3.2 Specific Objectives

The specific objectives of the research are:

i. To establish how to provide uniform data on informal producers using a DLT system.
ii. To develop a DLT system whose features support provision of visibility and traceability in the distributed manufacturing industry in Kenya
iii. To assess the provision of traceability and visibility of data to aggregators in the Kenyan distributed manufacturing sector using a DLT system
iv. To assess the effect of use of the system in terms of transparency of processes in informal distributed manufacturing by artisans and aggregators.

1.4 Justification

DLTs provide a data-aware process for companies who are seeking innovation for business collaboration. These ledgers help companies to track the state of the processes in their business and execute each task using a space-optimized data structure.

Providing a technology that enables organizations in the Kenyan distributed manufacturing industry to have transparency into their operations while having the elusive traceability and visibility will boost the Kenyan economy and allow local manufacturers to compete on a global market. It will also help the informal manufacturers have better access to financial services such as loans and grants as their data will be in a centralized location that is trustworthy due to the immutability of records.

This research can also be used in other developing markets such as India, the rest of Africa, South and Central America as the regions share a manufacturing model.

1.5 Scope

The scope of this study is limited to the informal Kenyan craft industry and organizations within the industry that act as consolidators or aggregators. The study involved understanding the challenges regarding transparency, traceability and visibility that the entities face and developing a software solution that uses Distributed Ledger Technology to solve the issues faced.

1.6 Limitations

The time of this study is limited to 6 months as per the regulations of the university. This affected the researcher's observation and software development time, considerations for this are addressed further in subsequent chapters.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In this chapter, the research dives into literature about the informal sector, going more specifically into the informal distributed manufacturing sector. It will outline the variables that will define the scope and area of the proposed study. The research will also explore the interest posed by Bitcoin and Ethereum, as examples of their underlying Blockchain and how the features they provide can provide transparency, traceability and visibility in the informal distributed manufacturing sector in Kenya

2.2 The Informal Sector in Developing Economies

2.2.1 Introduction

Based on traditional industrial manufacturing standards, Africa is not considered a manufacturing hub. Apart from South Africa and a few other African countries, large scale industrial manufacturing continues to be very minimal. However, distributed manufacturing booms in the African economy. This consists of workers in small unregistered factories or workshops, and industrial workers who work from their homes (also called homeworkers) (Chen, M. (2005).

Despite previous predictions of its decline by economists during the 1950s and 1960s, the development of the informal sector has continued. The Government of Kenya (KNBS, 2012) has defined the informal sector as covering all small-scale activities that are semi-organized, irregular and use fewer and simpler technologies. In contrast to the general depiction of the informal economy as a single "undivided" group of workers, the sector is largely dynamic, cutting across a wide range of micro, small and medium enterprises. It also includes workers employed on such occupations and self-employed workers who earn a living from activities such as domestic work, street trade or small scale farming.

A major feature of the Kenyan manufacturing sector is the large number of micro and small enterprises in the region. Although the sector is made up of firms of various sizes, it is estimated that informal micro and small scale industries (MSE) constitute about 85% of firms manufacturing products manufactured in Kenya (Marti and Ssenkubuge, 2009).

Classified as a major player in the informal sector, the local craft/manufacturing industry, popularly known as JuaKali, literally means fierce sun in Swahili, is an area that contributes heavily in Kenya's GDP. The 2014 Economic Survey of Kenya indicated that 80 percent of the 800,000 jobs created in 2014 were in the informal and/or JuaKali sector that is dominated by small and medium enterprises (SMEs). JuaKali employs over 14 million people, which translates to 83.4 percent of the total jobs in the country and contributes 34.3 percent to the country's gross domestic product (GDP), making it one of the most intensive sectors in the Kenyan economy.

The informal sector produces extensively for the local Kenyan market and saves the country's foreign exchange. Less expensive machinery and technology that can be produced locally is needed which helps establish the country's technical capabilities. JuaKali operators mimic products that are already in the market and thus spreading technical skills.

In a 2016 study done for the Supporting Economic Transformation Programme, Furniture making and metal work emerged as the strongest subsectors in informal manufacturing. This was thought to be due to the strong availability of raw materials, and manufacturing farming related materials in formal areas and the growth of the construction industry in the country. Due to lack of data, it was unclear which subsector was the weakest within the informal manufacturing sector.

The Jua Kali trends in Kenya are compared to countries such as India, which have seen an increase of one-man establishments, and where the informal sector accounts for a significant percentage of employment. In India today, the small scale sector is said to represent 80% and 99% of Indian manufacturing employment and establishments respectively.

2.2.2 Characteristics of the Informal Sector

Ownership Structure. The most common structures in establishment ownership are partnerships, family businesses or sole proprietorships. Most formal sector enterprises are sole proprietorships, contrary to ILO's (1972) belief that informal sector firms are more likely to have family ownership than formal firms (Atta-Ankomah, 2014).

Table 1: Ownership structure by cluster/sector in percentages (%)

Nature of Ownership	% of Informal sector clusters					
	Ngong	Gikomba	Kebuye	Informal Sector	Formal Sector	All
Partnership	7.6	16	24.2	14.4	30	16.8
Family Owned	0	4	0	0.9	70	11.5
Sole Proprietor	92.5	80	75.8	84.7	0	71.8
Total	100	100	100	100	100	100

Source: Atta-Ankomah, 2014.

Size of operation. The Kenyan informal sector is characterized by micro and small enterprises, which typically operate locally, on a modest scale and at the subsistence level. They have fewer employees (especially home-based enterprises), work for shorter periods, barely reach essentials like water and electricity and rarely sell outside the entrepreneur's residence (World Bank, 2006). According to the 1999 baseline survey, 80% of the total MSE employment comprised only owners and their family members. Regular hired workers accounted for only 11.6% of total MSE employment. 96.7% of MSEs did not employ more than five employees, with the other 2.6% employing 6-10 individuals, meaning that 99.8% of MSEs do not have more than 10 employees, as shown in table 2 below.

Table 2: Percentage Distribution of MSE Sizes

Size (Persons)	**Nairobi and Mombasa**	**Other Major Towns**	**Rural Towns**	**Rural Areas**	**Total**

1	68.6	73.5	74.4	69.5	70.1
2	16.9	14.1	18.5	18.8	17.9
3-5	11.5	9.3	5	8.2	8.7
6-10	1.4	1.9	1.7	3.1	2.6
11-15	0.9	0.8	0.4	0.4	0.5
16-25	0.3	0.4	-	-	0.1
26-50	0.4	-	-	-	0.1
Total	100	100	100	100	100

Source: National Baseline MSE Survey. 1999

Nature of employment. Due to the small-sized operation, the number of employees per establishment in the informal sector is minimal. Employment in informal sector groups, based on the piece rate system of remuneration, is also largely casual. Atta-Ankomah's 2014 research shows that the average number of employees in an establishment is 3.4, without the proprietor. 2.3 are temporary workers and the rest are permanent workers who are casual but regular workers who have worked continuously for the enterprise for more than three months. Some of these workers receive monthly salaries, but are not covered by insurance or public welfare.

Competition. It is quite common in the informal sector to have businesses within a particular area to operate in a similar variation of products of related designs. This gives rise to robust competition which is a major challenge for the development of their businesses. (Atta-Ankomah, 2014).

Education and skill acquisition. Those working in the informal sector have limited access to formal education. The majority of informal workers have completed secondary education. Some skills used in being an artisan can be derived from their secondary school education, based on a policy of the Government of Kenya, where each secondary school should provide at least one technical and vocational together with academic subjects (Republic of Kenya, 1984). According to Okaka (2001) these technical and vocational subjects are: agriculture, woodwork, metallurgy, electrical mechanics, electricity, drawing and design, building construction, home science etc.

Table 3: Level of education by clusters/sectors

Level of education	# of Informal sector clusters					
	Ngong	Gikomba	Kebuye	Informal Sector	Formal Sector	All
High school	17	11	11	39	6	45
Basic +poly	3	2	2	7	0	7
High school +poly	11	0	1	12	3	15
University	5	0	0	5	9	14
Total	36	13	14	63	18	81

Source: Atta-Ankomah, 2014.

King and Abuodha (1995) observed in their Kenyan study a new occurrence of highly educated people joining the informal economy. This can be attributed to the weakening employment opportunities in the formal sector.

It is important to note that most informal sector workers possessing skills have gained them through non-formal training or traditional education/informal training outside state plans of formal education. Informal training such as apprenticeships and learning-by-doing often play the most important role in providing skills to informal sector workers (Overwin, 1997). Non-formal and formal education often do not reach the same level of importance as learning-by-doing. However, King and Abuodha's study (1995) of 100 Kenyan micro-entrepreneurs in the informal sector shows that those receiving both formal and informal training are advantaged.

Labour-intensive & adapted technology. Most of the tools and machines used by artisans in the Jua Kali sector are hand operated and very few are precision tools. Most of the tools are machines replicated from memory by workers, seen in their previous formal workplaces. Artisans can also import tools from Chinese and Indian markets, which are expensive and not at the reach of many artisans. (Daniels, 2010).

In a study done by Maina et al 2017, 90% of the 300 artisans interviewed had a range of less than 13 tools shared among them while 10% of the well-equipped workshops had up to 40 tools shared among the artisans. Some of these tools included Screwdrivers, welding tools, Pliers, Jack planes etc.

Reliance on local resources. Artisans in the sector rely heavily on locally-available raw materials as they help keep costs down as low as possible. Majority (71%) of Jua Kali firms use recycled timber and scrap metal. These materials are usually rejects from the formal industry, (Maina et al 2017). Jua Kali enterprises specialize in consumer goods such as textiles, metal work, carpentry and ceramics (Daniels, 2010). The materials to make these goods are sourced from local suppliers, most located in downtown Nairobi.

2.2.3 Challenges Faced by Informal Manufacturers

Inadequate Regulation

As large and influential this industry is to the local economy, it remains heavily under-regulated and undocumented. Despite its significant role, very few of the micro and small enterprises of the informal sector become medium or large sized enterprises due to challenges like "lack of access to markets, information on and access to finance; limited access to technology; low education levels of the entrepreneurs; lack of managerial, marketing and production skills; use of rudimentary technology; low-skilled work-base; lack of access to credit; very low purchasing power of their consumers/clients; and regulatory constraints emanating from difficulties of obtaining legal status" (Stevenson & St-Onge, 2006).

Isolated Nature

A major factor contributing to the performance of micro and small enterprises is their isolation, as this limits their access to markets and resources such as information, capital, and institutional support, (Ogot, 2014). The likelihood of an individual worker in the Makina market in Kibera having access to a customer in Europe is very minimal. Without the existence of a union, the problems facing informal workers remain unsolved.

Poor Access to Financial Services

Due to the informality of these businesses, access to financial resources is limited. A large number of the physical and financial transactions carried out in such establishments are not tracked. This poses a challenge when requesting access to credit to cater for expansion & running costs from banks and SACCOs. Financial institutions are focused on formal businesses that can provide collateral, which these businesses lack.

Limited Access to Markets

Limited access to local and international markets due to poorly developed value chains e.g. quality testing to ensure that export standards specifications are met, is another aspect that slows down the growth of such businesses.

2.3 Aggregators

In Agriculture, small scale farmers have been able to gain access to global markets by being members of cooperatives. Cooperatives are established by members driven by the need to reduce the isolation of individual producers and allow them to do business together and benefit from economies of scale. The cooperatives movement in Kenya has evolved over the years after the initial cooperative society was formed in 1908 under the colonial government, to 18,573 cooperatives in 2016, (Ministry Of Industry, 2017). Cooperatives offer members a chance to optimize their economic, social and cultural needs.

However, in the last decade, Kenya has seen other members of the informal sector such as the transport industry and craftsmen also registering 57 and 211 cooperatives respectively. While this is only above 1% of the number of existing SACCOs, this indicates that informal workers are realizing the benefits of being a large entity.

To alleviate some of the challenges faced by informal manufacturers, external partners are also coming into distributed manufacturing as aggregators. They bring together groups of producers and provide them with access to funding and local and international markets. An example of this is Lynk, a Kenyan company that brings together informal service providers such as carpenters, plumbers, etc. and the final consumers.

Once the cooperatives or aggregators purchase goods from the producers, some choose to do more value addition processes on the products to get them to a global standard. This creates a supply chain that is dependent on distributed producers, which brings about a different set of challenges. Producers would like to have product data which will help them improve their product offerings in the global market. The supply chain is interconnected, with real-time transactions ongoing at every moment. Consumers are more interested in knowing how the product was made. 66% of the global market are happy to spend more for sustainable goods, more specifically 73% of Millennials (Curtin M, 2018).

Fulfilling the needs of the producer and consumer, as well as seamlessly running a supply chain leaves an aggregator having a difficult time coordinating all aspects of their business. The business leaders require the visibility of the product as it goes through the value chain and being able to trace the product's life cycle.

2.3.1 Challenges in Supply Chain Management

Dershin (2000) posits that the supply chain is the "mother of all processes" because, due to its size, scope and nature of intricacy, a majority of processes in the supply chain are not controllable. Management of the supply chain can be very complex with the existence of differing stakeholders and the large amount of content being distributed (Agwata, 2014). Interconnected or interlinked networks, transactions, channels, and node establishments are involved in the delivery of goods and services required by final consumers in a supply chain (Beamon, 2004).

Inadequate Literature about Developing Countries

Although the literature on the global supply chain is growing, little attention has been paid to the issue of global/international supply chain problems in developing countries (Msimangira & Tesha, 2009). Most of the discourse is focused on supply chain practices in developed countries, and less attention on the issues that suppliers or buyers from developing countries face (Msimangira & Tesha, 2014).

Interconnected Components

Management of various supply chain components; transport, equipment, communication, suppliers, customers, labor and finance presents the major challenges facing supply chains (Barua, 2010). These challenges are even bigger in developing countries due elements like unstable governments and policies, corruption, labor intensive industries, deteriorating infrastructure and other factors such as new technologies, unemployment, child labor and low levels of education in the population (Galal & Momeim, 2016).

The failure of a stage or player in the supply chain will affect the general performance and competitiveness of the supply chain. Developing nations face supplementary challenges because their economic benefits depend on the exploitation of natural resources (Msimangira&Tesha, 2014).

Need for Quick Responsiveness

To respond effectively to today's market dynamics, organizations must be have flexible operations and be responsive in an increasingly complex and fast changing environment. Supply chain information is spread across people and departments within the business (Williams et al, 2013). To coordinate the flow of information and materials across a group of linked businesses, organizations must build external relationships that allow supply chain partners to learn about upstream and downstream supply chain operations and activities (Fiala, 2005; Mabert and Venkataramanan, 1998)

Increased Customer Pressure

Due to customer pressure in the age of the conscious consumer and legislation in industrialized countries, businesses are evolving and restructuring their supply chains to be more sustainable. Sustainable supply chain management can defined as “the management of material, information and capital flows as well as cooperation among companies along the supply chain while integrating goals from all three dimensions of sustainable development, i.e., economic, environmental and social, which are derived from customer and stakeholder requirements”(Seuring& Muller, 2008)

Managing Risk Adequately

The 2011 study by Christopher et al. regarding methods to handle worldwide sourcing risks uncovered that a large number of organizations do not have a structure to manage risks associated with supplies and systems to mitigate the risks and therefore depend on informal techniques of coping with risk.

Generally, literature shows that organizations that engage in the global supply chain face varying challenges, all which require synchronization of their operations. Coupled with the challenges facing the informal sector, aggregator companies require visibility and highly efficient systems in order to succeed in the ecosystem.

2.4 Role of Technology

The Kenyan Government has in recent years placed increased emphasis on industrialization, which is largely notable in the Sessional Paper No.2 of 1996 on Industrial Transformation to the Year 2020 and Kenya National Industrialization Policy Framework, 2011-2015 (which is built on Vision 2030 which is Kenya's current policy and long-term development plan).

In the earlier policy plans, limited attention was given to technology choice and the impact of suboptimal technology choices on development. This is quite visible as an effect of the import substitution (IS) industrial policy, which is believed to have largely neglected technological capability building in MSEs while favoring traditional large scale manufacturing firms. These firms had access to foreign and fairly expensive technologies and were mostly created with private foreign capital – foreign direct investment (FDI). (Atta-Ankomah, 2014).

Policy documents that have been created recently such as Sessional Paper No. 2 of 2005 on Development of Micro and Small Enterprises for Wealth and Employment Creation for Poverty Reduction, which have highlighted the need for development of the technological capacity of MSEs. The aim is to grow the ability of MSEs to adopt and adapt to new technologies as well as to enhance their access to available technology.

Apart from the changes in policy, by recent infrastructural ICT developments also empower distributed manufacturing. These improvements enable connectivity to support coordination, governance, and control, and crucially enable demand and supply to be controlled in a more synchronized manner. "An emerging body of research shows that the reduction in communication costs associated with mobile phones has tangible economic benefits, improving agricultural and labor market efficiency and producer and consumer welfare in specific circumstances and countries, Jensen, 2007; Aker, 2008; Aker, 2010; Klonner and Nolen, 2008" (as cited in Aker & Mbiti, 2010).

The emergence and usage of mobile technology in Sub-Saharan Africa has grown dramatically over the last two decades, with Kenya leading by having 91% penetration of mobile subscriptions in contrast to Africa's 80%. 3G network coverage has shot up from 67% in 2014 to 85% in 2017, with a larger expansion of 4G, that is now accessible to over 33% of the population, (Business Daily, 2019). With the establishment of mobile money, businesses can track their financial transactions and the records used to request for financial resources.

It is imperative that technologists continue to develop human-centered products that aim to solve the sector's needs. Connecting informal producers with the global market can be made possible by providing visibility and traceability into the value chain. This would include capturing the producer data, any value addition done on the product, logistics companies used, up to reception by the final consumer. Emerging technologies like Distributed Ledger Technologies can be explored to provide these solutions.

2.5 Distributed Ledger Technology

The International Telecommunication Union (ITU) in 2019 defined a distributed ledger as a type of ledger that is shared, replicated, and synchronized in a distributed manner. A distributed ledger is a public ledger that is accessible to every participant of a network, and records transactions between peers in a chronological order by using time stamps. Compared to traditional ledgers, distributed ledgers do not have a sole custodian who has exclusive rights to edit the state of the ledger by adding new transactions. Every participant can access the complete history of transactions, has read, write and store rights within the ledger (Lenz, 2018). Distributed ledger technology (DLT) allows the maintenance of a "global, append only, data structure by a set of mutually untrusted participants in a distributed environment" (Bencic & Zarko, 2018).

DLTs can have two different access control structures: permission-less/public or permissioned/ private. In permission-less any member can take part in the consensus protocol of the ledger and propose data to add to it, while in permissioned only a set of known entities can propose data to be added. Public ledgers create trust using mathematical equations and a consensus mechanism that encourages individual behavior to attain a shared objective. Private ledgers are centrally managed and use 'trust by default of a legal contract' or 'trust by reputation'. Permissioned ledgers are mostly used by private industries. (Voshmgir, 2019).

Several researchers have provided literature that defines DLT and its components. The ITU - T 2019 identifies the DLT components as user, DLT node, DLT service provider, and user groups. The figure below shows a simple illustration of the components of the distributed ledger technology.

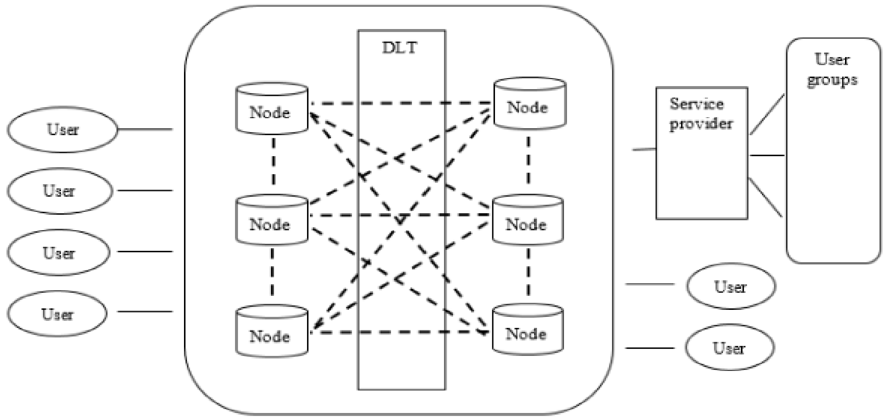

Figure 1: A typical example of DLT actors and components

Source ITU -T 2019

Node: independent system that exists inside the distributed ledger. Some of the nodes known as "full nodes" store the ledger data, pass along the data to other nodes, and ensure that newly added blocks are valid.

Service Provider: Component that offers a DLT based service to other parties by means of the service interfaces it provides.

User: A component that utilises a service or consumes the output of a service provided by another component. A component can be a provider or a consumer of services.

User Group: A set of DLT system users, this can be a group of people and/or organizations.

From the above structure, a distributed ledger is information in digital form that has been validated by consensus, replicated, and stored in different nodes.

Entries or proposed changes made into a distributed ledger contain **transactions** which can be stored. DLTs can provide access rights to transactions, which regulates initiation of transactions, write and read access to the leger. A DLT system has to reach consensus before a transaction is permanently written to its ledger. DLT systems also utilize **tokens**, which are identified as a unit of value issued within a DLT that can be used as a medium of exchange or unit of account. Tokens can work as an incentive to encourage self-organization and lead to societal benefits such as contributing to the UN Sustainable Development Goals (SDGs). (Ballandies, Dapp & Pournaras, 2019)

Smart contracts are programs that can be deployed and run on DLT systems. They are a type of contract that executes on their own, and handles contract enforcement, management, performance, and payment. The smart contract refers to a programmed, predefined agreement between two entities, which is automated to execute independently on the distributed ledger (Mattila, 2016). For example, smart contracts can be coded to buy a certain amount of shares every day if the price falls below a predetermined level. Smart contracts can also be programmed to continue in a never ending loop or alternatively self-destruct after a certain time. After a contract is agreed upon by a contractor, it acts on a ledger just like any other node: its transaction is validated by a consensus system of bookkeeping, and it is based on cryptographic elements (Pinna & Ruttenberg, 2016). Ethereum is the most widely used DLT system that supports general-purpose (Turing-complete) smart contracts.

Rauch et al, 2019, identifies 4 key actors who are defined as entities or individuals that directly or indirectly interact with a DLT system.

Developers: These are the contributors who write and review code used as the technical building blocks in a DLT system.

Administrators: They control access to the codebase repository and are involved in the governance process. In permissioned/private DLTs, they operate the network or hold the IP of the networks and intellectual property rights. In public DLTs, they propose changes which are 'ratified' by users independently.

Gateways: They bridge the DLT system to the outside world by providing interfaces to the system.

Network Participants: These are entities that communicate by passing messages among each other.

A single entity can play the role of multiple actors at the same time and likewise a specific role can be performed by several actors at the same time. Each DLT system is varied in its composition of actors, roles and entities.

2.5.1 DLT Features

Given that any participant can make new entries, the issue of data validation in distributed ledgers brought about some of the most notable features of DLTs below:

Immutability (append only) - A participant ought be have the ability to add new transactions but not delete, change, or change the order of existing ones (Narayanan & Clark, 2017). The record is added to the database using hash functions and time stamps for new data entries. An attempt to change the data later would destroy the chronological order and logical consistency of the chain of information and would immediately be flagged (Lenz, 2018).

Proof of origin - The distributed ledger infrastructure uses asymmetric private and public digital keys when writing into the database to ensure that every new piece of information is uniquely linked to the sending participant (Lenz, 2018).

Consensus mechanism - DLTs have an algorithm whose role is to ensure that information is only recorded once in the base to prevent duplication of records (Lenz, 2018). In permission-less DLTs, the algorithm performs without depending on one party or side-agreements, and in the absence of an initial trusted relationship amidst the parties. In permissioned, it works through a number of record producers that have been approved and bound by some type of contract or other agreement (Rauch et al, 2018).

Shared/decentralized record keeping. Several parties can all together create, maintain and update the shared ledger (Rauchs et al, 2018). Many copies exist within the network which are permanently synchronized, so that every network participant has at every time the same information (Lenz, 2018). The shared result of the reconciliation/consensus process i.e. the ‘ledger’ serves as the authoritative version for these records.

2.6 Blockchain

The most prominent implementation of DLT shared over a network is blockchain. It is a type of distributed ledger, made up of digitally recorded data, arranged as a series of blocks, which are cryptographically linked to each other and the block hardened against tampering and modification (ITU -T, 2019).

A blockchain is a data structure consisting of an ordered list of blocks, with a list of transactions contained in each block. Blocks of data are connected to each other, where each block is 'chained' to the previous block because it represents a hash of the previous block. The data (set of blocks) is managed redundantly in a distributed network. (Lenz, 2018; Xu et al, 2017). A Blockchain is composed of a list of blocks starting at a "genesis" block and extending until the present time. Transactions are consolidated into batches called blocks and appended to the Blockchain. Different implementations utilize different mechanisms to deter invalid blocks and fraudulent transactions.

Blockchain applications use asymmetric public-key cryptography or digital signatures to ensure authenticity of a network participant sending a message. The sender inscribes the message with their private key and sends it to a recipient who can verify the legitimacy of the message with a corresponding public key. Hash functions are also applied to the message to secure the message and ensure uniqueness since the probability of a hash function generating the same output for any two different outputs is negligible. (Lenz, 2018).

Adding fresh blocks to the blockchain data structure is known as mining. In a blockchain network, miners combine legitimate transactions into blocks and attach them to the blockchain. New blocks are transmitted throughout the network to ensure that all nodes have a copy of the entire structure. Since there is no central authority, the network has a consensus mechanism that determines whether a transaction is deemed to be committed or confirmed which makes the transaction immutable.

There are different consensus mechanisms used in different implementations. (Xu et al, 2017)

Proof of work (PoW) is a random mechanism used in large public permission-less networks. Miners are allowed to choose which transactions to include and which block in the history of the Blockchain to build off of. The rationale behind the name PoW is that adding a new block requires finding the solution to a very hard cryptographic puzzle (Nchinda, 2018). The puzzle is often updated on a regular basis in order to maintain an approximately fixed generation time of new blocks. There exists several proof of work implementations such as Ethash used in Ethereum and Hashcash used by bitcoin. It takes about 10 minutes for the entire Bitcoin network working together to find the solution to Bitcoin's puzzle.

Proof of Stake (PoS) is a mechanism where consensus is achieved through a voting process that is linked to economic power in the system (Ballandies et al, 2019). Network participants that have a large amount of coins during the election period are more likely to be chosen to validate the data. Tokens are bonded to encourage honest behaviour and can be destroyed if any malicious actions are detected in the network(Rauchs et al, 2018).There are several proof-of-stake protocols, such as, Tendermint used in Eris, and Casper used in Ethereum. PoS is cost efficient compared to PoW since much less computational power is used in mining. Also, PoS network attacks are easily penalized compared to PoW. In PoW, the miner still owns the hardware used in the attack, while in PoS burning stake has an economic effect on the miner (Bencic & Zarko, 2018).

Byzantine Agreement. The Byzantine fault tolerance (BFT) protocol makes it necessary that all participants agree on the list of participants in the network, which makes it ideal for consensus in permissioned blockchains (Xu et al, 2017). A successful communication protocol is established only if there aren't too many ‘black sheep’. Blockchains using BFT guarantee strong stability and low latency for a small size of participants. Compared to PoW, it is more traditional within distributed systems. Stellar, which powers IBM world wire uses the BFT protocol.

Hybrid. Some blockchain implementations use a combination of any of the above consensus mechanisms (Ballandies et al, 2019). E.g. the core of Tendermint in Eris is a BFT protocol but uses PoS to prevent Sybil attacks.

There are different blockchain network types that differentiate the access authorization and validation type. For example in public networks anyone can validate, write and read transactions while in private networks, only invited members can do so. These differences are outlined in the figure below.

Table 4: Blockchain network types

Blockchain architecture options		**Architecture based on read write or commit permissions granted to the participants**	
		Permission-less	**Permissioned**
Architecture based on ownership of the data infrastructure	**Public**	A willing person can join, read, write and commit Hosted on public servers Anonymous and highly resilient Low Scalability	Anyone can join and read Only authorized and known participants can write and commit Medium Scalability
	Private	Only authorized participants can join, read and write Hosted on private servers High Scalability	Only authorized participants can join and read Only the network operator can write and commit Very high scalability

Source: McKinsey & Company 2018.

2.6.1 Blockchain Use Cases

Financial Services Industry

Following a 2008 white paper "Bitcoin-as-peer-to-peer electronic cash system" by Satoshi Nakamoto, that was circulated among an email list of cryptographers (Popper, 2015), the digital currency system has expanded to be valued at over $60 billion in mid-2017. This led to the rise of an ecosystem of fresh and inventive ideas and services that spread far beyond the financial sector (Tapscott & Tapscott, 2016).

Bitcoin is the most used DLT based system, using public Blockchain infrastructure. It is also very controversial as it helped enable a multi-billion dollar industry of anonymous transactions that lacked any government control (Crosby et al, 2016). Bitcoin is a cryptocurrency and consensus network used globally by millions of people to send monetary transactions.

The bitcoin Blockchain contains all the transactions on the net-work going back to the first Bitcoin transaction in 2009. Bitcoin uses Proof of Work (PoW) mechanism. Maintaining the security of Bitcoin's Blockchain requires a large amount of energy and computational power. Data stored on the Bitcoin Blockchain can generally be assumed to be indelible. Therefore, data saved on the Blockchain would remain accessible to the world in perpetuity, with no need for further action by users. Archiving services would be provided by Bitcoin miners. Unfortunately, this design makes a user's technology subject to the externalities of Bitcoin. In the future the network may change in a way that prioritizes the primary use of cryptocurrency and harms secondary uses such as data storage.

Ethereum is another prominent cryptocurrency open software platform founded on blockchain technology that allows system developers to create and deploy decentralized applications. It is depicted as a blockchain with a built-in Turing-complete programming language, which allows a person to create smart contracts and decentralized applications where they can make their own ownership rules, transaction formats, and state transition functions (Buterin, 2013).

Despite some major technical differences between the two, the key difference to consider is that Bitcoin and Ethereum vary greatly in purpose and capability. Bitcoin provides a special application of the blockchain technology, a peer-to-peer electronic cash system that enables online bitcoin payments. The Bitcoin blockchain follows the ownership of digital currency (bitcoins) and the Ethereum blockchain runs the programming code of any decentralized application.

In Ethereum, miners work to earn Ether, a type of crypto token that fuels the network, instead of mining for bitcoin. Apart from being a tradeable cryptocurrency, Ether can be utilized by app developers to pay transaction fees and services on the Ethereum network. Gas is another kind of token used by minder to pay fees for adding transactions in their block. For a smart contract to be executed, a certain amount of gas has to be sent with it, to convince miners to add it to their blockchain.

With respect to the blockchain architecture, the principal distinction between Ethereum and Bitcoin is that unlike bitcoin (which only includes a copy of the transaction list), Ethereum blocks include a transaction list and a copy of the most recent state (Ethereum Homestead, nd)). Block number and difficulty are two other values that are also stored in the block.

Asset Tracking - Blockchain has also been used in the location of physical products by allowing records of ownership to be preserved for each product. A major example is Everledger, an organization that monitors diamonds by having a digital identity of each diamond on a blockchain network. The authentication of transactions helps prevent 'blood diamonds' from being part of the global jewelry market. Provence Company also creates a series of ownership or custody records for their physicals products.

Digital Identity - A blockchain technology that provides the infrastructure to enhance digital identity at a very low cost with significant security improvements was released recently bt Onename. Users all over the world can acquire their own digital identity on a decentralized system, without waiting for a government agency to issue them. A lot of government organizations had their interested peaked by this system.

Supply Chain - Microsoft Azure has developed a Blockchain development toolkit that is intended to help developers extend the key management, off-chain identity and data, monitoring, and messaging APIs and develop blockchain enabled software. This has been used by a Nigerian organization, Interswitch, to manage their payments and financial information of their supply chain Clients. It has also been used by Buhler, a centralized manufacturing organization to manage their food processing.

IBM has also developed a blockchain food trust solution for supply chains so that organizations can trace food through the supply chain and vendors can monitor any contaminated food and recall it. This technology is in use in Europe and is mostly used by centralized manufacturers. It's built using Hyperledger Fabric (the open source DLT) and it runs on IBM Cloud. The technology is permissioned and immutable, participants can set custom access levels and collaborate securely.

2.6.2 Limitations of Blockchain

Analyzing the characteristics of blockchain, it is clear that its solutions work well for processes which involve a large number of participants who require complete and reliable information about the ongoing status of the process at all times (Lenz, 2018).While the advantages of blockchain are vast, it also has some technical limitations.

Data privacy is limited because information on a blockchain is accessible by all participants. This is particularly prevalent in public blockchains because there are no privileged users, any participant who has joined can access all information on the blockchain.

There also exists limitations on scalability; data size, the rate which transactions are processed and data submission latency on the blockchain. The bandwidth of nodes participating in the leader election limits the amount of transactions in each block. The consensus mechanism affects the time consumed between the submission of a transaction and its confirmation from committed to confirmed state. This means that when transactions are broadcast to the network, they must wait until that transaction is validated and included in the network's historical ledger of transactions. Since each node on the network must verify each transaction, the network becomes slower with more transactions. Well known public blockchains can take up to 3-20 transactions per second, while mainstream payment services such as Visa average 1700 transactions per second. (Xu et al, 2017).

Transactions recorded in Blockchain are also immutable. SWIFT noted, "Once an error is embedded in the Blockchain, this may be highly problematic, legally, in that often law requires the ability to rectify errors as a matter of law in a way foreign to DLT" (Le Borne, 2017). This may be a challenge system users make mistakes that will need correcting.

2.6.3 Application of Blockchain in the Distributed Manufacturing Sector

Aggregators working with the widespread informal distributed manufacturing sector need to keep track of their complex network of suppliers. They also require visibility into their supply chain processes and trace the movement of products through the value chain at all times. Customers also want transparency into the sourcing of materials used and whether the products they buy are manufactured ethically.

Tremendous improvements in the distributed manufacturing sector have been brought about by providing companies and consumers with reach to immutable and extensive records at the level of individual products (Mattila, 2016). With the elimination of a central authority, trust is built by the transparency that is brought in by blockchain technologies. Every participant can verify who wrote what and how the state of a ledger has changed (Lenz, 2018).

2.7 Conceptual Framework

The key variables in the research study are:

Use of a system implementing DLT - Independent Variable. Introduction of a system that implements blockchain technology into the aggregator and artisan ecosystem would change how the value chain works.

Traceability - Intervening Variable. A report done in 2014 by the United Nations Global Compact and BSR defines traceability as "The ability to trace and identify the history, distribution, location and application of products, parts and materials; to ensure the reliability of sustainability claims in the areas of human rights, labour (including health and safety), the environment and anti-corruption." The International Organization as Standardization (ISO) defines traceability as "the ability to keep track of the history, application, or location of an entity through recorded identification", (ISO, 2007).

The information captured during traceability is more granular, which relates to individual parts or components like e.g. Purchase Order (PO) data, the operator who worked on the product etc., and is collected as the specific components progress along the supply chain.

Visibility - Intervening Variable. The definition of supply chain visibility by Williams et al 2013 is "as access to high quality information that describes various factors of demand and supply". For information to be of high quality, it should be timely, accurate, complete and in a working format. To achieve a peak levels of supply chain visibility, various types of good quality information must be obtained.

Greater visibility would mean that customers can confirm whether the manufacturer is really sustainable and socially responsible.

Transparency -Dependent Variable. Transparency is about the revealing of information to business partners, shareholders, customers, consumers and regulatory bodies. Customers and end users of an enterprise's product benefit a lot from transparency. (Duckworth, 2018).

Business can map their complete supply chain therefore gaining greater visibility into their operation. This also improves trust between all the stakeholders namely the artisan, the aggregator, the logistics companies and the customer.

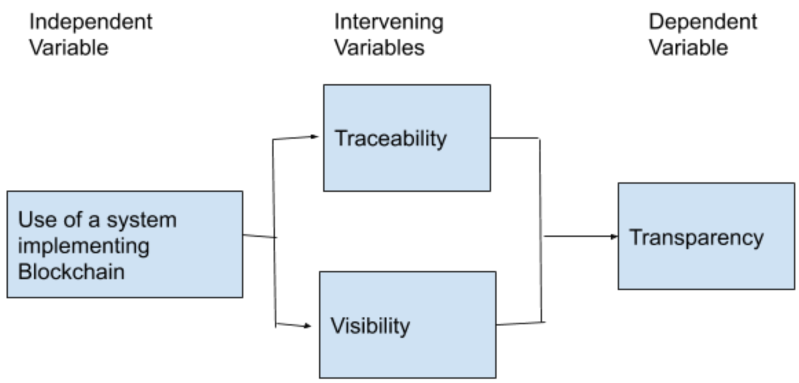

Figure 2: Conceptual Framework

2.8 Conceptual Model

Based on the literature review, existing systems are not built for the distributed delivery context. The proposed approach involves a decentralized distributed system that utilizes a private permission less blockchain to capture, store and manage key product information of each product in its life cycle. This will create a secure, decentralized trail of data for each item as well as distinct product information.

As displayed in Figure 3 below, the tool will have the following components; the distributed ledger, cryptographic encryption, verification function, and the certifying authority. The distributed ledger is the base storage and will contain the encrypted transaction blocks. Cryptographic encryption generates an encrypted key based on a transaction and will continue to build on previous transactional blocks. The block and its encrypted data are sent to the ledger and shared across nodes. The verification function ensures validity of a blocks checksum to confirm that the transaction chain has not been broken. A certificate should be issued by the certifying authority on completion of the process, which can confirm the chain of history of transactions on the block. This certificate should contain the checksums, key and the product details.

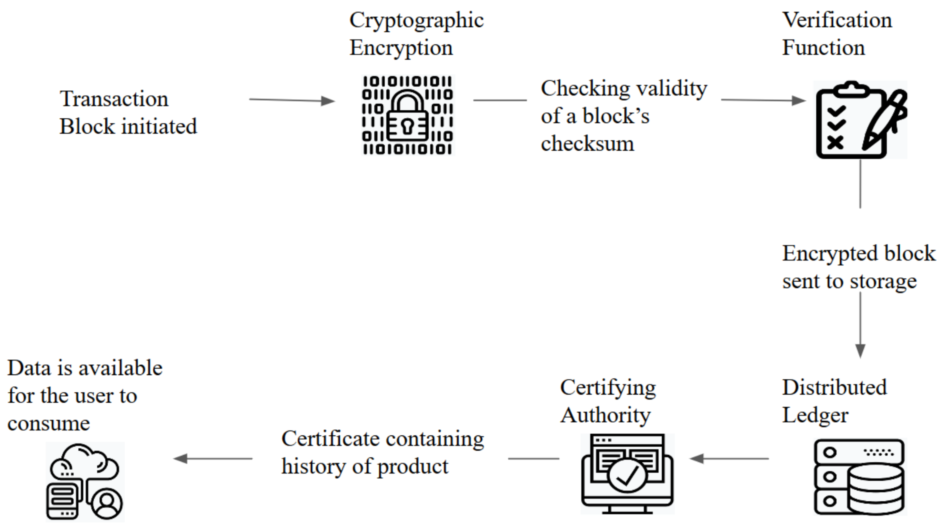

Figure 3: Conceptual Model outlining the components

An aggregator may use just in time inventory management or would need to make purchases in advance and wait for orders. In some cases, businesses use both approaches and would need to track consumption of the items purchased. In order to cater for both cases, transactions can be initiated in 2 ways; when a customer makes an order (Case A) and when the procurement team makes a purchase order (Case B).

Each product will be enclosed with an information tag, in the form of a barcode, RFID or QR code. The tag stands for a distinct digital cryptographic identifier that associates a physical product on the network with its virtual identity.

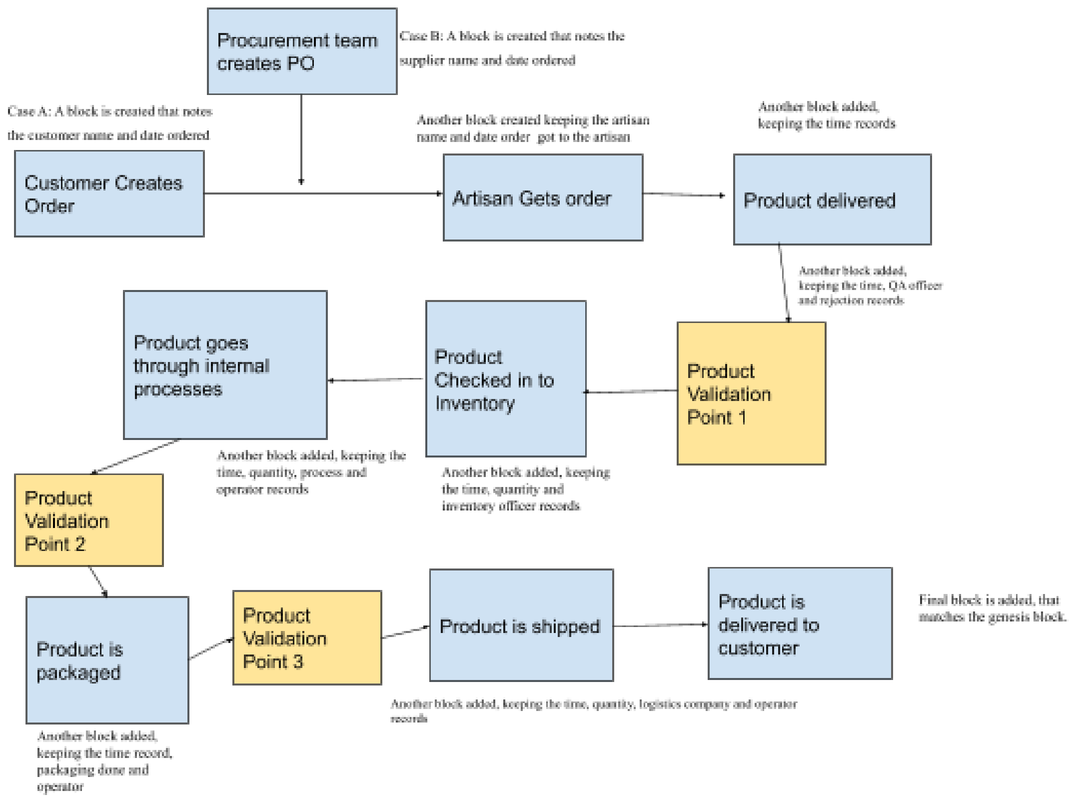

Figure 4: Process Model indicating the flow of processes and data

All the transactions that will take place for each product will be stored in an encrypted state in the distributed ledger. By querying the distributed ledger, a user should be able to have complete visibility of the transactions the product has been through. The verification function shall work with the designated product validation stages to validate the checksums of the previous transactions. Once the product has been shipped and delivered to the customer, a certificate should be issued. The certificate should contain the history of the product's transactions, from the initiation of the order, the in-house processes until delivery to the customer. This certificate should be available for any member of the blockchain network.

2.9 Conclusion

Distributed Ledger Technology enables fundamentally new forms of collaboration between individuals or organizations within the network. It will accelerate and reinforce the already existing social trend towards decentralization towards peer-to-peer interactions and new network organizations.

This research problem requires that it is solved by a system that allows large data amounts to be collected about products and actors in the local distributed manufacturing industry. This data may be valuable to various people, organizations, governments, and researchers. For example, consumers will be able to easily access specific data for any product manufactured, thus allowing them to make better purchasing decisions. Vendors participating in the design, manufacturing and production processes can gain a better understanding of how their products are used along the supply chain. Such feedback is beneficial to help improve their skills and sourcing funds as lenders can be provided with data. The integration of smart contracts into this system can further improve the security of transactions as each item can only be received by the buyer who has signed the respective contract with the seller; enabling the system to identify fraudulent transactions or lost items. All the features described above are provided by the blockchain structure.

CHAPTER 3: SYSTEM DESIGN AND DEVELOPMENT

3.1 Introduction

This research was carried out by adding blockchain capabilities to an existing system. SOKO is a distributed manufacturing company that has an artisan network, a supply chain and existing technology. This chapter captures the analysis of data collected from SOKO for the research to understand the system's shortcomings and describes the design of the proposed system. The system design is informed by the findings of the data collected.

3.2 Software Development Methodology

For software development, the agile software development methodology was used as it allows software to be developed in iterations and gain feedback, as the development process is ongoing. Agile is all about short development, the agile software development methodology was used as it allowed the software to be developed in using cyclical and incremental delivery, failing quickly, recieving feedback, provide customers with business value early on and people, collaboration and interactions (visual paradigm, n.d.). This agile process was composed of one month sprints (iterations). In these iterations, the researcher was involved in generating user requirements, building software, releasing the software to the end user, getting interactions with the end user, gaining feedback and implementing that feedback.

Using cyclical and incremental delivery, failing quickly, recieving feedback, provide customers with business value early on and people, collaboration and interactions (visual paradigm, n.d.).

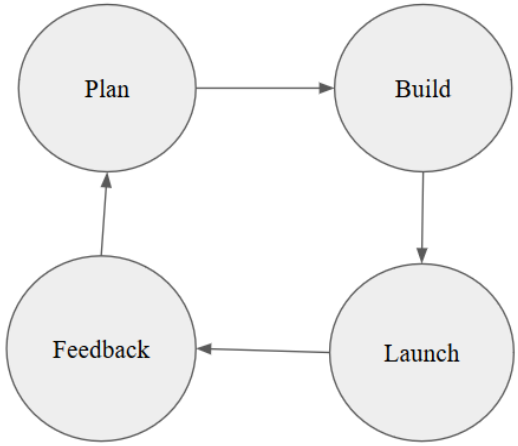

Figure 5: Agile Software Development methodology

3.2.1 Plan

During this stage, the researcher collected information about distributed manufacturers and aggregators. This was information regarding challenges that they face related to transparency, traceability and visibility which were captured by reviewing literature, doing interviews and observation. It was also important to identify their relationship with technology and any technology tools that they use.

With the challenges identified, the researcher then created a design of the prototype of the proposed solution. Mockups and wireframes were used to model the user interface and Unified Modelling Language (UML) diagrams represented the flow of information and interaction of different system components.

3.2.2 Build

In this stage, the researcher implemented the designs made in the previous stage. The programming language used to develop is python for the server side and AngularJS for the client side. Testing and validation of whether the implementation works was also done on this stage.

3.2.3 Launch

The software developed in the previous stage was then released to the intended users for them to use. This process also included developing user training documents and releasing them to the users for them to utilize.

3.2.4 Feedback

The researcher spent time with the users of the technology gaining their insights regarding the software. This feedback was recorded as it informed the next planning stage, especially the design that was developed for the next iteration.

3.3 Feasibility Study

3.3.1 Introduction

In accordance with the software development methodology, the first stage of research involved creating a plan for the technology. With the variables of the study in mind, interviews and observation of the potential users of the technology kicked off. The findings from this study were used to design how the system would work.

A total of 33 respondents; 21 artisans and 12 SOKO supply chain employees, were contacted. They were questioned about the challenges they were facing using the existing technology and how much traceability and visibility they thought the existing technology offered. The information collected was stored in Google Docs and Google sheet and Dovetail were used to analyze the findings.

3.3.2 Analysis of Results

Being that the group of respondents was composed of different entities; artisans and the SOKO supply chain, it was deemed necessary that the findings for each population are analyzed separately and any relationships that affect both parties addressed.

3.3.2.1 Artisan Data

For the study, the researcher interviewed 21 artisans from 3 separate geographical locations, as shown in figure 6 below. The high number of artisans in Kibera was influenced by the large number of artisans who were located in a central place and the proximity to the researcher's base of operations. In Rongai and Dandora, the workshops are scattered and not in a centralized location.

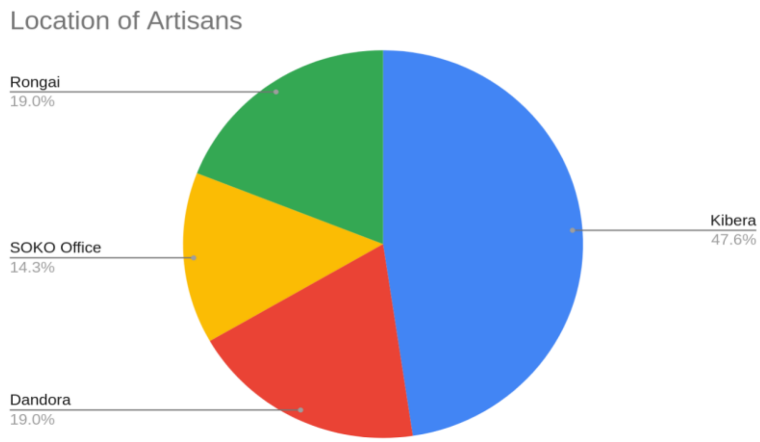

Figure 6: Distribution of artisans

3.3.2.1.1 Usability of Current Solution

Of all the artisans interviewed, only one artisan did not have the SOKO artisan app. This artisan explained that he was still new and had not worked with SOKO long enough to purchase an android phone and install the app. Of the remaining artisans, only one expressed that they felt that the app did not meet their business needs. 2 artisans were not happy with the service that the app provided. They stated the reason for unhappiness to be that they were not getting as many orders as they would like to receive. From the figure 7 below, it was clear that usability of the current solution was not a problem for the artisans and they would be happy to continue with it.

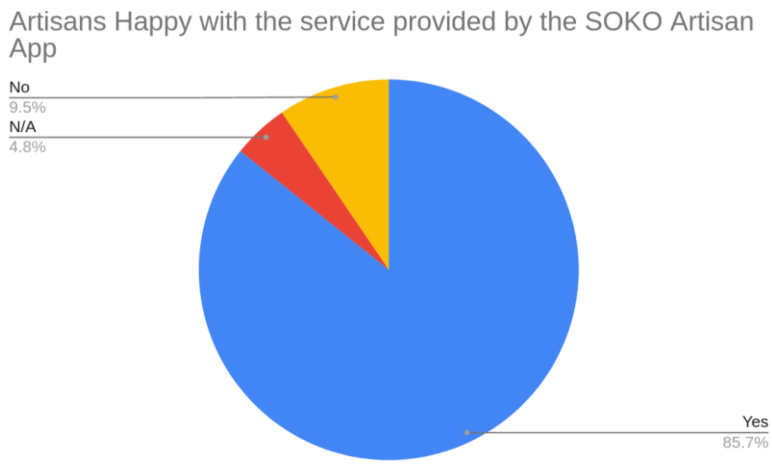

Figure 7: Feedback on usability of the existing technology

3.3.2.1.2 Traceability

To understand the effect that adding better traceability measures would bring, artisans were asked if they would like to know more information about products they have worked on, after the artisan has delivered the product and been paid by SOKO. This would include information about the customer who wore products they have worked on and the quality of their products after value addition by SOKO.

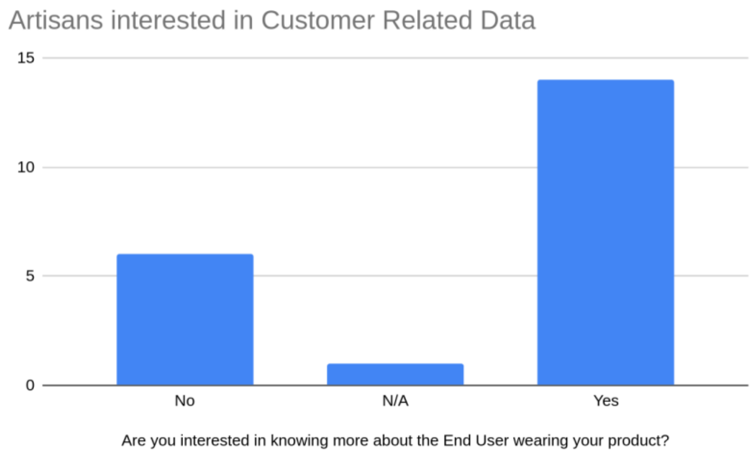

Figure 8: Artisan respondents' interest in final customer data

These questions received varied answers with more artisans interested in knowing about the customers than about quality. The artisans who were not interested cited that it was none of their business what happens to their product after they had handed it to SOKO and gotten paid for it. From figures and 9, it is clear that the majority of the artisans would like to know more information about products they have worked on, even after they have handed them over to SOKO.

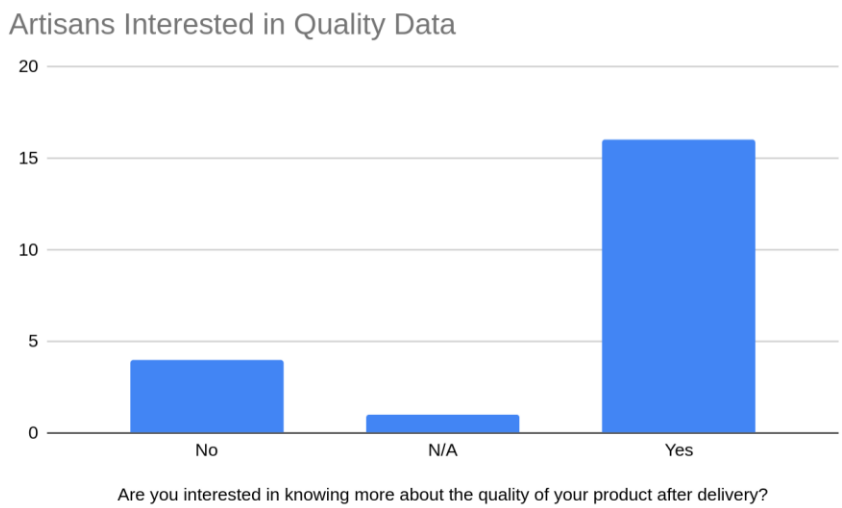

Figure 9: Artisan respondents' interest in quality related data

3.3.2.1.3 Visibility

With the SOKO Artisan App, it is clear that SOKO has done very well with providing artisans with visibility of matters relating to artisans such as their orders, payments and any deductions made to their payments. When posed with the question on whether there was anything at SOKO they would like more visibility, 61.9% said yes, as shown in figure 10. Majority of those who wanted to know more, wanted visibility into SOKO's pricing model and how SOKO decides the price of a product.

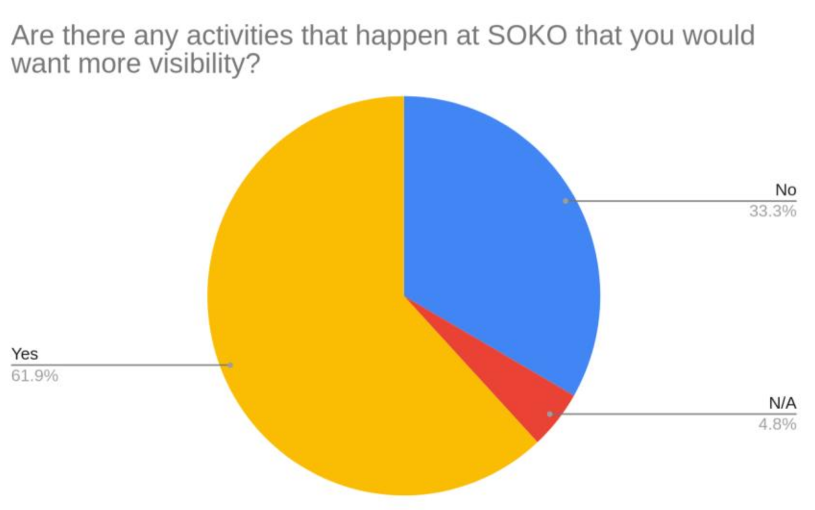

Figure 10: Artisan respondents' views on visibility

3.3.2.2 Supply Chain Data

12 people were interviewed and observed in the Supply Chain, 10 being operators and 2 being part of the senior management. Semi structured interviews and participant observation were the methods used to collect data on the operators. For the senior management, the interview methods were the same, but non participant observation was used. It was clear that the supply chain was a fast moving operation and speed was of the essence.

A common question amongst both the operators and senior management was for the team to rate the ease of tracing and finding a product in the existing technology. Figure 11 below shows the graph of the responses. The average rating was 2.67, on a scale where 1 is very difficult and 5 is easy.

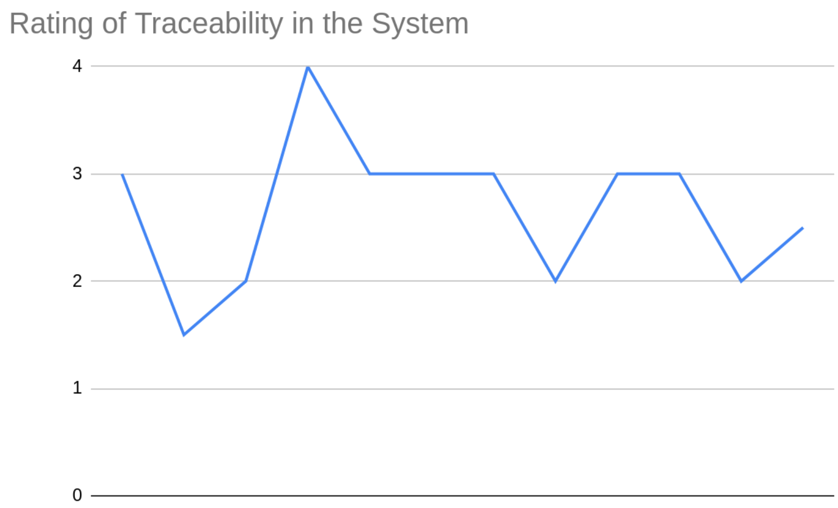

Figure 11: Traceability rating of the existing technology

3.3.2.2.1 Opening too Many Pages

When the data was uploaded on Dovetail and codified, the subject of opening too many pages performed an activity and it was even worse when trying to find a product. To understand the usability of the existing technology, the participants were asked what changes they would make on the product and a majority of them answered that they would reduce the number of pages and number of transactions that a product undergoes. As shown in figure 12 below, the phrase 'opening many pages' appeared 21 times compared to tracing a product's movement which was second with 15 appearances. This indicated that this was a major pain point that hindered the process of tracing products and affected the usability of the technology.

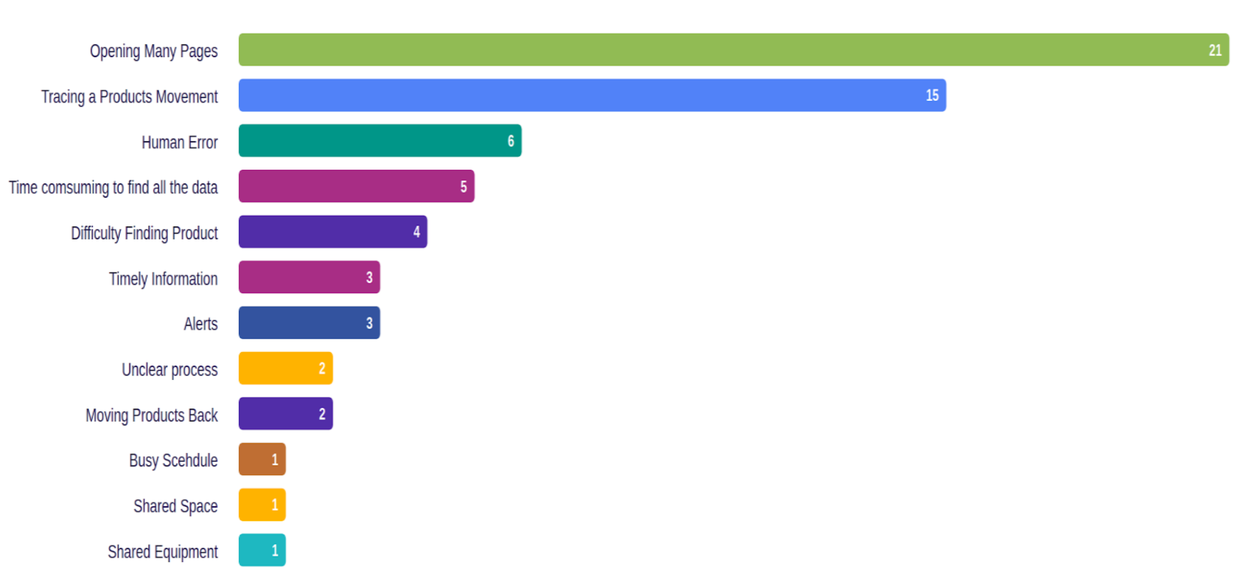

Figure 12: Results of axial coding

3.3.2.2.2 Tracing Product Movement

When the question was posed of whether the participants thought there was traceability in the system, 100% of the participants said yes. However as shown in figure 13 below, some of the participants added more statements indicating while it was possible to find a product, the process is time consuming and tedious. From the researchers observation, when working with the supply chain operators, if a product was missing, finding out the last point it was logged would take about 5 minutes and opening several pages.

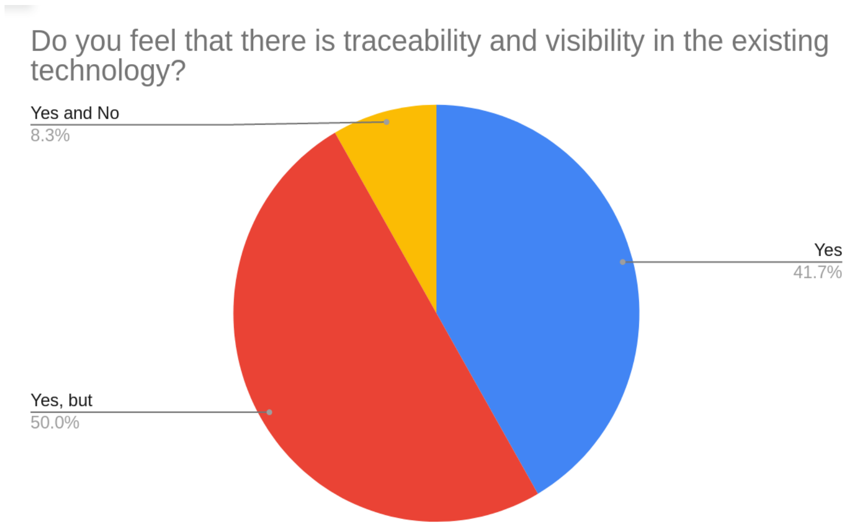

Figure 13: Traceability on the existing system

3.4 Requirement Analysis

By analyzing the feedback received from the respondents it is clear that there is a lot to be done to improve transparency in the SOKO ecosystem. The ideal system would offer the tracing of a product from when it is worked on by an artisan to when it gets to a customer. It is also critical to the supply chain team that all this information be represented in a single page that is accessible to all in SOKO. The proposed system should be immutable, allow the collection of data to be collected, and should show the data regarding each transaction that a product undergoes.

3.4.1 Functional Requirements

Functional requirements are the main things a user expects from software. These are requirements that specify a function that a system or system component must be able to perform. In this proposed system, the functional requirements are:

- The system must store records of each transaction that a product in the supply chain goes through
- The transaction data collected should have the user who initiated the action
- All the stored transactions must be immutable.

- A central page where a supply chain team members can search and view all the transactions that a particular product has.
- The system must reduce the time it takes to find information about a product.

3.4.2 Non Functional Requirements

These requirements are used as a point of reference to infer how a system operates, instead of the specific behaviors of the system. Nonfunctional requirements are not essential to how a system operates and functions but ensure the applicability and effectiveness of the entire software system. For this system, they are:

- Data integrity through immutability
- Accessibility of the system to all users
- Response time to queries by users
- Security
- Usability
- Ease of maintenance

3.5 System Design

This details how the system should behave as well as the flow of information across the different actors, objects and components. System design entails schematic representation of the proposed architectures and models for the system as well as graphical representation of the various system aspects. Doing system design allows the researcher to validate the system requirements, meet user expectations and update the flow of information as needed.

In this study, the architecture, design and software processes in the system were modelled using Unified Modelling Language (UML) diagrams.

3.5.1 Use Case Diagram

A use case model describes the functionality of the system i.e. the system's functional requirements. It is a representation of the interaction the system and it's user and it displays the relationship between the user and the activities that the user participates in. To put it simply, it demonstrates the different ways that the user will interact with the system.

Figure 14 shows the interaction between the main actors, artisans, supply chain operators and supply chain management and the system.

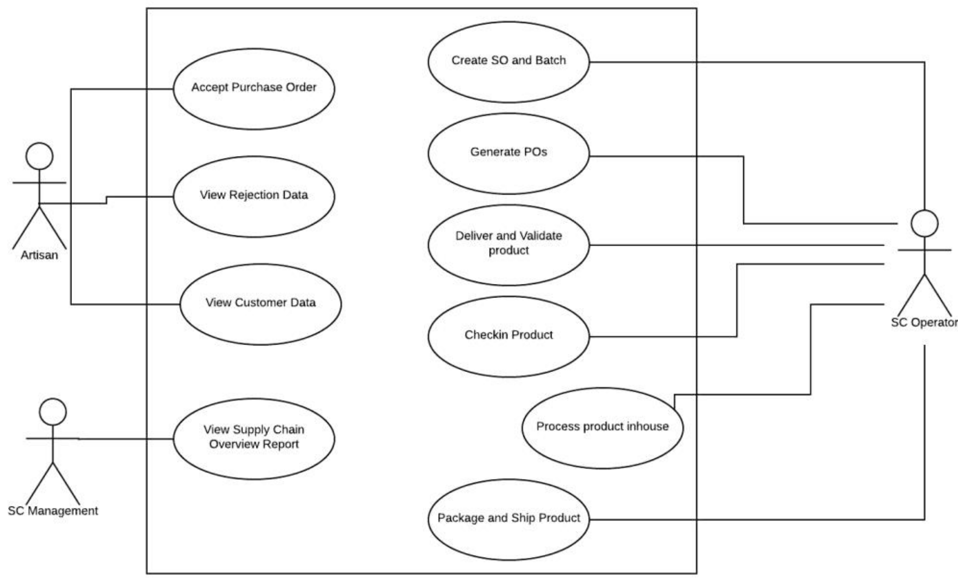

Figure 14: Use Case Diagram

3.5.2 Sequence Diagram

It is an interaction diagram that shows the communication between objects over a period of time in a use case. A sequence diagram shows the order of objects and classes participating in the layout and the exchange of messages between objects that are required for the functionality of the layout.

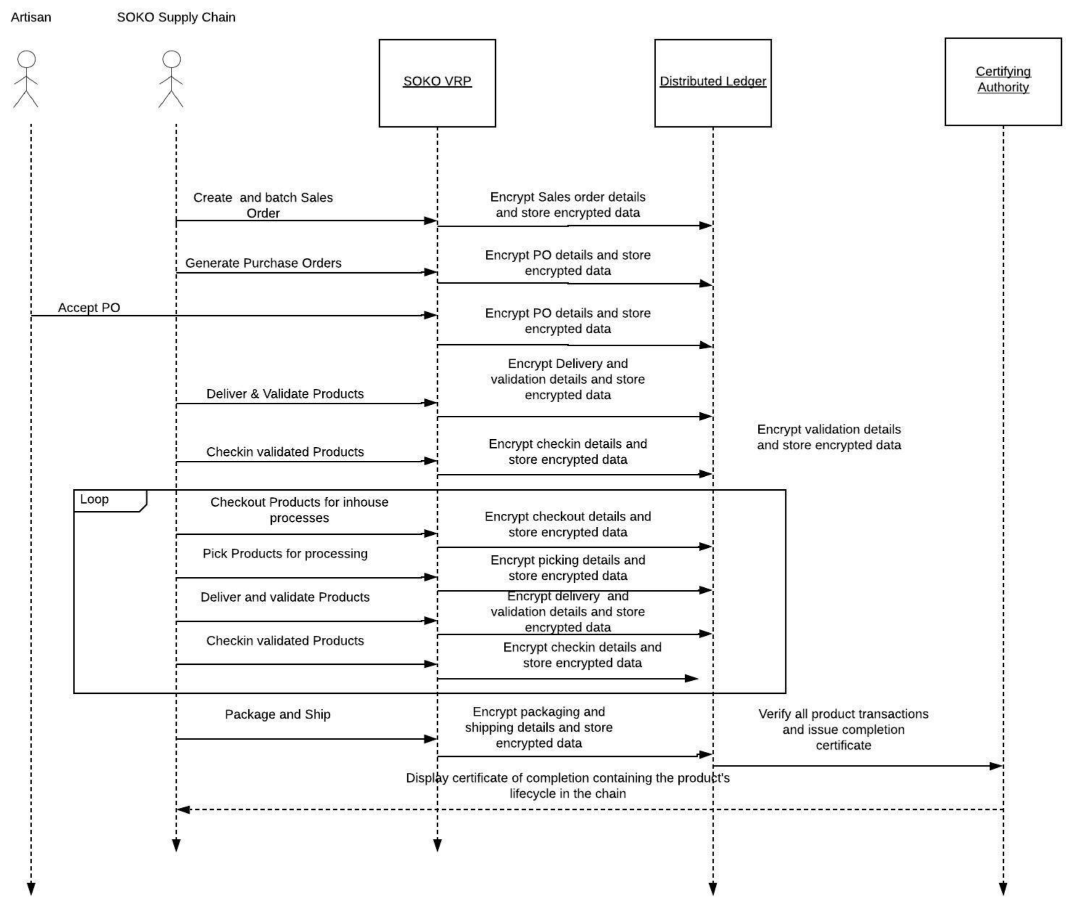

Figure 15: Sequence Diagram

3.5.3 Data Flow Diagram

Data flow diagrams (DFD) represent the processing of data by a system with regard to inputs and output. They are used to show the flow of data as it moves throughout the system, in terms of inputs and outputs and the data stores (Burge, 2011). Figure 16 below shows the data flow diagram outlining the inputs and outputs in this system.

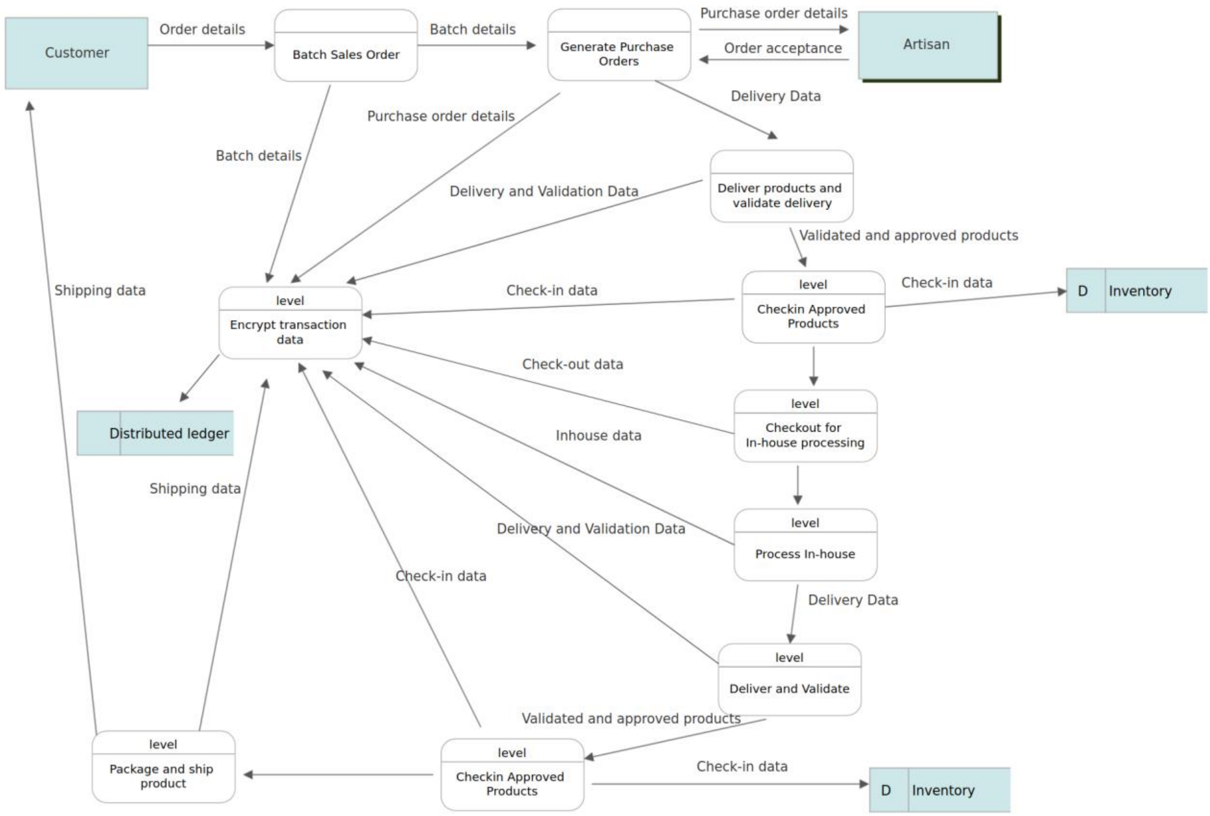

Figure 16: Data Flow Diagram

3.6 System Architecture

For the purpose of this study, the researcher modified an already existing system. It was important that the additions proposed by the researcher maintain the core functionality of the system and only improve it.

The additions to the system were the following components; the distributed ledger, cryptographic encryption, verification function, and the certifying authority.

Cryptographic encryption generates an encrypted key based on a transaction and will continue to build on previous transactional blocks. The encryption function is triggered by users moving a product through the supply chain. The verification function ensures validity of a blocks checksum to confirm that the transaction chain has not been broken. The verified block and its encrypted data are sent to the ledger and shared across nodes. The distributed ledger is the base storage and contains the encrypted transaction blocks.

A certificate should be issued by the certifying authority on completion of the process, which can confirm the chain of history of transactions on the block. This certificate should contain the checksums, key and the product details.

3.7 Development Tools

The existing system is built using python programming language on the Django framework which offers high scalability and a fast prototyping environment. MySQL database is used for information storage. Blockchain technology is used in the encryption and verification and a hyper ledger used for transaction storage.

3.8 System Requirements

The system built is a web-based system and must run in such an environment. For a device to operate the system it must have the following:

- A device with an operating system; Windows 7 or higher, Ubuntu 16.04 or higher, Android 6.0.1 or Mac OSX.
- The computer processor should be above i3 2.4GHz, with a minimum RAM of 4B and minimum hard Disk Space of 10GB.
- The Computer must be pre-installed with a web browser preferably Chrome or Firefox both of versions after 2018.

3.9 System Functionality

To ensure that the main research objective is met, the researcher will be adding key modules to the existing system. These are the modules described on the conceptual model and the system design.

3.9.1 Cryptographic Encryption and Block Creation

In the system, a class called Block contains the method _hash_ which is what is used to encrypt that data received using sha256 encryption. Method generate_next creates the block and adds the block to the chain.

```
class Block(models.Model):
    time_stamp = models.DateTimeField(auto_now_add=False)
    index = models.IntegerField(auto_created=True, blank=True)
    data = models.TextField(blank=True, max_length=255)
    hash = models.CharField(max_length=255, blank=True)
    previous_hash = models.CharField(max_length=255)
    chain = models.ForeignKey(to='Chain', on_delete=models.CASCADE)
    nonce = models.CharField(max_length=255, default=0, blank=True)
    action = models.CharField(max_length=255, null=True, blank=True)

    def __str__(self):
        return "Block " + str(self.index) + " on " + self.chain.name

    def __repr__(self):
        return '{}: {}'.format(self.index, str(self.hash)[:6])

    def __hash__(self):
        return sha256(
            u'{}{}{}{}'.format(
                self.index,
                self.data,
                self.previous_hash,
                self.nonce).encode('utf-8')).hexdigest()

    @staticmethod
    def generate_next(latest_block, data, action=""):
        block = Block(
            data=data,
            index=latest_block.index + 1,
            time_stamp=datetime.datetime.now(tz=pytz.utc),
            previous_hash=latest_block.hash,
            nonce=SymmetricEncryption.generate_salt(26),
            action=action,
        )
        while not block.valid_hash():
            block.nonce = SymmetricEncryption.generate_salt(26)
```

```
        block.hash = block.__hash__()

        # block.save()                # todo: remove

        return block
```

The encryption function is triggered by users performing actions in the system. These actions can be actions like creating a purchase order, validating a product, checking in a product etc. The method described below is added to the save method of every activity that the researcher would want to log in the value chain. When the save method is called, the encrypted block is added to the chain and saved on the ledger.

```
def get_chain(self):
        chain = None            chain = self.parent.get_chain()

        if chain is None:
            chain, created = Chain.objects.get_or_create(name=self.code)
            if created:
                chain.create_seed()
        if self.parent:


        return chain

    def add_to_chain(self, data, action):
        chain = self.get_chain()
        block = chain.add(data, action)
        previous_block = chain.last_block
        if block.is_valid_block(previous_block):
            block.save()
```

3.9.2 Verification Function

The system checks the validity of blocks to ensure that they match with the previous block. The method below is_valid_block checks the block of the previous blocks hash and if valid, it adds it to a chain.

```
  def is_valid_block(self, previous_block):
```

```
        if self.index != previous_block.index + 1:
            log.warning('%s: Invalid index: %s and %s' %
                        (self.index, self.index, previous_block.index))
            return False
        if self.previous_hash != previous_block.hash:
            log.warning('%s: Invalid previous hash: %s and %s' %
                        (self.index, self.hash, previous_block.hash))
            return False

        if self.__hash__() != self.hash and self.index > 1:
            log.warning('%s: Invalid hash of content: %s and %s' %
                        (self.index, self.hash, self.__hash__()))
            return False
        if not self.valid_hash() and self.index > 1:
            log.warning('%s: Invalid hash value: %s' % (self.index, self.hash))
            return False
        return True

    def valid_hash(self):
        """simulate Proof of work"""
        return self.__hash__()[:4] == '0000'
```

3.9.3 Certifying Authority

To verify that the chain is valid and that all the blocks follow a sequence, the method is_valid_chain checks the indexes of the blocks within the chain and verifies their validity.

```
    def is_valid_chain(self, blocks=None):
        blocks = blocks or list(self.block_set.order_by('index'))
        if not len(blocks):
            log.warning('Empty chain')
            return False
        if len(blocks) == 1 and blocks[0].index != 0:
            log.warning('Missing seed block in chain.')
            return False
        if not all(pblock.index + 1 == block.index == required_index
                   for pblock, block, required_index in zip(blocks[:-1], blocks[1:],
range(1, len(blocks)))):
            log.warning('Chain is not sequential')
            return False
```

```
        return all(block.is_valid_block(pblock)
                   for pblock, block in zip(blocks[:-1], blocks[1:]))

    def replace_chain(self, new_chain):
        if self.is_valid_chain(new_chain) and len(new_chain) > len(self):
            self.block_set.all().delete()
            for block in new_chain:
```

3.10 System Testing

To ensure that the functional and non-functional requirements of the system were met, different types of tests were carried out. These tests include unit tests, integration tests, and user acceptance tests.

3.10.1 Unit Tests

In this stage of testing, individual units/components of a software are tested. Tests are performed on the key components of the system to ensure they can operate independent of the other parts of the system. The purpose of the test is to validate that each unit of the software performs as designed.

Table 5: Unit Test and Results

Component	Test Case	Test Steps	Test Data	Expected Result	Actual Result	Status
Cryptographic Encryption	Encrypt data collected from transactions	1. Select a set of data 2. Encrypt the data 3. provide the	Pass a block of data through sha256 encryption	Hashed value	Hash value	Pass

		sha256 encrypted data				
Block Creation	Encrypted data is added to a block	1. Create a product transaction 2. Pick the transaction data to be encrypted 3. check if its index matches with another existing block 4. if no, create a new block 5. If Yes, add the block to a chain	Create purchase order	A block indicating the activity	A block indicating the activity	Pass

3.10.2 Integration Tests

During integration testing, individual units are combined and tested together. Integration tests validate the interaction of various components and behavior if put together. The purpose of this level of testing is to uncover defects in interactions between integrated units.

Table 6: Integration Tests and Results

Test Case	Test Steps	Test Data	Expected Result	Actual Result	Status
Chain Creation	1. Create a product's transaction 2. Transaction is encrypted 3. Block is created 4. Another transaction is initiated 5. Data is encrypted 6. Block is added to a chain	Create a purchase order. Accept the order, add a delivery and validate the delivery.	A chain containing blocks indicating the actions of PO creation, acceptance, delivery and validation	A chain containing blocks indicating the actions of PO creation, acceptance, delivery and validation	Pass
Chain is Verified	1. Several products	Create purchase	A chain of the blocks all	A chain containing	Pass

	transactions are made 2. Blocks are added to the chain. 3. Chain is verified as valid with the transaction's blocks being sequential	orders, deliver, check in and take product for value addition, package and ship	within the same chain	blocks indicating the actions of PO ,checkin, value addition, packaging and shipping	

3.10.3 User Acceptance Test

During the User Acceptance Tests (UATs), actual software users use the software and test it to confirm that it meets expectations and can handle required tasks in real-world scenarios, according to specifications. User Acceptance tests ensure the functional requirements are met and the research objectives are achieved.

Table 7: User acceptance tests and results

Scenario	Test Case	Precondition	Test Steps	Test Data	Expected Result	Actual Result	Status
Visible transaction of product's	User should be able to view the	All of the products transaction through	1. Search for the produ	Batch Test 05/28	View of the movement of the	View of the movement of the	Pass

activities	previous transactions	the supply chain took place on the system	ct on the search page 2. Open the details and view transactions		product through the supply chain	product through the supply chain	
Product Goes through Supply Chain	User should be able to push the product through the supply chain without failure	Transactions taking place on the system	1. Push products through the system	Batch Test 05/28	Product Goes through Supply Chain without failure	Product Goes through Supply Chain without failure	Pass

CHAPTER 4: RESEARCH DESIGN AND METHODOLOGY

This chapter entails the research methodology that was used to achieve the stated research objectives. It covers the research design, data collection methods, and data analysis techniques procedures. To properly investigate the research problem, it was imperative that the researcher uses the build methodology.

4.1 Research Design

4.1.1 Research Philosophy

The researcher used an interpretivist research approach in investigating the research problem. Perspective used in formulating the research problem, research objectives and choices made in the research design belong only to the researcher. It was therefore necessary that the researcher gather as much research data from many sources during the literature review.

4.1.2 Study Design

For this course of study, the researcher used exploratory research design with a leaning towards using the analysis of 'insight-stimulating' examples. This is because there isn't a lot of work done in the area of using Blockchain in distributed manufacturing that could act as a guide. This method required intensive study and exploration into the area of Blockchain in cryptocurrency as well as applications of other DLTs. By studying these examples, the researcher was able to bring together an understanding of the key features and insights required to make traceability and visibility possible.

To achieve this, the researcher started by reviewing the relevant literature including the current applications of DLTs in cryptocurrencies and went further to review other areas apart from the financial sector where DLTs have been used. The literature review served to identify the current capabilities of DLTs, the benefits they add, why using Blockchain is ideal for the research problem, and what is required to build a technology that provides traceability and visibility.

A prototype was designed and developed; the prototype was later evaluated in order to evaluate whether the afore-stated objectives had been met. To test the prototype, the researcher used the single case study methodology with the group selected in the case study being the organization SOKO Inc. SOKO was ideal for this situation because the organization has an internal supply chain and for manufacturing, works with artisans who make jewelry and are distributed all over Nairobi. One of the current challenges that the organization faces is the difficulty in traceability since once the products are delivered from the artisan, it is difficult to tell which artisan worked on which product. The senior management in the organization would also like better visibility in the flow of product from the creation of the order to the order being delivered to the customer.

The limitation in this methodology is the use of a single case study. A control group or using multiple case studies would provide more information towards solving the research problem. However, the researcher used only one case study which limited the scope of study. Using case studies is time consuming and paired with the use of interviews and observation, the researcher would have faced time constraints during the data collection and data analysis stage.

4.2 Target Population & Sampling

As indicated in the research design, the researcher used a case study of SOKO Inc., an organization that works as an aggregator of artisans. This organization was selected as it is representative of the typical scene in the distributed manufacturing sector. Also, it is convenient to the researcher since the researcher has an established relationship with the organization and the artisans.

The organization has access to a network of over 2000 artisans with more than 250 workshops spread all over Nairobi, mostly in Kibera, Dandora and Rongai areas. SOKO also has 80 employees in the Kenya office. The sampling methods used in this study were purposive and convenience based sampling. Only artisans who were actively working with SOKO over the last year were approached. Table 8 below describes the numbers of the total population and the sampled population.

Table 8: Target Population and Sampling

Area	**Description**	**Total Population**	**Sampled Population**		**Total**
			1st Round	**2nd Round**	
Kibera	Artisan	59	10	12(5 New)	15
Rongai	Artisan	36	4	5(1 New)	5
Dandora	Artisan	28	4	5(1 new)	5
SOKO Office	Artisan	7	3	5(2 New)	5
SOKO Office	Supply Chain Operator	54	10	11(6 new)	16
SOKO Office	Senior Management	3	2	1	2
Total			33	35	48

A larger number of artisans in Kibera were sampled compared to the artisans in Dandora and Rongai. This was influenced by Kibera's proximity to the researcher's base. Additionally, the majority of the artisans in Kibera are situated in the Makina Market which centralizes them making it easier for the artisans to be contacted.

The respondents in Dandora and Rongai were more difficult to reach as they are not in central location. Their workshops are spread out all over the area, some requiring the use of both matatu and motorbike transport to reach them. The researcher reached out to the artisans whose workshops were close to matatu stages and did not require travelling long distances.

SOKO also has artisans who do sampling and are located within the SOKO office premises. The researcher contacted 3 of the artisans, 2 who have worked with SOKO the longest and one who joined the organization in 2019. This was to ensure that the data captured would not be biased by the period of time spent working with the organization.

Employees in the organization who work in the supply chain department and handle the jewelry product were a key part of the study. Their insights were essential as they encounter the day to day problems associated with the lack of traceability and visibility. Senior management, specifically the Supply Chain Manager and the second in command were included as they gave feedback on overall visibility and transparency in the organization.

4.3 Data Collection

Two rounds of data collection took place, in March 2020 and May 2020. The first round involved observation and in person interviews with the respondents to capture information on the usage of the technology that was already existing. As indicated in the software development methodology, this first round of data was used to inform the development of software. During the second round of data collection, phone interviews were incorporated, in addition to the methods used during the first round. This was due to the Covid 19 pandemic, which hindered the movement of the researcher.

At the start of the data collection sessions, the researcher would introduce themselves to the participants in the case study and explain the purpose of the study. In these moments, the researcher provided details of the study such as the time period, scope and explained that there would be no collection of data that the participants might deem private. Participants of the study were asked to provide any questions, requests or concerns that they have so that they can be addressed.

4.3.1 Interviews

Data collection commenced with conducting semi-structured interviews with artisans, supply chain operators and senior management, in the respective order. On the first round of interviews, the goal was to get a general overview of the experience that the participants have using the current technology. On the second round, for the respondents who were available for in person interviews the researcher showed the respondents the changes made on the software and asked them to give their thoughts. During this period, the measures input due to the Covid 19 pandemic that restricted movement made it necessary to use telephone interviews to reach the respondents in Dandora and Rongai. Screenshots of the software were sent to the artisans via WhatsApp and later, the researcher called the respondents to follow up with the questions. Kibera respondents were interviewed during face to face meetings at their places of work. In this case, the respondents interacted with the application during the face to face meetings.

Preset interview questions in an interview guide were used to start the interview and any interesting issues that came up were explored in depth. Interviews were conducted at the participant's workstation to minimize any interruptions from their duties.

Interview questions were designed keeping in mind the objectives and the variables of the research. The process of conducting the interviews was iterative. More questions were developed after each iteration of the software was done and given to the participants to test. This ensured that the researcher was in line with the research objectives and was developing a solution that is favorable to the participants.

4.3.2 Observation

"Observation is a purposeful, systematic and selective way of watching and listening to an interaction or phenomenon as it takes place" (Kumar, 2014). In this study, observation is appropriate as it is important to understand the interaction of the participants and the technology. While interviews gave insights into how the participants feel about the technology and the challenges they face, it was important that the researcher infers on their own since it could be difficult for the participants to detach themselves from the existing technology. Taking notes, photographs, audio and video were the methods used to record the data.

The researcher used non participant observation to observe the artisans and the senior management at their place of work using their current technology to identify ease of use. With the supply chain operators, participant observation was used. The researcher joined the operators and performed their duties while also using the technology. Working with the operators provided the researcher with insights about ease of use as well as the attitude of the operators towards the technology which can affect uptake of the technology.

Another key aspect that was tracked is the ease of implementation of the technology. This was tracked by observing the design and software development processes. From these insights, the researcher could improve the development process for the next iteration and also provide insights into the field on how to navigate specific circumstances.

After every session of observation, the researcher would set aside 20 minutes to compile their notes or any other material collected.

The observation process was also iterative, with the researcher observing the participants after every iteration of the software was released. It is necessary that the solution remains easy to use, and if there are any existing problems, the next iteration resolves them.

4.4 Data Analysis

Content Analysis: Since most of the data collected was qualitative, the best method to analyze this data is the qualitative method. The researcher used the content analysis method and was looking to find any patterns and themes that would emerge. Some predetermined themes based on the research objectives were; traceability, visibility, transparency and how they were achieved as each iteration went by. While the usability of the technology is not on the objectives, it is a key aspect of determining the uptake, therefore it was also a key theme.

|**Data handling Environment:** The researcher kept the collected data on Google Drive as it has the functionality to store text, images, audio and video. It is also online which reduces the risk of losing the data and has a lot of storage which allowed the researcher to make duplicates of data so that the original data collected retains its original form.

Data analysis tools: After every session of observation, the researcher would set aside 20 minutes to transcribe the notes to and compile any other material collected. The main tool used to analyze data was Google Sheets as it offers an appropriate user interface and visual tools such as graphs and pie charts for data representation. Dovetail, a data analysis application was also used to codify the data. After every data collection excursion, the researcher would do open coding to analyze the data and identify any recurring themes or patterns.

Data Coding: Axial coding was then done in order to find relationships or connections within these patterns or themes. While analyzing the data collected from the design and software development process, the researcher was looking to identify themes and categories as well as any approaches taken that made the software design and development process easier or more difficult. These themes were also analyzed in the method described above and used to inform the next iteration.

Use of the Analysis Results: The final data set was used to inform the next iteration of software development and finally was compared against the research objectives to identify if the purpose of the research study was achieved.

A foreseen limitation with this proposed analysis approach was the likelihood to miss some key themes since the researcher has already set themes. It was also possible for the researcher to make conclusions based on their previous bias, which may not be an accurate reflection of the real-world situation.

CHAPTER 5: Results and Discussion

This chapter captures the analysis of data collected for the research. Qualitative research analysis approach was chosen for this study because qualitative methods are especially useful in discovering the meaning that people give to events that they experience (Merriam, 1998).

The experiences and feedback of the participants provided insights to the research objectives of this study. By listening to, observing and analyzing the experiences of the respondents, important data was captured regarding traceability, visibility and transparency in distributed manufacturing. In this chapter, the objectives of the research are addressed with supporting evidence, including both direct quotes and feedback from the participants.

5.1 Introduction

The primary objective of this study was to address the lack of transparency in the informal distributed manufacturing industry by developing and implementing systems that provide traceability and visibility in the sector using distributed ledger technology. One of the specific objectives of the study was to identify a DLT implementation whose features support provision of visibility and traceability in the distributed manufacturing industry in Kenya.

In the SOKO case study, the researcher used interviews and observations as the primary method of data collection. Interview and observation notes were taken on a notebook and after the interview transferred to a Google Doc which is secure from loss and available from any device with access to the internet. After all the data was centralized in a Google Doc, the researcher then transferred the data to Dovetail which is a data analysis tool that works best with qualitative data. This allowed the researcher to review the data and tag any phrases that were appearing several times, which is the process of codifying. Questions and responses that were answered with a yes or no or those that were related to rating the existing system which are numerical were copied over to a Google Sheet, which helped the researcher analyze and visually represent the feedback.

In the course of this chapter, comparisons between the findings of the first round and the second round of data collection were compared in order to address the study's research objectives.

5.2 Presentation of Results

5.2.1 Demographics of Participants

The total number of participants of the study was 48 people, 30 being artisans and 18 being SOKO employees who work in the supply chain. The composition of respondents is detailed in depth in figure 17 below. The first round of data collection had a total of 33 respondents; 21 artisans and 12 SOKO employees. The second round had a total of 38 respondents; 26 artisans and 12 SOKO employees. 33 respondents appeared on both the first round and the 2nd round of data collection and 15 appeared on only one round.

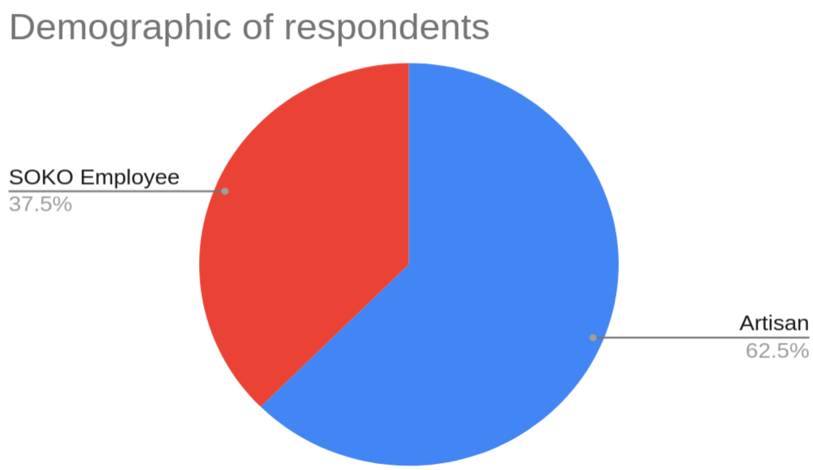

Figure 17: Distribution of respondents

Two thirds of the respondents interviewed were male, and the remaining third were female, as shown in figure 18 below. The disproportionate number was due to the larger number of artisans interviewed. The artisan community has historically been male dominated. Out of the 30 artisans interviewed, only 3 were women. With follow up questions, the female artisans explained that women in their communities preferred other jobs whose returns were immediate and did not require learning a skill such as laundry and housekeeping services. They cited that to become an artisan, one has to apprentice at a workshop where the workshop owner trained them. This could take from 3 months to a year before one can be an accomplished artisan. Of the 3 women interviewed, 2 were workshop owners who have employees in their workshops.

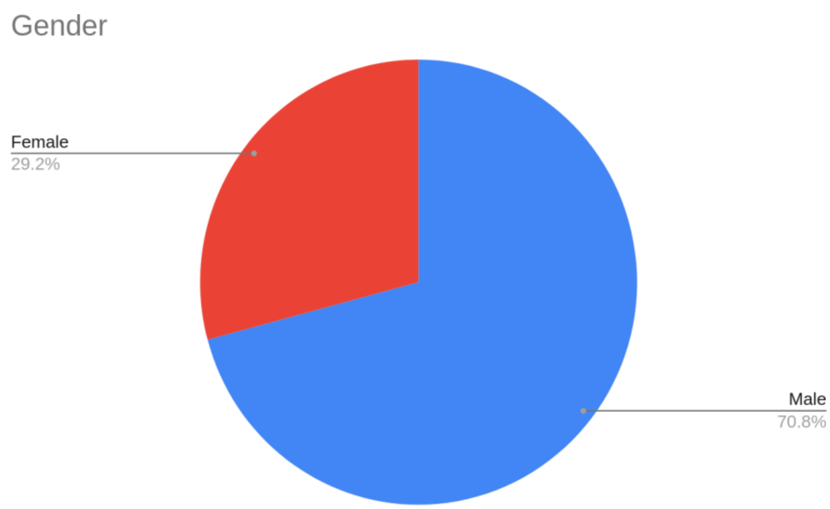

Figure 18: Gender distribution of Respondents

Figure 19 below shows that 48% of the artisans interviewed owned workshops while the other 26% were co-owners of workshops. The 28% who did not own workshops relied on the use of machines and workshop spaces belonging to workshop owners. They also worked as part time non-permanent employees at other workshops.

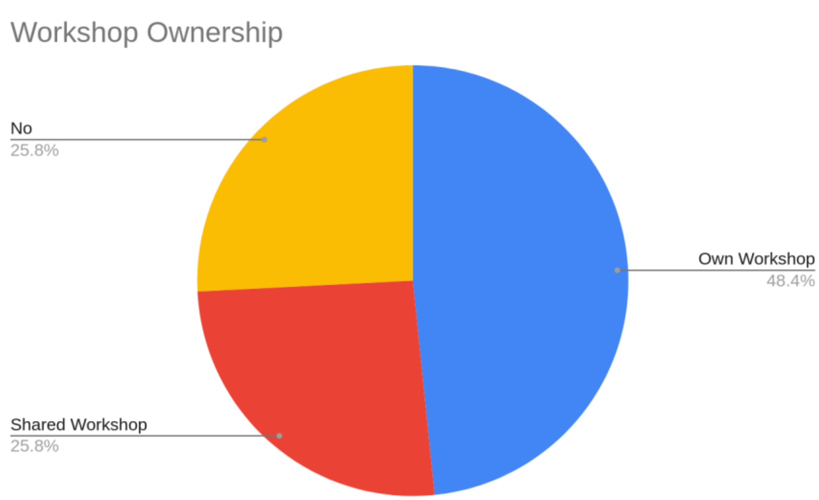

Figure 19: Artisan workshop ownership

5.2.2 Usability

Compared to the first round of the data collection where 86% of the artisans were happy with the technology solution offered by SOKO, 100% of the respondents on the second round of data collection indicated that they were happy, as shown in figure 19 below. They were particularly happy that the SOKO artisan allowed them to keep track of their orders, payments and more recently added loans. 100% of them did not have any challenges with the app. The only challenge cited by the artisans was the decrease in the number of orders they were receiving, which they understood was caused by the Covid 19 pandemic.

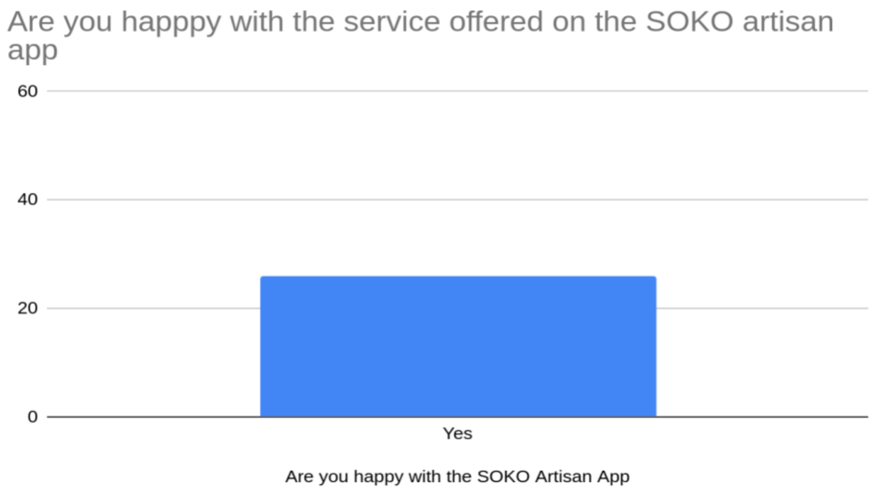

Figure 20: Feedback on usability

5.2.3 Traceability

During the first round of data collection, the supply chain team gave traceability on the existing system an average rating was 2.67, on a scale where 1 is very poor and 5 is excellent. This was attributed to the users having to open several pages in order to view the movement of a product. On the improved system, changes done on a product going through the system were captured, tagged, and a block created which was indexed in order. This led to the team giving the system's traceability an average rating of 4.8.

Figure 21 below indicates that the lowest rating given was 4, where the users indicated that they would like to interact with the technology for a longer period in order to give a detailed analysis.

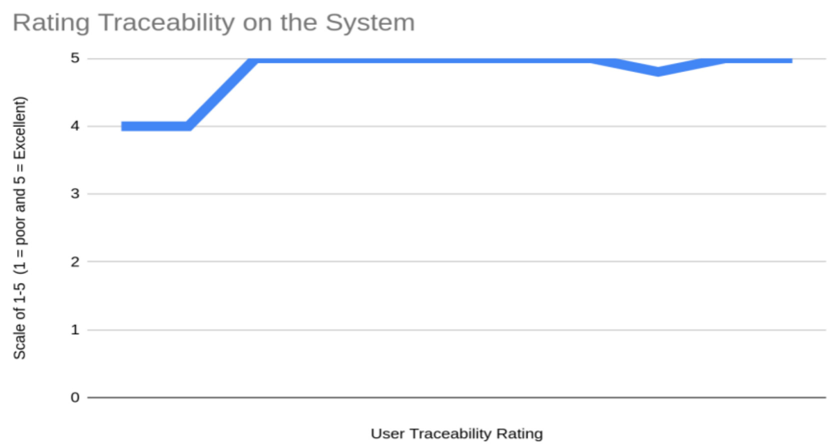

Figure 21: System Traceability Rating

On the artisan side, the researcher ran into a challenge of physically differentiating products from different artisans once they were delivered to the SOKO premises as they are stored in the same storage bins. It was clear that to accurately track an individual artisan's unit, the unit would have to be tagged when being delivered by the artisan to the SOKO premises. This is further discussed in the next chapter.

5.2.4 Visibility

Visibility of the solution was rated at 4.3. The lowest rating given was a 3 which was given by a respondent who is in charge of product movement. The respondent stated '*It is still difficult to tell why an item has not moved. I would still need to rely on people to give me information, like why have they not done something.'* Other respondents were happy with the simplified interface where they had somewhat of a bird's eye view of the interface. 3 of the respondents asked that more specific filters be added in order to improve the searching experience.

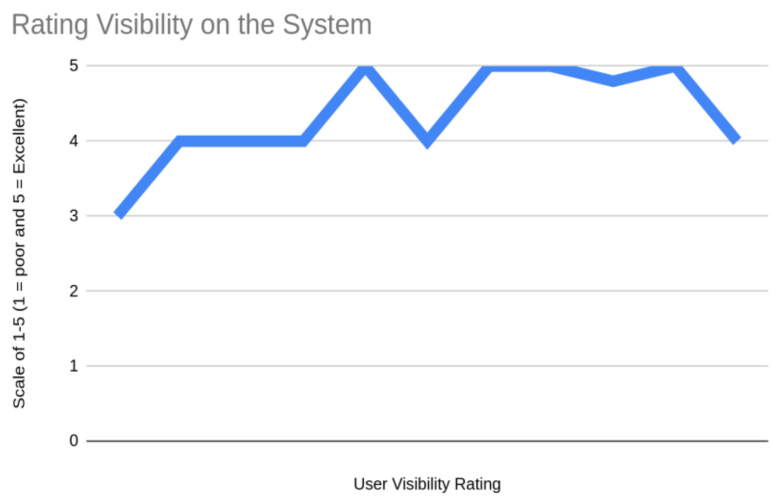

Figure 22: System Visibility Rating

On the artisan side, during the first round of data collection, artisans were asked if they would like to have more visibility into the activities happening at SOKO, and 61.9% confirmed that they would. They were interested in information about how pricing was done, the final customer and where they were from. The SOKO management was not able to comply on matters of pricing due to privacy matters. However, for the study, the researcher was able to display the customer name and their country of origin on the artisan app.

67% of artisans during the first round of data collection stated that they would be interested in viewing customer related information. When asked whether they were happy with the customer name and country of origin were now visible to them, 86% responded positively. The other 14% were undecided and were okay with not knowing.

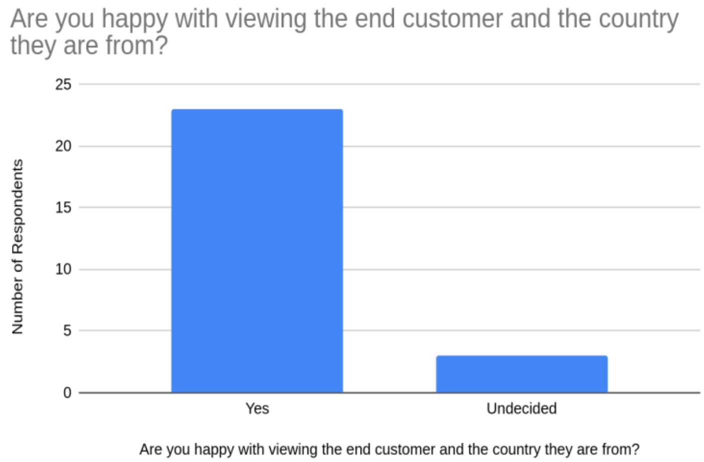

Figure 23: Response on viewing of customer data

5.2.5 Transparency

Figure 24 below shows how the respondents rated transparency on the system, during the second round of data collection. On a scale of 1-5 where 1 is poor and 5 is excellent, an average rating of 4.5 was given. 55% of the respondents gave a rating of 5 and the other 45% rated it at a 4.

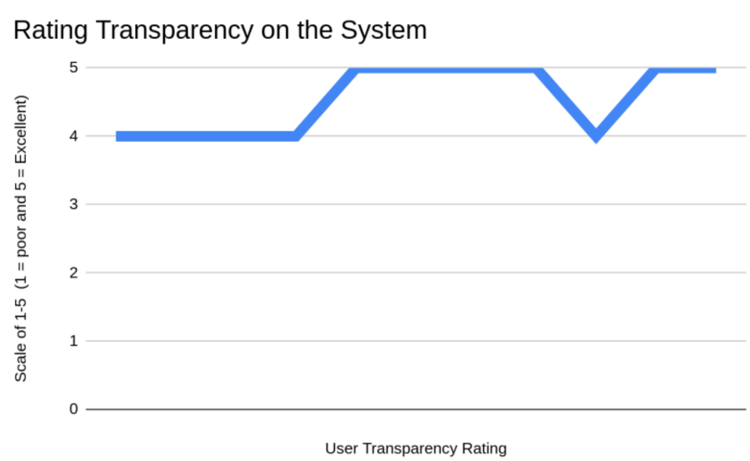

Figure 24: Transparency rating of the system

66.7 % of the artisans interviewed in the first round indicated that they were interested in the SOKO's customer. For the study, the researcher added the name of SOKO's customer and the country residence.

88.5% of the respondents were happy to see the information, and the other 11.5% were undecided. Interestingly though as shown in figure 25 below, only 19% of the respondents admitted that the added knowledge would affect how they did production. The other 81% indicated that they would continue production as usual since they put in the same amount of care in their work, despite the customer.

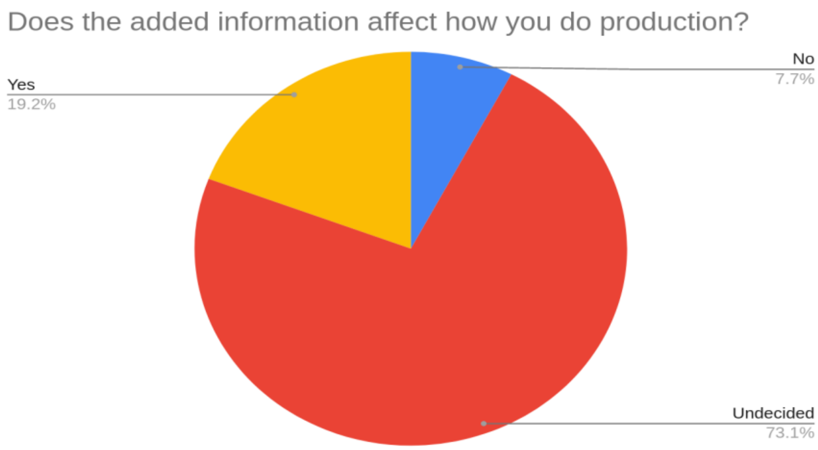

Figure 25: The effect of having additional customer Information on artisans

5.2.6 Accountability

This was a theme that came by surprise. As shown in figure 26 below, out of the 37 tags of appearing themes, accountability and ownership appeared 11 times in the SOKO employees. When supply chain respondents were asked how they felt in general about the solution, a lot of them expressed sentiments of excitement because this would increase accountability between team members and between departments.

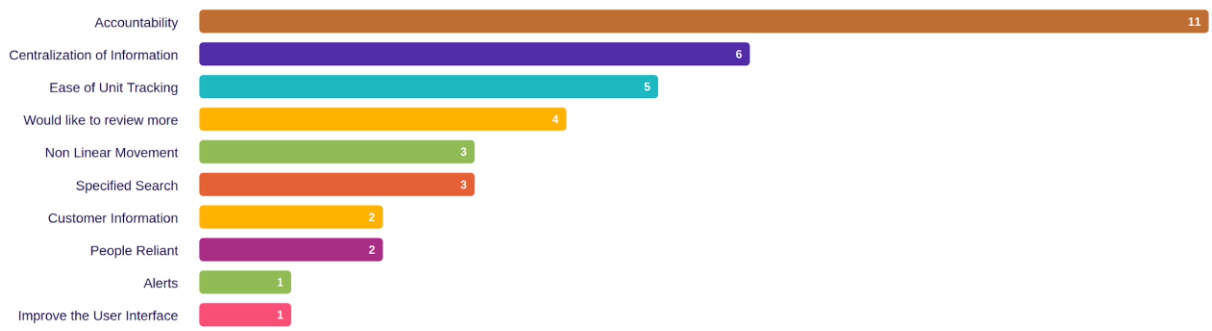

Figure 26: Results from axial coding in the 2nd round of data collection

5.3 Discussion

In the last 3 decades, supply chains are changing to become larger, longer, more decentralized and increasingly complex. African countries are seeking to be viewed globally as potential manufacturing hubs and are attempting to replicate China's trajectory in industrialization by creating special policies, (Ekekwe, 2019). Particularly in Kenya is Vision 2030, which aims to develop a diverse, strong and competitive manufacturing sector by emphasizing local production, expansion into regional markets and identifying Kenya's niche in global markets (Republic of Kenya, 2007).).

However, on the global stage, lack of transparency into the supply chains has led to major scandals which have rocked the industry. In 2013, the horse meat scandal in the UK and some European countries raised a lot of questions on current issues within the food supply chain. What began as an issue with a suspected supplier became an industry-wide concern. Concerns raised also highlighted complexities in surveying and security and effective and efficient supply chains (Sarpong, 2014).

Keeping in mind the challenges that already face the Kenyan informal distributed manufacturing sector, to be able to compete at a global level, it is important that the industry evolves and addresses the problems in the global stage using the infrastructure available locally. In this study, the technology used and developed is locally available and utilizes use of mobile phones and spread of internet connectivity in the country.

In this study, traceability and visibility were enhanced for a network of artisans and an aggregator, which saw the increase in transparency and accountability. To enhance traceability, granular information about the product in all stages of production was collected. This was especially important in the SOKO case study as the product goes through a large number of processes. Earls, 2013, states that the longer the chain, the greater the risk of integrity breakdown. By adding traceability, organizations create transparency as an important input and therefore stability comes along (Sarpong, 2014). Traceability can also be significantly quicken and simplify the process of catching a problem item, with as little impact as possible on the business' bottom line.

Supply chain visibility is described by Barratta & Oke (2007) as ''the extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit''. They hypothesize that visibility is achieved by combining the linking of activities and information sharing. In this study, the inclusion of traceability, which involved the linking of activities, and providing this information to all actors in the supply chain greatly enhanced the visibility.

Globally, increased transparency, visibility, and traceability have seen companies being accountable to their customers and the communities in which they operate. This was also noted in this study, with accountability being enhanced within the supply chain. Organizations are being held accountable to their sustainability goals and food safety in assured, (Barling, Sharpe, & Lang, 2009). After questions about the use of underage labor and sweatshops, in 2005 Nike published a list of its international suppliers, schocking its competitors. A few months later, Levi-Strauss (Levis) followed suit (Doorey, 2011). Scholars have noted a trend toward increased transparency in relation to sustainability more generally (Egels-Zandén & Hansson, 2015). The use of technology that verifies the claims made by the companies would further enhance accountability within the organizations and towards the consumers, employees and the community.

CHAPTER 6: Key Findings, Conclusion and Recommendations

6.1 Summary of Key Findings

The main objective of this study is to address the lack of transparency in the informal distributed manufacturing industry using a DLT system. During the course of the study, blockchain technology was identified as the suitable DLT as it provided features like immutability and proof of origin which support traceability and visibility.

At the start of the study, the users of the system rated the system's traceability at 2.67, with the main problems being that it took too long and it required opening so many pages. To add traceability to the system, every transaction that a product goes through in the supply chain process was tagged and key details about it encrypted and indexed. With this addition, there was general excitement about how easy it was to track a product. During the user acceptance tests, it was observed that it would normally take at least 3 minutes for a user to trace a product's movement, but with the inclusion of blocks in a chain, this now took less than a minute. This contributed to the improved rating of 4.8. Unfortunately, due to financial limitations to purchase tagging technology that would enable the operators to physically link an item to its digital record, traceability for the artisans was not achieved.

Merriam Webster (n.d.), defines visibility as the capability of affording an unobstructed view. During the first round of data collection, a lot of challenges regarding visibility were raised. Most were related to limited access to data, the need to review too many pages and different departments having different standard operating procedures (SOPs). One respondent stated '*To find one data set, I have to open so many pages. And when a product is in a transition state, it's hard to find it unless you check both stages that it should go through.*'

To solve the stated problems, a single page that contains all the chains, blocks and the index of the transactions was created that was made accessible to all. Respondents in different departments were asked to perform an action on the system. They were able to keep track of the other user's activities and give their feedback. While this improved the visibility and the overall rating, there is still more that could improve the rating from 4.3 to a 5. This includes adding more intuitive searches, improving the page's user interface and collecting more information.

At the beginning of the study, the supply chain and the artisan community existed as completely separate entities, who interacted occasionally. Within the supply chain, the different departments also functioned as silos, with limited access to each other's information. When a senior manager, a respondent, was asked what his biggest challenge was on the job, he responded '*Things are not very clear. It is hard and time consuming to trace a single product from end to end. The lack of clarity has led us to miss some major incoming problems early.'*

The combination of features added to improve traceability and visibility contributed to improved transparency within the supply chain. During the second round of data collection, the traceability average rating given was 4.5, with 100% of the rating being 4 or greater than 4. When asked why they gave the high rating, one of the respondents stated '*With great visibility comes transparency'.*

While the artisans were aware that their products are sold all over the world, once they produce and sell the products to SOKO the interaction ends there. They were interested in information about how pricing was done, the final customer and where they were from. The addition of the final customer and the country of origin was a highlight. Knowing that their products were sold by worldwide brands and worn by people all over the world, with some of the people being celebrities was a source of pride for the artisans. Having access to this information enabled them to understand the reach that their work has. However as shown in figure 25 above, only 19% of the respondents admitted that the added knowledge would affect how they did production. The remaining group admitted that this knowledge would not change how they work. They insisted that they would continue the same amount of care and diligence they put into their work.

Accountability was not among the predetermined themes, but it came up many times during the second round of data collection within the supply chain. With follow up questions, some of the respondents gave instances of departments having wrangles due to he said she said. A respondent said, '*There will be more ownership. People will be aware that whatever actions they do on the system are visible to everyone.'* Another respondent gave an anecdote where his department had a misunderstanding with another department when products went missing, and neither department would take responsibility for the loss. This led to both departments being charged for the lost product.

The benefits of the immutability and proof of origin that comes with using blockchain technology are clearly visible in this case. The index of activities, timestamps, as well as the hash functions give the transparency and trust that is needed. If an action was deleted, the index on the block page will clearly show if there is a number that was skipped.

6.2 Conclusion

To establish how to provide uniform data on informal producers using a DLT system.

Being that SOKO already has an established relationship with its artisan network, achieving the first specific objective of the study was not complicated. SOKO has provided it's artisans with an android app that allows them to manage their workshop and keep track of their orders and payments. This made the process of data collection straight forward.

To develop a DLT system whose features support provision of visibility and traceability in the distributed manufacturing industry in Kenya.

To capture security, reliability and immutability, blockchain technology was the DLT technology used. As stipulated earlier in the literature review, blockchain provides immutability and proof of origin by hashing and timestamping each transaction. These features provided the much needed traceability and visibility in the system developed

To assess the provision of traceability and visibility of data to aggregators in the Kenyan distributed manufacturing sector using a DLT system.

The SOKO case study gave the researcher an opportunity to observe firsthand the challenges faced before and the results after adding blockchain technology into the ecosystem. Feedback from the artisans, supply chain operators and the top management confirmed that there was an improvement in visibility and a drastic enhancement of traceability on the system.

To assess the effect of use of the system in terms of transparency of processes in informal distributed manufacturing by artisans and aggregators.

Using the research findings, it is clear that traceability and visibility are key to building transparency and accountability within the distributed manufacturing ecosystem. While the SOKO artisans were independent entities, they were still interested in the information about their customer SOKO. Increased visibility and transparency created trust between both parties. Operators within the supply chain were able to retrieve information that they previously did not have access to and they were able to do this faster. Due to the improved access to secure and reliable information, individuals and departments within the supply chain can now hold each other accountable to the organization's operations and goals. It will be interesting to see the long term effects of the provision of transparency within this sector.

By setting up a secure, reliable and immutable log of transactions and information that provided traceability and visibility, the study's main objective of addressing the lack of transparency in informal distributed manufacturing by developing and implementing systems that provide traceability and visibility in the sector using distributed ledger technology was tackled.

6.3 Recommendations for Practice

To ensure growth and increased transparency within the Kenyan informal distributed manufacturing sector, the following are some actions that would greatly enhance future works:

- As expressed in the findings, to achieve the highest level of traceability, the use of unit based tagging technologies such as barcodes, QR codes or RFID is key. This is especially useful when working with many producers who produce similar products.
- To ensure that there is full visibility and transparency within the informal distributed manufacturing, the information from the suppliers of the producers/artisans should be captured.

6.4 Recommendations for Further Research

- Due to the case study selected, access to customer information was difficult. In future works, researchers should consider the final consumer's perspective to give a wholesome depiction.
- Researchers should avoid the use of linear software development models e.g waterfall methodology when creating software tools whose requirements are unclear. The use of the agile methodology which allows continuous feedback from the users proved invaluable in this study.

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Appendix

Round One Interview Questions

Sample Questions for artisans

- Does the existing technology serve your business needs?
- What challenges have you faced regarding visibility when using the technology?
- Are you interested in knowing how many final customers have worn your products?

Sample Questions for Supply Chain operators

- On a scale of 1 - 5, 1 being very difficult and 5 being very easy, how easy is it to trace products on the existing technology?
- In your opinion, do you feel that there is traceability and visibility in the existing technology?
- What challenges have you faced when tracing the movements of products in the supply chain when using the technology?
- What challenges have you faced regarding visibility of movements of products in the supply chain when using the technology?
- What are some things that you would like to change in the current system?

Sample Questions for Senior Management

- On a scale of 1 - 5, 1 being very difficult and 5 being very easy, how easy is it to trace products on the existing technology?
- What challenges have you faced regarding visibility of movements of products in the supply chain when using the technology?

- What challenges have you faced regarding traceability of products in the supply chain when using the technology?

- On a scale of 1 - 5, 1 being very difficult and 5 being very easy, how easy is it to get an overall view of the product movement in the supply chain?

- What kind of reports can you get on the existing technology?

- What are some things that you would like to change in the current system?

Round Two Interview Questions

Sample Questions for Supply Chain

- With regards to traceability in the supply chain, on a scale of 1-5, how would you rate the solution you have just viewed?
- With regards to visibility in the supply chain, on a scale of 1-5, how would you rate the solution you have just viewed?
- On a scale of 1-5, how would you rate the solution you have just viewed with regards to transparency on the system?
- From your interaction with the system, what additions would improve your experience of using the software?

Sample Questions for Artisans

- Do you (still) have the SOKO artisan app?

- Are there any challenges that you are facing at the moment when using the application?
- Are you happy with viewing the end customer and the country they are from?
- Will this in any way affect your production?
- On a scale of 1-5, how would you rate the visibility that you have into your operations and interactions with SOKO?
- On a scale of 1-5, how would you rate the transparency that you have into your operations and interactions with SOKO?

Workshop Images


SAMSUNG