Utilizing the Blockchain Technology as an Effective Means for Supply Chain Traceability.

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Abstract

Given the broad range of activities carried out in the supply chain, product traceability stands out as the core of any successful supply chain management program. Traceability therefore is the planning and execution of activities which allow a person or an entity to monitor the pathway of a product from its origin down to the consummation of the product. This helps a company or an organization to be in control of all of the processes involved in a product's lifecycle, it also increases transparency during the manufacturing phase of a product and thereby enhancing consumer trust.

Though traceability is critical in achieving success in any supply chain transaction. However, the effectiveness of this effort relies on the method by which it is carried out. In the past, and even up till now, various means have been utilized in carrying out the traceability activities in the supply chain, such as the use of RFID in product labelling and identification and manual register for recording transaction levels. Nonetheless, due to the diverse nature of the supply chain industry which cuts across various industries, these methods have not been wholly sufficient in achieving product traceability, and this has led to multiple product losses and recalls.

In this paper, we propose the use of blockchain as a means of improving the efficiency of traceability activities in the supply chain industry. By initiating the use of digital smart contracts in the blockchain as a technique to automate and track the path of a product within the supply chain, we are able to track the state of every transaction and produce an audit trail of the trace path of any product in a supply chain transaction. The result of this implementation is the elimination of certain human errors which occur during the creation of traceability logs and an optimized cost function of traceability in the supply chain industry.

Furthermore, we compared the time-length of writing a traceability transaction log, in a supply chain and error rate of transactions between blockchain, RFID and manual register, by using a waiting line simulation technique in MS Excel as basis for the choice of a tech solution in any traceability effort, the result of this comparison is that the blockchain technology has a much lower time to complete a transaction trace log with an optimized error rate of 0.000001% and therefore we conclude the choice of blockchain is preferred as a technology solution to supply chain traceability.

Keywords: Supply chain, Blockchain, Traceability, Technology, Smart Contracts

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1. Introduction

The supply chain consists of the intersection between manufacturers, distributors (logistics, freight-forwarders, packaging, shipping etc.), technology companies, retailers, wholesalers and even government agencies. These layers of stakeholders makes-up the supply chain and provides certain difficulty level in traceability. Essentially, the three key processes in standard-based supply chain traceability include: Product Identification, Information Extraction on products, and securely sharing this information with trading partners. Inadequate traceability program has led to massive losses witnessed in various organizations and loss of products during recalls [1]. Often these recalls are due to manufacturing errors that are the result of lack of oversight during the production stages and inefficient integration of consumers need in the production stages; other times it can be because of improper integration of the spare parts of a product. However, either of these causes can be fixed with proper implementation of a traceability effort, this is due to the fact that traceability allows a company to be in firm control of all the processes involved in production.

Predictably, in order to minimize losses and enhance transparency in product traceability and in the agri-food business it is expected 'that traceability will become a prerequisite (law) for a successful food enterprise in the years to come [2]'. The adoption of traceability laws by various countries in the production of agri-food businesses means that traceability program in the future will become an inevitable path to a successful supply chain. Additionally, it will require that most organizations will seek ways to improve their product trace programs. These laws exist to protect the agri-food consumers and has been implemented in various forms, for e.g. the European Union's general Food Law which included important elements like rules on traceability and the withdrawal of dangerous foods from the market traceability is defined as the ability to track any food, feed, food-producing animal or substance that will be used for consumption, through all the stages of production, processing and distribution [3, 4]. Furthermore, the bio terrorism act of the united states of America mandates all the organizations involved in agri-food business to register with the Food and Drug Administration and to maintain records and information for food traceability purpose[3, 5]. The Can-Trace act 2003 in Canada enacted a policy framework aimed at the development of traceability standards for all food products sold in Canada[6]. Can-Trace establishes traceability requirement based on the GS1 system – which is a standard that identifies various traceability processes and describes the choice for data management technologies. From the foregoing it can be seen that the imperativeness of developing a traceability standard in the agri-food industry is based mainly on the regulations and

Due to the imperativeness to comply to these regulations', companies are spending huge amounts of money in acquisition of traceability standard technologies. Unfortunately, the effectiveness of some of these technologies are lacking. In order to implement an efficient traceability the trace process should start at identifying the origin of the production process by assigning unique identifiers called the Global Trade Number (GTIN) and extends such identification numbers to the source of all raw materials. The GTIN is then made visible to every partner in the supply chain. This identifier number provides an identification component for all the supply chain partners and forms the backbone partners can depend-on to trace a product. Additionally, the GTIN is critically important in that it connects a product to a brand and identifies different brand make-ups in a product. In the agri-food sector the GTIN works by helping to provide a Traceable Resource Unit (TRU) for products traceability as identifying the optimal granularity level of traceable unit is necessary when implementing traceability of food [7]. With the knowledge of the GTIN the product in transit in various location can be monitored or tracked by using the Global Location Number (GLN) this is used to identifier supply chain partner locations such as a farm, a warehouse, transit haulage, ports, manufacturing plant, a restaurant house, wholesaler location, a distributor loading deck, or a store. The GLN enables a supply chain partner to record each stop a product makes in any supply chain transaction. This forms a critical component of any efficient traceability program.

In this paper, we determine that the output of any successful traceability GTIN and GLN will be the production of an automatic product and process audit trail, automatic distribution of information to stakeholders, easy accessibility of information by supply chain stakeholders and integration of the consumers in the supply chain – to enhance transparency.

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Literature Review 2:

The purpose of our literature review is to gain a deep understanding of the topic at hand, which is the traceability of products in a supply chain using technological means.

In order to understand the current state of the art; we used a few search key terms in *scopus.com* - an online repository of published journal papers and conference articles. We determined that the key search should be such that goes through from a generalization of the problem area of focus to a specialization of the solution; we implemented a deep-dive keyword search.

- Traceability: this search key term attempts to identify the entire subject of traceability in the supply chain. The result is that there has been about 19,950 published papers in this area with the earliest publication dating in 1963. This means that the issue of traceability has been an age long issue. NEXT we looked at supply chain traceability and how it has evolved.
- Traceability in Supply chain management: this allows us to understand the how the issue of traceability has been discussed and researched upon in the context of supply chain management. The result is that the papers published so far till date are 1493, with the earliest publication in 1996.
- Technologies used in traceability: this identified various technologies with the earliest paper published in 1997, this has a total of about 581 publications.
- RFID and Supply chain Traceability: this has a total of about 394 publication and the earliest publication in 2002
- Blockchain and Traceability: this has a total of 103 publications and with the earliest publication in 2016
- Audit-trail, Blockchain and Traceability: this is the research work we are trying to develop it has only one paper publication with in 2019.

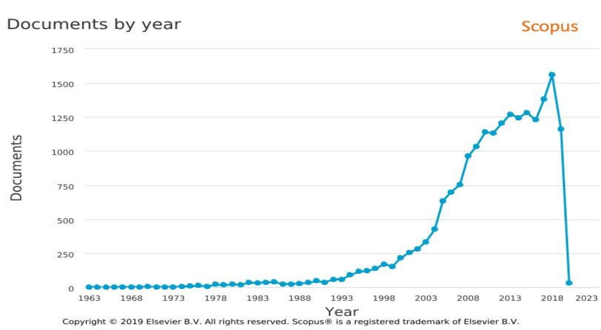

Figure 1 Publications on Traceability

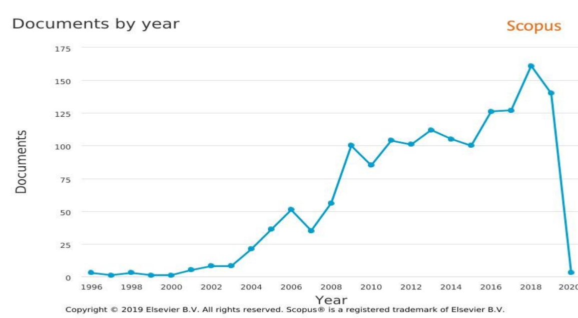

Figure 2 Traceability in Supply Chain

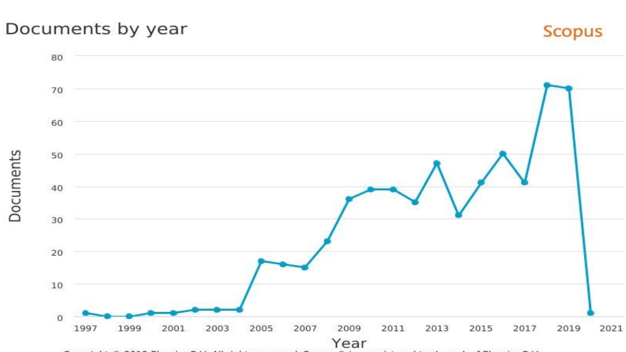

Figure 3 Technologies used in Traceability

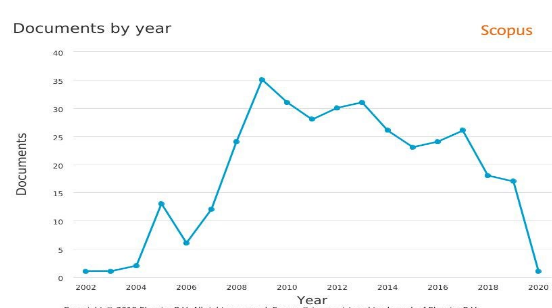

Figure 4 RFID and Supply Chain Trace

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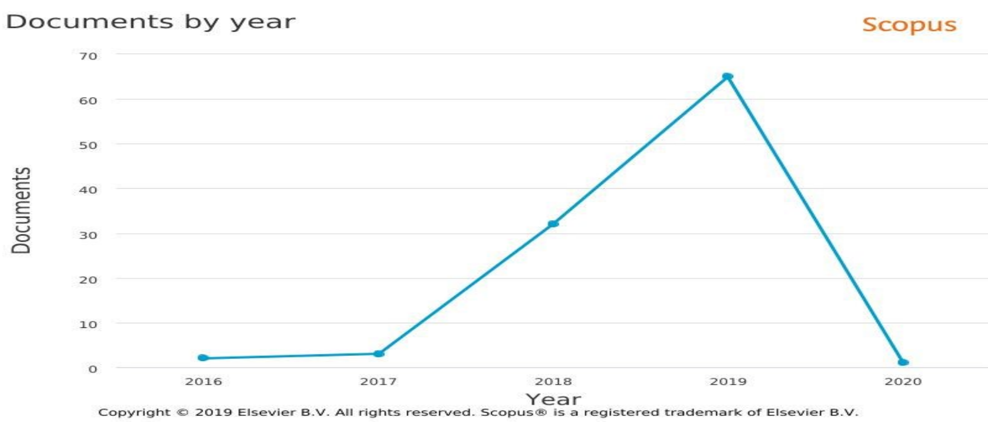

Figure 5 Blockchain and Traceability

Looking at the importance of supply chain traceability, the authors Techane Bosona et al: noted that an effective food traceability system is important in the food supply chain [8]. This points to the fact that having a traceability system is a critical component of any supply chain product. Fabrizio Dabbene and co supported Techane by noting that the ability of a traceability system to monitor the composition and the position of each lot in the production and supply chain represents a very powerful tool that can be used to define new management objectives and to improve the overall performance of the FSC[9]. Additionally, some authors referred to traceability in most cases as the most important factor in the food supply chain; Caprole V et al described traceability as widely recognized to be the basis of any modern food safety control system integrating both animal health and food hygiene components[10]

Authors Aye Chan Myae et al, J, Hamprecht et al, and Iris Vermier et al; [11-13] all identified traceability as important to sustainable production, they assert that traceability can be used as a method of certifying production, processing and the nutritional credence attributes of a food product.

In identifying what technologies that can be used for supply chain traceability authors: Corrada Costa et al identified RFID as a flow control technology which allows traceability of goods through all steps of production chain [2, 14-16] While, author Feng Tian identified both RFID and Blockchain as source technologies for supply chain traceability, In his writing Feng Tian noted that RFID and Blockchain technology helps in realizing information identification, product inquiry, tracking and tracing the whole supply chain transactions and it could also be a secure transparent and traceable platform for the members in the agri-food supply chain ([17]. Francisco Curbera identified business provenance as a way to trace end to end operations – "Business provenance gives the flexibility to selectively capture information required to address a specific compliance or performance goal [18]" Provenance here refers to a way of identifying the source or origin of a business product and process and creating a trace path for it. Though Francisco curbera identified business provenance as a way of consummating a traceability process in the supply chain; he felt short of stating RFID or blockchain technologies can be used to advance this process. Authors Gildas Avoine et al, mentioned the ways RFID can be used to implement supply chain traceability; and stated that RFID has three layers, application, communication, and physical [19], while their paper on RFID Traceability attempts to showcase how to utilize RFID in traceability program, however, they did not provide a comprehensive overview of how RFID compares to other traceability technologies. Furthermore, W.HE et al identified RFID and GPS as technologies for track and trace; they opined that the synergized hybridization of RFID and GPS will feature the benefits of both systems in process tracking and outdoor positioning [20] but did not highlight how these technological means can be used for supply chain traceability and more so how they can enhance traceability in the chain. In their writing S.H Choi et al mentioned what ways RFID and modern technologies can be used to enhance supply chain traceability: "however, these track and trace systems tend to support some specific applications, such as eliminating inventory inaccuracies, reducing inventory shrinkage and achieving fine grained recalls [21]." We observe that mere stating these methods are not complete in themselves, rather a complete trace technique in our sense will be to state what the technologies are meant to achieve and how they can be implemented to achieve those stated objectives.

In general our paper objective will observe a slight modification from the existing literature; by comparing technologies used in supply chain traceability and mentioning ways to enhance them and also showing how these methods can be implemented in practice.

RELEVANCE OF OUR STUDY 2.1:

A supply chain is a composition of three or more entities (individuals or organizations) directly involved in the upstream and downstream flows of products, service, finances, and/or information from a source to a customer [22]. Another definition of supply chain is the network of organizations that are involved through the upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to ultimate consumer [22, 23].

The management of this complex chain gives the total picture of what supply chain management is all about. Looking at the composition of supply chain management, there is no doubt that the supply chain is a critical component of the overall economy, according to Delgado et al, in their paper on the categorization of the USA economy, for example, it is estimated that in 2012 the supply chain industry accounted for about 43 million jobs in the US which is equivalent to about 37% of the total jobs in the US, while about 2.5 million firms in the US were in the supply chain sector and that is about 43% of employer firms [24]. These figures are not exhaustive in themselves; to support them according to report by the United Nations Conference on Trade and Development (UNCTAD) in their 2013 report of GLOBAL SUPPLY CHAINS: TRADE AND ECONOMIC POLICIES FOR DEVELOPING COUNTRIES they estimated that the value of trade in intermediate products (supply chain) represents about 40 per cent of world merchandize trade [25]. This is discounting the value of raw materials. It will not be an overstatement to say that the supply chain is the driver of most economies and if this is the case then it is worth studying this area of the economy to understand how to improve it. However, in order to understand how to improve the sector and make it more efficient and goal oriented we have to first understand what those challenges are in the sector are:

Challenges in the supply chain industry:

According to various internet source but most notable according to an online source *supplychainbeyond.com* they identified the four major challenges with their proportion contribution in the supply chain to be

- Traceability
- Product maintenance
- Supply chain cost
- Communication between partners

Their proportion can be seen thus:

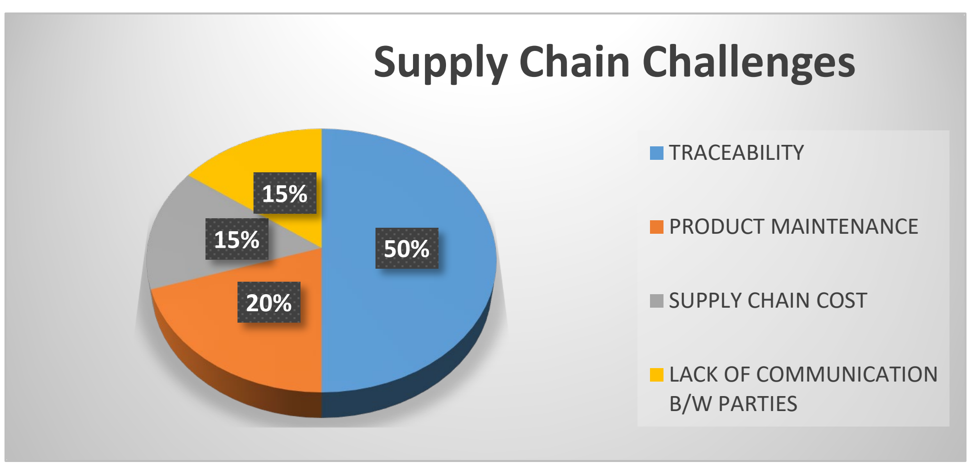

Figure 6 Bar chart representation of supply chain obstacles

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Evidently, traceability represents about 50% of the challenges witnessed in the supply chain industry. Again, it is not surprise why this is so, and therefore understanding the ways to make traceability program effortlessly is vital for the improvement of the chain.

To be clear, there are many reasons why we need to ensure the enhancement of viable traceability programs in the supply chain, but mainly the importance of traceability is due to the following factors:

1) Traceability helps to fulfil certain government regulations.
2) It provides visibility in the supply chain.
3) It reduce the overall cost of product recalls.
4) It helps to solve product serialization problems.
5) With an efficient traceability program a manufacturing company will be able to implement appropriate lean manufacturing in their production.
6) It helps to reduce waste that are due to malfunctioned products.
7) It integrates the interest of a consumer in the manufacturing process and helps to increase consumer confidence.

Looking at the points highlighted in this section, it is therefore without doubt that finding a cheaper and more effective solution to traceability problems will be beneficial to the overall supply chain and by extension to the global economy.

Traceability and Technology Solutions 3:

As we already highlighted in the abstract and introduction section, most up to date problems are solved using various technological means or method and traceability is one of those challenges that require technological solutions. Expectedly, the application of technological solution to sectoral problem/challenges simplifies the complexities of those problems. In the case of traceability in supply chain there are various technologies that have been used for its implementation, but for our study we will limit our focus to only the use of Manual Register, RFID and Blockchain.

Traceability as a process has four components as mentioned by McEntire et al and Golan et al [9, 26, 27] and these processes are:

- Breadth – this is the amount of quantities that are in each unit.
- Precision – this describes in accurate terms the precision of a traceability process.
- Depth – what stage is a traceable element at in either the upstream or the downstream in a supply chain.
- Access – this is the speed with which traceability information is communicated to supply chain stakeholders and partners.

These constituents form a critical basis for the choice of any technological solution. These components can be represented in a traceability matrix in order to capture their different status during traceability operation.

ID #	Category	Product	Priority	Source	Date	Transport	Utilized
0001A001	Must have	XXXX	High	*****	*****	*****	*****
0001B002	Should have	XXXX	Medium	*****	*****	*****	*****
0001C003	Nice to have	XXXX	Low	*****	*****	*****	*****

Table 1 Sample Traceability Matrix

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The structure of most technological solutions used in a supply chain traceability is such that there are servers that enable transactions to be processed. Take for instance the case of RFID, it has three main parts: a transponder, a reader and a middleware deployed in a host computer [28]

RFID Technology 3.1

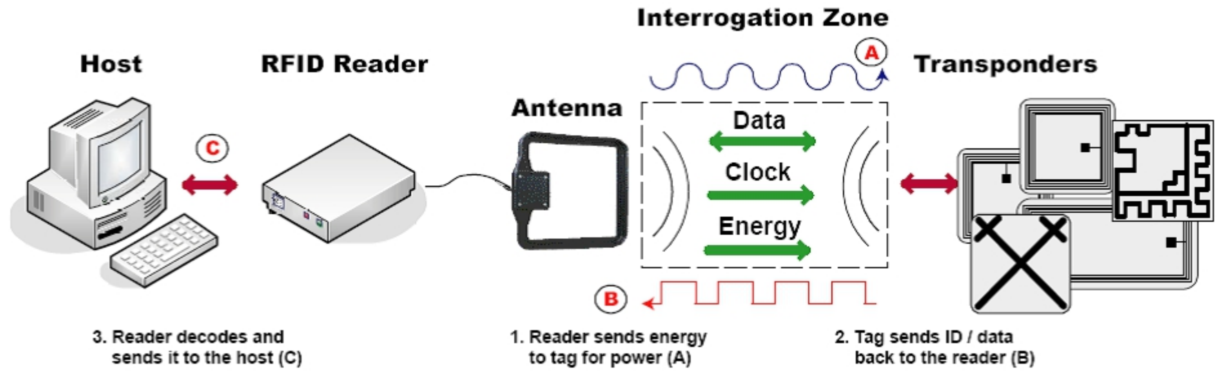

Figure 7 RFID Structural Components.

The transponder of the RFID is made up of a chip and an antenna, and its usage is in the storage of serial numbers of traceable elements, while the antenna is used to transport information to a reader.
The middle ware works to provide a software link that connects the RFID reader's data to enterprise information system. it provides visibility to supply chain partners.

Looking at the make-up of the RFID it is evident that it supports traceability through tag reader and middle ware transposition, however even as this is sufficient, it is still not the optimum or the highest that technological solution can offer. At some point one may be forced to ask how the RFID system will trace goods or services that are transit or how it can provide a trace program for intermediate goods, at such point it becomes clear that RFID does not provide a holistic traceability for the supply chain goods. Again, another concern that may come up when one examines the efficiency of the RFID for traceability is to understand how the partners in a supply chain transaction can be instantly informed of the transit record or the status of every transactional change happening in the supply chain.

These concerns expose the inherent inefficiency in RFID for traceability program and makes the case that RFID may not be as suitable as Blockchain in implementing traceability efforts in the supply chain. Other loopholes that may be seen in the RFID system with regards to traceability program in supply chain is that there is a small time loss $(-T_{L})$ in sending information between the transponder and the middleware; though this may not count for something but it may be amplified in the event of a network slowdown or middleware malfunction.

As a centralized server application, RFID may be an easy target for DDOS (Distributed Denial of Service) attack and hacker intrusion, with these possibilities it makes it harder to rely on the RFID for traceability implementation.
Furthermore, RFID records various the stages of various transactions through a mechanical update; by this it means that as we progress through the supply chain, tracing the paths of some goods will be prone to error this is because the readings of the RFID will be updated in a way to represent their status update, therefore taking such upgrade will bring up some human errors in the system. To illustrate; assuming a good go through these simple paths

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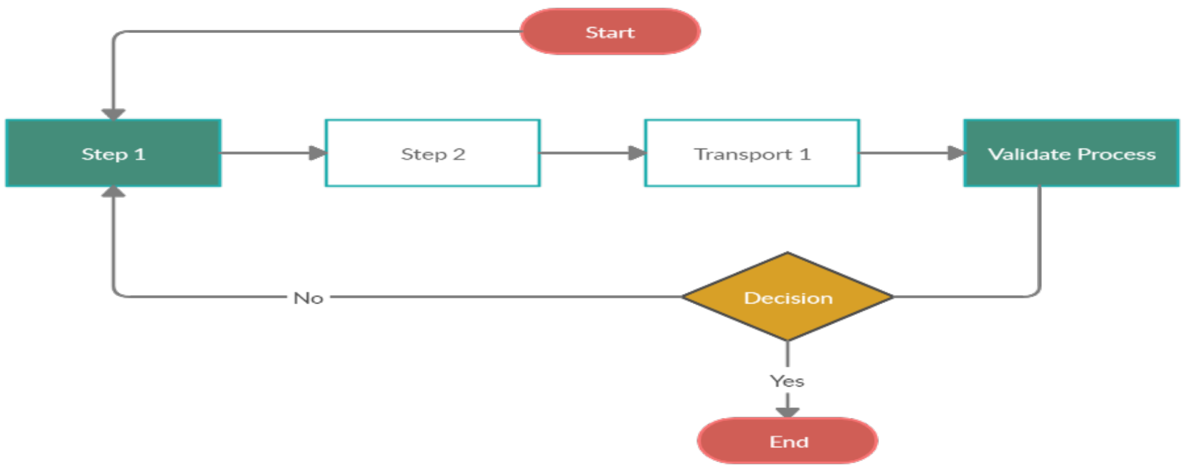

Figure 7 Traceability Transit Path

Reading through this transit paths means that every progress made in the path will be updated in the RFID through a manual means. However, since we are aware that there is a mean error for every mechanical update, therefore we have to calculate for the average error for the whole supply chain systems as:
Average Error Percentage: μ = 0.02%
System Mean Error =

$$\sum_{n+1}^{k} n_1 + n_2 + n_3 \ldots nk * mER$$

mER = the mean error rate = 0.02%, n = the number of transactions,

with this calculation it means for every 200 transaction the average error rate will be 4 (four) errors. Though this may seem somehow marginal, but looking at the entire supply chain industry and the amount of transaction that goes through it daily, it makes sense that even this figure are way beyond

Therefore using the data for average mean error rate for mechanical update which is 0.02% we can calculate the inherent error derivate in RFID supply chain traceability as

$$\sum_{n+1}^{k} n_1 + n_2 + n_3 \ldots nk * mER$$

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Blockchain as a tech solution 3.2:

A blockchain is essentially a distributed database of records, and transaction shared among participating parties. The blockchain differentiates from traditional transaction systems with respect to how it irreversibly stores transaction data in a distributed ledger [29]. The blockchain works by combining various transactions into blocks and each block with a unique header, that cryptographically commits to the content of a block, a timestamp and this creates a chain of blocks with previous headers. Each of the block in the system contains a chain Merkle root which can be referred to as the hash of all hashes [29, 30].

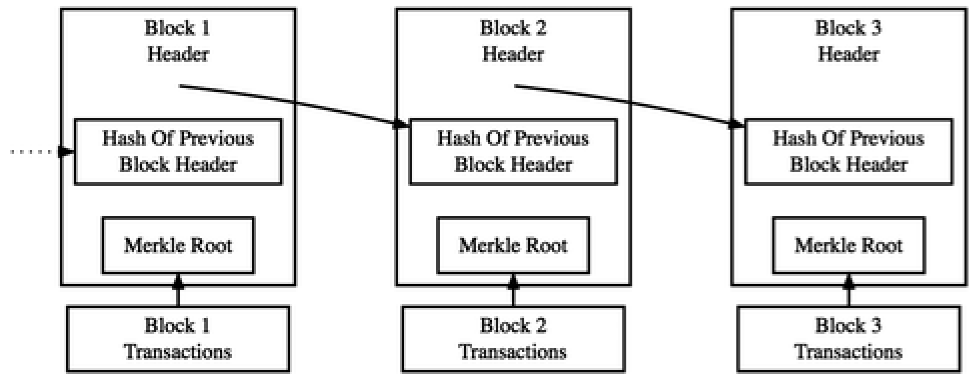

Figure 8 Blockchain linkage blocks

In its basic form a blockchain can exist as either a public blockchain or a private blockchain. A public blockchain is one that is open to the public and in which anyone can participate, an example of a public blockchain is the bitcoin cryptocurrency. While, a private blockchain is developed for a closed enterprise solution such as for enterprise traceability requirements.

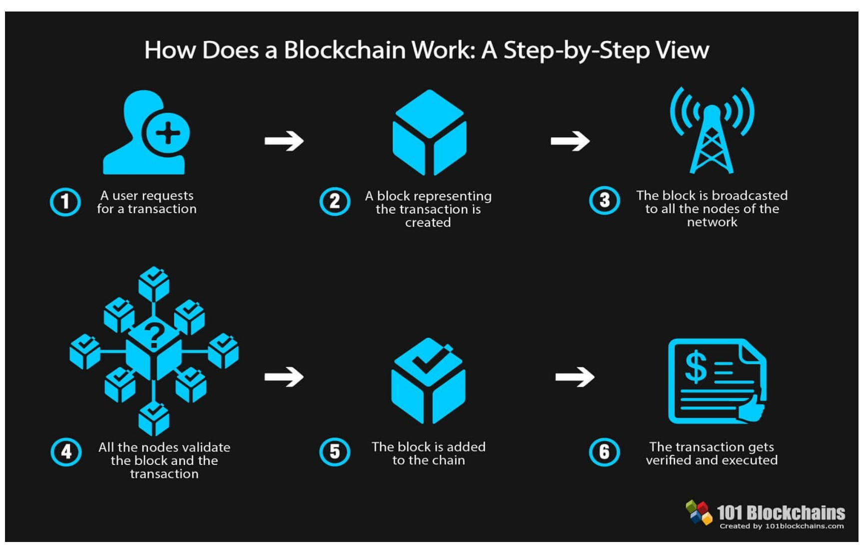

Figure 9 The Internal Operations of a Blockchain

To operate, a blockchain starts by requesting that users initiate a transaction and a block representing the transaction is created. The block is then broadcasted to every node inside the network, and to ensure data integrity every node in

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the network has to validate the block and the transaction. By validating the block, it is now added to the chain and the transaction gets verified and executed.

Blockchain as enterprise solution 3.2.1:

As decentralized database a blockchain has some inherent advantages in the way it relays information to stakeholders when compared to centralized database. For e.g. the decentralizes aspect of blockchain makes it possible for every participant in a transaction to be notified instantly of any change in the state of the transactions. Therefore, the complete make up of a blockchain essentially makes it a standard unique technology for traceability operations.
The components of a blockchain that makes it easy to be used for Enterprise Solution are:

- DAPPs
- Smart Contracts
- Web Interface

Dapps: this is an acronym for a decentralized application. Blockchain Ethereum makes it possible to connect all the participants or stakeholders within a particular blockchain network using the dapps. Essentially a dapp is developed using a Web3.js software tool and once it is developed participants in the network can communicate to each other instantly.

Smart Contract: Smart contracts are applications which are deployed on the blockchain ledger and execute autonomously as part of transaction validation [31]. This is a very powerful feature in the blockchain that makes it possible for transactions to be completed without the interference from the physical world.

Web Interface: this makes it possible for transaction in a blockchain to be completed on the world wide web using a web.js web interface.

Supply chain Traceability Implementation3.2.2

The adoption of smart contract makes it possible to produce an audit trail in a supply chain traceability implementation as seen in the figure below

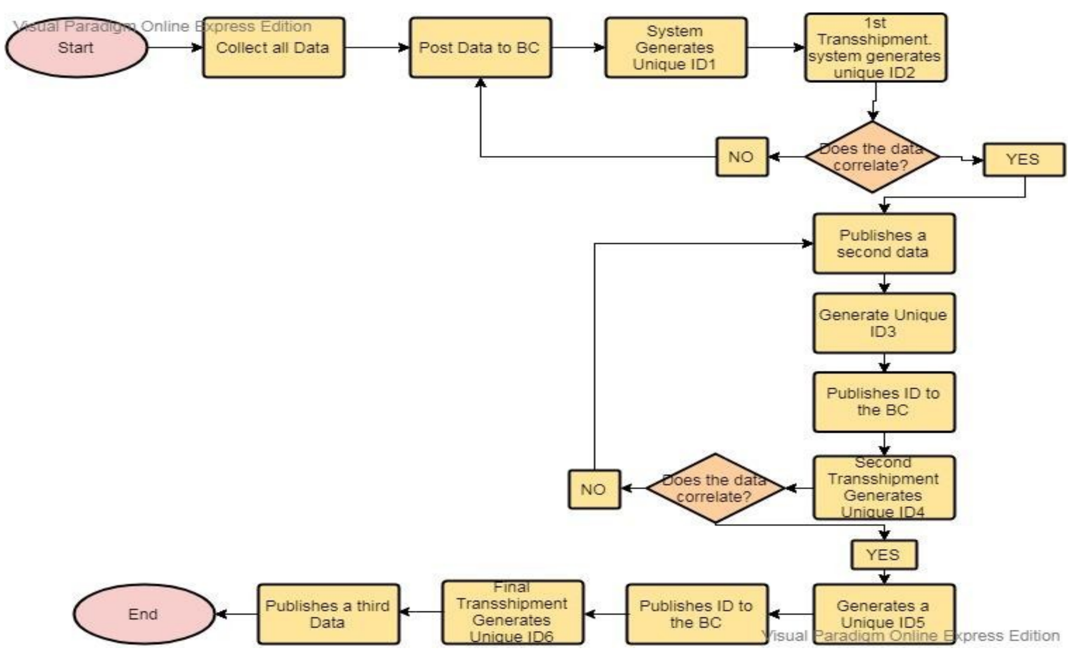

Figure 10 Trace Function in Blockchain

Looking at the diagram the smart contract automatically produces a check at each transactional stage, this check is a verifier that corresponds to the state-change of each transaction. When the transaction is accessed as complete – (because it corresponds to the original/initial product path flow) it is passed on to the next change and a record certifying this transaction is read and recorded in the transaction log. However, when in the case the transaction is not certified as complete, it raises an alarm error and in which case the human verifier has to fix what is wrong.
This technique makes the trace function system dependent and on the same hand eliminates human errors.

RESULTS 3.3

The outcome of development of a trace program that utilizes the blockchain technology when compared with similar technologies like RFID and Electronic Register, will yield results that include a faster traceability program with a lesser margin of error. To illustrate, we compared the speed of transactional traceability execution using a queuing problem in Microsoft Excel between blockchain and RFID, the result of the comparison can be seen thus:

				BLOCKCHAIN				RFID							
Transaction	Random	IAT	AT	START	ST	FINISH	WAIT T	START	RN2	ST	FINISH	WT	TIME B/W ARRIVALS	PROBABILITY	MAPPING0-99
													5	0.5	0-49
1	16	5	5	5	7	12	0	5	83	12	19	4	10	0.3	50-79
2	19	5	10	12	7	19	2	17	17	4	28	7	15	0.2	80-99
3	53	10	20	10	7	17	2	21	3	8	33	6			
4	8	5	25	20	7	27	4	29	14	4	49	15			
5	67	10	35	25	7	32	4	31	19	12	56	16			
6	29	5	40	35	7	42	2	39	25	8	59	22			
7	67	10	50	40	7	47	2	47	13	8	61	16			
8	31	5	55	50	7	57	3	53	14	8	68	19			
9	24	5	60	55	7	62	2	61	82	8	79	17			
10	29	5	65	60	7	67	2	69	73	8	81	18			
11	75	10	75	65	7	72	4	77	61	8	89	19			
12	72	10	85	75	7	82	2	89	22	12	95	24			
13	90	15	100	85	7	92	3	101	35	8	101	21			
14	23	5	105	100	7	107	2	109	48	4	110	14			
15	92	15	120	105	7	112	2	113	69	4	121	22			
16	66	10	130	120	7	127	1	117	71	12	125	27			
17	23	5	135	130	7	137	2	129	39	4	136	29			
18	9	5	140	135	7	142	2	133	9	8	145	19			
							2.277778					17.5			

Figure 11: Execution time between BC and RFID

From the diagram above we can see that the time expected for each trace execution in blockchain is 2.28MS (Milliseconds) while for RFID it is 17.5MS. what this means is that in any traceability program, utilizing the blockchain technology as a source solution will yield faster execution of a traceability performance than with RFID and electronic register.

Furthermore, we determined that looking at the aggregate composition of the various elements of a traceability program using the decision support system, we compared the result of comparing the RFID, Electronic Register and Blockchain with those elements, the outcome of the result indicated that Blockchain is a better solution for traceability program within the supply chain.

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Factors to Consider	Blockchain	RFID	Register
Speed of Execution	2.27MS	17.5MS	17.5MS
Error Rate	0.0001%	0.002%	0.002%
Derived Efficiency	22,700	8750	8750

Table 2 A Comparison between BC, RFID & Register

Factors to Consider	Blockchain	RFID	Register
Breadth	✓✓✓✓	✓✓✓	✓✓✓
Precision	✓✓✓✓	✓✓✓	✓✓✓
Depth	✓✓✓✓	✓✓✓	✓✓✓
Access	✓✓✓✓	✓✓✓	✓✓✓

Table 3: A DSS (Decision Support System) for choice of technology solution

RECOMMENDATIONS 4.1

- We recommend that the usage of the blockchain solution or technology in a track and trace effort should be concentrated only in those instances where the traceability efforts involve a cross section of stakeholders from various sectors.
- For example, we do not advice that the blockchain solution be utilized in implementing a traceability effort within a small and an individual section, like in a small warehouse traceability. This is because the cost associated with implementing a blockchain solution will not compensate for the gains of an individual platform traceability.
- In the overall, we recommend the implementation of a blockchain technology as a solution in traceability only when the traceability effort involves multiple stakeholders.

CONCLUSION 5.1

As can be seen the supply chain traceability is essential for maintaining a sustainable supply chain system. The practice of tracing every element used in supply chain has some challenges due to the convoluted nature of the blockchain. Therefore, to mitigate these challenges various solutions have been created. Presently one of the most efficient method of solving these challenges is the blockchain technology. The blockchain technology helps to obviate these difficulties because it is composed of digital execution, operates on decentralized server and scales indefinitely. By using these features of blockchain we can bring visibility to most aspect of the supply chain and help to make the supply chain system more efficient.

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