Blockchain Ready Port Supply Chain Using Distributed Ledger

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Received 08 January 2020; Accepted 08 January 2020
Published 28 January 2020

Abstract

Blockchain technology, as a bedrock for distributed ledgers, offers a platform for innovation for a new decentralized and transparent transaction machinery in industries and businesses, and the port is not an exception. The inbuilt features of this technology enrich trust through transparency and traceability within any transaction of data, goods, services, and financial resources. Notwithstanding initial doubts about this technology, lately government and large corporations have offered to adopt and enhance this technology in various fields of applications, from social and legal industries, and finance to design, maritime and port networks. In this paper, the authors review the current status of the Blockchain technology and some of its applications. The potential benefit of such a technology in port and maritime supply chain is then discussed, and a vision for the future Blockchain ready port and maritime supply chain are proposed. The importation of containerized vehicles is used as an example to demonstrate how such technology can be deployed in a global port industry. Finally, the requirements and challenges to adopt this technology in the future in relation to, port and maritime systems are discussed.

Journal of NBICT, Vol. 1, 1–32.
doi: 10.13052/nbjict1902-097X.2020.001

Keywords: Blockchain, trust, port and maritime systems, technology adoption, global port industry.

1 Introduction

Marking the dawn of a new era, Blockchain is one of the most important and innovative technologies developed in recent years [1–4]. Blockchain (BC) technology is a ground-breaking innovation in decentralized information technology. First invented as part of Bitcoin's underlying infrastructure in 2008 [5], its potential application goes far beyond digital currencies and financial assets. The BC technology is meant to minimize fraud risk, increase transaction settlement speed, improve on the auditability of transactions, minimize trading costs, and increase the effectiveness of monitoring [4, 6–8]. This technology is still in its infant stages and is yet to explode to reach mainstream and enterprise adoption. It is instructive to note that as the technology gained wider recognition and acceptance in recent years, there has been an outbreak of advancements, new use cases, and applications [9].

BC is growing from a secure monetary transaction system into part of an ecosystem of emergent technologies that include artificial intelligence, robotics, Internet of Things (IoT), and crowdsourcing. Similarly, [10] expects that BC will enhance collaboration among individuals and businesses, the transparency of business processes and data, and, ultimately, the productivity and sustainability of an economy. These technologies together epitomize the technical groundwork of future commerce [10–13]. The range of potential application of BC technology is unending, from digital currencies to BC enabled legal contracts [14], with the most auspicious of application awaiting to be developed.

Seaport trade remains one of the most important drivers of every economy especially for most import dependent countries. Seaborne trade continues to expand, generating benefits for importers/exporters across the globe through competitive freight cost. According to [15], there are about 50,000 merchant ships trading internationally, transporting every type and kind of cargo besides the estimated annual income of over half a trillion dollars the operations of merchant ships generates. Therefore, the management of seaport information is crucial to the survival of the port and maritime industry, considering the fact that about 80 percent in volume of global trade is carried by sea and over 70 percent of global trade by value are carried by sea and are handled by ports worldwide [16].

There has been countless complains in the past and recent about the excessive delays in the clearance of cargo in most of West Africa sea ports [17, 18]. Some of these delays are attributed to lack of integrated systems which has led to excessive bureaucracies in the port supply chain network. Studies in related areas in the port industry have stressed on the need to improve on the efficiency of the port systems through port information management. For instance, [19] and [20], stressed on the consequences of port congestion due to delays on logistics and supply chain network in Africa.

Figure 1 illustrates a typical port supply chain network system where a supplier at the port of origin (shipper) moves cargo to a customer (consignee) at the port of discharge. To facilitate this movement of cargo, certain required documents (Manifest, Bill of Lading, Bill of Entry, Commercial Invoice etc.) must be exchanged via systems (mostly Electronic Data Exchange) by actors or stakeholders (Customs, Port Authorities, Freight Forwarders, Regulatory Agencies etc.) in supply chain to play their mandated roles to complete the transaction. The various challenges identified by [19] and [20] among others give rise to the need to explore the potential of adopting BC technology to the port supply chain ecosystem using the importation of vehicles to ports in West Africa sub-region as a scenario case. The purpose of this paper is to propose a BC ready port supply chain for ports in West Africa. Specifically, this paper explore the need for transparency and traceability in port supply chain , the current state of the BC technology and the potential growth in other areas and finally propose a BC ready port supply chain concept using west Africa seaports as a case study.

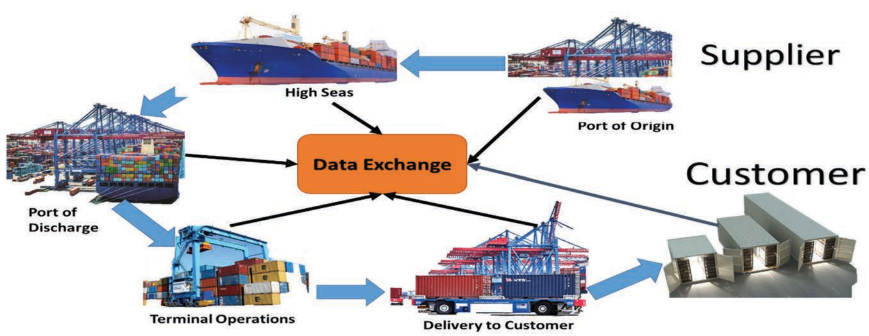

Figure 1 Typical port supply chain network.

Source: Boison (2016)

2 Need for Transparency and Traceability in Port Supply Chain Eco System

Global seaborne trade continues to grow, reinforced by the 2017 pick-up in the world economy. Increasing at 4.0 percent, the fastest growth in five years, global maritime trade gained grounds and raised emotions in the shipping industry [21]. Estimated total volumes reached 10.7 billion tons, reflecting an additional 411 million tons, almost half of which were made of dry bulk commodities [21]. Containerized trade accounted for 17.1% of seaborne trade in 2017 and generally global seaborne trade growth is projected at an upsurge of 3.8% from 2018–2023 [21]. However, there is very little knowledge of how, where and when products (cargo) are moved from continent/region to the other on the high seas. Even before cargo reaches its final destination and is discharged and delivered to the consignee (customer), cargo travel through a vast network of retailers, distributors, transporters, storage facilities and suppliers before cargo is loaded on board a vessel, nevertheless in almost every case these journeys remain an unseen dimension of our possession [22]. Supply chains are getting progressively more complex, more extended, and more global. An event (natural or man-made) on one side of the world can stop production or delivery of a service on the other side. However, if the supply of a very important component or service is disrupted, the consequences can be brutally harmful to stakeholders or companies further along the network, both financially and in terms of reputation [23].

Additionally, there are many potential negative consequences of seaborne trade causing threats to human life and cargo theft, disrupting the entire supply chain network. For example, in April 2017, BBC reported that nineteen crew members were freed from a ship captured by Somali pirates in the Gulf of Aden [24]. Another similar example also reported by the BBC was the Somali pirates who hijacked an oil tanker and released it without condition [25]. The International Convention for Safety of Life at Sea (SOLAS) adopted in 1974 and came into force in May 1980, is one of the most important treaties concerning the safety of merchant ships at sea [26]. This Convention was spearheaded by the International Maritime Organization to curb the disruptions of seaborne supply chain network which normally culminates in delays and additional financial cost. Furthermore, Maersk Group had to reinstall 45,000 new computers after hacker attack in 2018. This attack, according to [27] was a major hit to the Maersk Group. To be specific, 4000 new servers, 45,000 new computers and 2500 applications were installed as a result of the attack which hit a large part of Maersk Group for days, corresponding to a replacement of a complete infrastructure, causing serious disruption in the entire global seaborne supply chain network [27]. The shipper and the consignee at the end of the supply chain are sometimes unware of the various crisis involved with the movement of the ship from a port of origin to a destination port or to be more specific how these cargoes are moved to the final destination. The events such as those mentioned earlier, have necessitated the demand for transparency in seaborne supply chains as a matter of consumer/labor protection and risk prevention. Due to the complexity in the seaborne trade, the current disruption and risk associated to the network is currently developing into a general demand for enhanced access to information in order to regain trust of stakeholders or actors [28]. Sustainability standards and certifications such as Fairtrade, or Organic have become vital tools that support reliable consumption by providing stakeholders in the seaborne supply chain network with a better understanding of the port service life cycle [29, 30]. Nevertheless, the result is simply a logo of the certification printed on container/cargo, and consignees are encouraged to accept this information without being able to validate nor completely comprehend the meaning behind it.

Validating the integrity of the claims made by these certifications is a costly process that requires strenuous auditing. For example, verifying or validating the authenticity of a bill of lading (BL) or a commercial invoice (CI) which is part of the required documents to release cargo from a terminal is expensive and difficult. Furthermore, the extension of certification schemes to regions with levels of high corruptions further endangers the credibility of such standards [22]. One of such examples of abuse of trust in the port and maritime industry is the under-declaration of the weight of cargo or under-invoicing in order to evade tax. The recent corruption allegation at Mombasa Port in Kenya involving cargo theft in 2016 is a classic example of breach of trust by the port authority [31]. We can also recount the 2015 scandal of abuse of trust by VW emissions [32] and Nissan in 2016.

Supply chain visibility is a key in seaborne trade, with most stakeholders having little or no information on their own considering that manifest information (document detailing the cargo, passengers, and crew of a ship, aircraft, or vehicle, for the use of customs and other officials) cannot be accessible until other processes have been performed. For instance, in most ports in the West African sub-region, a manifest information must be rotated (validated and given a unique code) by customs before all other stakeholders can access this information. End to end visibility and transparency in the supply chain transparency can aid model flow of cargo from the port of origin to the port of destination, loading of cargo on board the vessel, generating manifest and BL, commercial invoice, import declaration form (IDF), payment of duties and taxes, examination of cargo, delivery of cargo among others, enabling new kinds of analytics for port and maritime operations, risk and sustainability. Shipping lines giants like Hapag-Lloyd and Singapore-based Ocean Network Express (ONE) Pte. Ltd announced they will join the BC-enabled digital shipping platform, jointly developed by A. P. Moller – Maersk [33]. These are initiatives to visualize end-to-end seaport supply chain and provide organizations with valuable knowledge on their third-party networks [34]. Nonetheless, this revolution of greater transparency in supply chains (port and maritime) is incremental and mostly voluntary at the moment [35, 36].

Transparency enables one to comprehend the effects and consequences of a decision on a cargo movement and its environmental circumstances. However, managing information across the spectrum in the seaport supply chain and control of transparent interactions about every ship and cargo in the supply chain can be a very difficult task. Even though there are cargo online tracking application like marinetraffic.com and other customized online tracking apps for specific ports globally, there remain problems with visibility across the port supply chain network. In view of these challenges, there is the need for accurate data collection and secure data storage to enable a flow of trusted information between stakeholders in the supply chain.

Currently, this responsibility is borne by shipping lines, port authorities, customs, governmental regulatory agencies or other third parties, through centralized information pools. Depending on one single organization/company to broker such sensitive and valuable information involves a great deal of trust to be invested by every stakeholder in a port supply chain. Such organizations (as stakeholders of the port system) will also gain substantial power through the access to the possession of this valuable data, which may be misused to damage, extort or manipulate other stakeholders, if biased. For example, there have been instances the Ghana Revenue Authority revoked licenses of some freight forwarders for under declarations in Ghana [37] and these acts were negatively attributed to manipulation of commercial invoices submitted to customs for duty assessment. Even if this stakeholder can be trusted to be a good actor, it must possess the requisite technical competences to handle and store this valuable information effectively. A major risk associated to this type of centralized system, is its single point of failure which exposes the entire system to risk (e.g. corruption or hacking). Several occurrences in the past decades have shown that a robust system with tight and high cost security features cannot assure total data security, exposing stakeholders who use port information to potential risk. Until now, a practical approach to achieve data security and controlled transparency in the port supply chains was a centralized system, until BC was discovered.

3 Blockchain: Background and Application

Fundamentally, a BC could be identified as a distributed ledger: a sequential chain of 'blocks' where each block contains a record of valid network activity since the last block was added to the chain [9]. Each block can be defined as an encrypted secured piece of information. BC was developed by [5]. Nakamoto used a chain of blocks to develop a decentralized, publicly available, and cryptographically secure digital currency system [5]. The system, named Bitcoin, allows peer-to-peer digital currency trading. This eradicates the need for financial intermediaries while establishing transaction safety. The Bitcoin BC can be viewed as a new type of accounting database that records the transactions of the digital currency into blocks [38]. The blocks are arranged in linear chronological order and shared to a network [39–42]. Theoretically, anyone can add data to the chain of blocks by transacting in the network, reviews can be made by anyone on this data at any time, but the data cannot be changed by anyone without adequate authorization [43]. According to [5], the main features of bitcoin BC include: (1) decentralization, (2) strong authentication and (3) tamper-resistance. This means that all nodes in the system have access to the entire list of transactions. Furthermore, this access allows nodes to both validate and publish new transaction records onto blocks, which are then occasionally added to the end of the main BC with a time stamp [5]. As a result, a BC is a comprehensive and immutable history of network activities, which are shared among all nodes of a distributed network and as such the technology is seen for the first time, enables two or more actors that may or may not know or trust each other to securely exchange value over the internet without including a third party [43]. Instead, the requirement for validation of transactions is attained through a process called 'mining' that warrants the security and validity of the information added to the chain. BC technology can, therefore, be elucidated as the technology that powers the Internet of Transactions [44].

An important asset of the BC is that it operates on a decentralized network demonstrating there is no single entity that controls or governs the system. Removing the need for third party control facilities towards eliminating resistance in all types of value exchange that can arise in the form of costs, risk, information and control [9]. Accordingly, enhancement to a system can be suggested by any user but are implemented only if accepted by all parties involved in the network, hence, enhanced transparency and trust. Trust among a distributed network is possible in a typical BC process due to the validation or mining process where each new transaction is validated by the entire network before being added to the network.

Mining is a process of adding new blocks of data onto the BC through validation by each node on the network [43]. A BC miner can add new block on the chain after a cryptographic algorithm is solved and which must be accepted by all (based on a defined block) of nodes in the network as a valid data. The miner is rewarded by the network for the addition of a valid block to the chain in some form of a digital credit. The credit is primarily an incentive for miners to regularly validate and maintain the consistency of the data throughout the network, and this credit will be in the form of financial gains, or an approval for an execution of an event once the block is accepted by the entire network [1]. Miners are independent entities in a BC network and no single miner is capable of changing or adding invalid data without it being detected by the rest in the network as a ‘ruthless actor’. When a block is rejected in the network, there is no reward for the miner, nonetheless, the block rejected is logged in the system, recognizing the miner as a possible threat to the network and this approach enhances the traceability in the BC network.

Since 2009, BC has grown through three phases: BC 1.0, 2.0, and 3.0 [4]. BC 1.0 purely focuses on the trading of cryptocurrency. The purposes of digital money transfer, remittance, and payment include a new ecosystem: the “Internet of Money” [1]. BC 2.0 comprises of similar trading, but with a broader range of financial applications. Such applications include derivatives, digital asset ownership, smart property, etc. [4, 6]. To enlarge the trading from simply digital currency to a large selection of products, a new type of application called a “smart contract” [4] was introduced in the second generation of BC. A BC-based smart contracts are computer programs operating on BC that autonomously verify, enforce, and execute the terms in contracts [44, 45]. Smart contracts allow for the encoding of rules and situations that are agreed upon by the various trading parties [38]. These contracts separately execute pre-specified tasks, or settle a contract, by investigating variation conditions in combination with the contract’s implanted rules. The concept (smart contract) was first introduced by [46], who indicated that the effecting and monitoring of contracts largely rely on a trusted central authority. The new

BC-based smart contracts decentralize the execution power to each node in the BC network [38]. Also, as the trading history is distributed to every entity in the network, repudiation or modification of a trade will be nearly impossible. Those functions of BC aid to intensely limit the counter-party risk [44].

3.1 Technological Advantages of Blockchain Technology

A number of studies have identified the relevant impacts of technology readiness and capability in EDI or ERP adoption [47–50]. Similar problems could be faced by BC forerunners. Many mainstream BC mechanisms, such as Bitcoin, are highly requiring of storage and computational power in order to guarantee the security of data, if even the data stream of transactions may not be too huge [38]. Consequently, projected expansion of larger storage systems, bigger bandwidth for data transmission, and substantial expansion of computational power will be required for the adoption of BC technology in big corporate systems. BC intrinsically offers many key technological advantages as a result of its structural architecture. Some of which including transparency, durability, immutability and process integrity are discussed in Table 1 below.

Table 1 Advantages of blockchain technology

Themes	Descriptions
Transparency	The level of transparency ensures network activities and operations are highly visible, thereby reducing the need for trust. This is because true copy of a BC is preserved by each node on the network, permitting auditing and inspecting of the data sets in real time [42].
Durability	As a result of decentralized networks which eliminate single points of failure as different to centralized systems, the distribution of risk among its nodes makes the technology much more durable compared to centralized systems and are well suited to prevent unauthorized accesses [42].
Immutability	Users can operate with the highest level of confidence because that is not altered and is accurate. This is because data that is stored on a distributed public BC is practically immutable due to the need for validation by other nodes and traceability of changes [9].
Process Integrity	Users are assured that actions described on the protocol are executed correctly and timely without human intervention. Distributed open source protocols are by nature executed exactly as written in the code [42].

4 Rapid Growth in New Application Fields

The BC technology field has seen tremendous growth through many new innovative and technological concepts put forward, since its discovery over the past ten years. The bad reputation the technology gained during its initial introduction was due to its association with some untraceable purchases on the 'dark net' where users used digital currencies such as Bitcoin to make unidentified purchases. Nonetheless, recent years have seen many big companies such JPMorgan, IBM, Barclays and Maersk investing in research and development of the BC technology [33, 51, 52]. Aside the interest from major organizations, and the large amount of money in cryptocurrency circulation, innovative and creative entrepreneurs and organizations have been fascinated with the new field of technology. Many governments have also seen the potential of this technology over its first affiliation with illegal activities, due to its rapid growth, which has changed their perspectives [53]. Some existing applications and use cases of BC are summarized below.

4.1 Social Applications

Digital Identity – BC technology could offer the infrastructure to scale digital identity at tremendously low costs with momentous enhancements in security. Instead of several governments issuing identities or passports to citizens, a decentralized identity service on using BC technology can offer users from all over the world to obtain their own digital identity through a decentralized system [42]. This application had appealed to the consideration of many governmental organizations.

Voting – This technology can be used for voting process using a "private key". Each voter has a key to authenticate the voting process. In this system, the system protocol can be designed such that the identities of the users can be validated but kept anonymous while calculating the result of the election in real-time. Since the protocol is transparent, voters can be certain that the results are accurate and not vulnerable to manipulation and fraud [42].

Birth and Deaths Registry – The BC technology could offer great gains for a birth and death registry system which arguably should be the backbone of any country. Birth and Death Registry provides accurate data about a county's population records, however, in most West African countries, population census is conducted nearly almost every ten years and the data is mostly inundated with errors. In cases where the Birth and Death Registry is computerized, issue of the integrity of the data is always brought to the fore, as some people can change their date of birth and others also fake ghost names on government payrolls.

BC can provide a trusted and secured decentralized network system which will prevent people from accessing births and death data once initial data is captured from the point of birth or death. BC technology has not been adopted yet in this space in the West Africa sub-region, regardless of the countless opportunities it evidently offers to some other industries and disciplines.

4.2 Financial Application

Currencies – Bitcoin was the first case study of BC technology, offering a fully decentralized issuance of currency, and traceable payments. Subsequent to Bitcoin's increasing success, a large number of digital currencies have been developed, which give differences of the Bitcoin system architecture. There are over 600 different digital currencies currently that use BC technology as their fundamental technology layer [54]. Digital currencies are the furthermost popular use case of BC technology, nevertheless, improvements and innovations in this field, have also resulted to many other use cases [42].

Exchanges – The facilitation of exchange of digital currencies such as Bitcoin or the exchange of any other form of assets that can be registered with its own digital identifier on the network can be deployed by the BC technology. Firms such as Coinbase, ItBit and Kraken are instances of digital currency exchanges that presently exist [55, 56].

Stock Market – BC technology can be powered by decentralized stock markets [57], where the stocks can be traded on a platform that is not controlled by any one governing body as different to present systems. Users are assured that the exchanges are carried out accurately since the system will only function as designated by the system protocol. Nonetheless, this application is yet to be considered.

4.3 Legal Application

Smart Property – The common idea of smart contracts is premised on the notion of transacting all property in BC-based models [58]. A BC system can create digital identities for any physical world hard asset. Ownership can be regulated or controlled through smart contracts by using these identities. For example, the expiration of insurance will prevent the user from driving the car, or the payment of rent automatically grants the user access to the room or the payment of roadworthy of a vehicle automatically grants the driver the access to drive the vehicle. Local governments in West Africa and beyond can leverage on BC technology to draw several property owners to the tax net, thereby increasing government revenue and creating visibility and assurance in the transactions.

Smart Contracts – There is the emergence of BC-based smart contracts as a use case of BC technology [59]. The concept of smart contracts is forthright: A software protocol executes an action (purchase goods or services, releases funds, sends information, etc.) when certain required conditions are satisfied (the outcome of an event is determined, a payment is received etc.). The BC-based contracts reduce the level of human participation required to create, execute and enforce a contract, thereby reducing its cost whereas guaranteeing the assurance of execution and enforcement processes. For instance, a consignee (owner of cargo) can effect payment to a freight forwarder in a BC enabled crypto and Fintech platforms. So a software protocol action to notify the consignee that cargo has arrived at the port of discharge, is executed on the platform, the consignee verifies the details of the cargo (ship name, cargo weight, BL number, cargo description etc.) and executes payment. This technology is yet to be implemented at the port and maritime industry.

4.4 Other Potential Application

Port Operations Application – Despite the countless advantages that the BC technology offers to other industries, the port and maritime industry is yet to benefit. Port operations applications are designed to basically import/export (inbound and outbound), stack (storage) and delivery cargo to consignees (customers). There have been incidences of missing cargo and wrong deliveries which compromise data integrity. How is it possible, for instance, that, cargo that has been manifested and discharged in a port of discharge (destination port) can be missing without any traceable events? Because in most cases data can be edited by some parties without authorization, and port operation application has not offered a comprehensive solution to deal with this menace. A BC enabled port operations application will provide decentralized secured platform that will ensure authentication, traceability and visibility to all transactions of parties.

Customs Classification Compliance – This concept relates to payment of duties and taxes by most of the customs port in the world. Most ports in Africa use the ad valorem (based on the value of the cargo) concept to calculate the duties and tax based on how the said cargo is classified by World Customs Organization (WCO), which is nomenclature of all items (cargoes) that are traded on international trade. For example, worn clothing has a code of 6309000000, bicycle has a code of 8712000000 etc. Each code provides the value of the cargo, and duties and taxes are computed accordingly. There have been instances where cargo is wrongly classified, or a feature of cargo is changed either to evade tax and duty or to assist in doing same. These trust issues are one of the main causes of excessive congestion in most ports in West Africa [20], because Customs will have to institute additional checks in the clearance process which evidently leaves cargo at the terminal for several days, accruing additional rent along its related demurrage charges. A BC enabled platform will provide a secured decentralized cargo classification which will prevent nefarious consignees, freight forwarders and custom officers to alter cargo features to evade taxes and duties.

Asset Tracking – This is also an area where significant gains can be made using BC technology to trace physical assets which permit a record of ownership to be established for each asset. For instance, Everledger (a firm) tracks diamonds through creating a digital identity for each diamond on a BC network [60]. This helps the authentication of the transaction, for instance, by avoiding what is known as "blood diamonds" to enter the jewelry market. Another example of asset tracking is provided by a shipper's authority, which focuses on creating visibility of the movement of the cargo from the port of loading through the high seas to the port of discharge (destination) alongside with every activity that affects the cargo in the terminal till cargo is delivered to the consignee. However, the latter example is not BC enabled and this concept could incorporate BC technology capabilities.

Port Supply Chain Applications – BC technology can be implemented in a complex port and maritime supply chain systems which are deemed to be the next potential application domain. The authors envisage a number of port supply chain related transactions that can immediately benefit from the BC approach. These include: cargo tracking from a port of loading to a port of discharge and after discharge; controlling cargo classification for import and export taxes and duties; regulatory agencies controlling compliances of cargo registrations and certifications; terminal operators and customs, controlling the movement of cargo within and outside the container freight stations; controlling financial transactions between and within stakeholders or actors in the port supply chain; tracking the condition of cargo at the destination port terminal and its clearing processing, until cargo exits the destination terminal to the consignee/customer. This is the focus of this article, using a typical example in the West African sub region, Ghana to be precise on the importation of containerized vehicle from Europe.

5 Methodology

The qualitative approach was adopted based on a case study design (Ports in West Africa). The sub region was chosen because of the similar customs processes employed. An extensive literature reviews of BC technologies in known sectors and potential sectors that BC could be deployed were conducted. In addition, contemporary and contentious issues in the BC growth in rapid areas were reviewed specifically in areas such as the birth and death registry, customs classification compliance, port supply chain application and asset tracking. Based on these reviews a proposed BC ready port supply chain concept was proposed and its merits and demerits discussed.

6 Port Supply Chain Transparency and Traceability Using BC Technology

Supply chain in port and maritime industry comprises of a series of system entities including people, logistical resources (Ships, Containers, Equipment, Terminal Space, Vehicles, Train etc.), processes, knowledge, financial contracts and transactions that facilitate moving a cargo from shipper at the port of loading to consignee at the port of discharge. It is tough to have the overall picture of all transactions within the chains in a large supply chain system [61]. This information is traditionally stored in multiple locations and are accessible to some system operators or stakeholders. In such systems, the consignee (final consumer or stakeholder in the network) normally has partial access to the entire information [62]. In some cases, fragment of the information is handled as a commodity for a shipping line (provider of the carrier service). Nonetheless, as a result of the low level of transparency, trust is arrogated only between the system actors to ensure tractability of transactions.

The application of BC technology in the port supply chain through immutable record of data, controlled user accesses and distributed storage can possibly enhance the transparency and traceability in the network. Throughout the entire service cycle, the technology can offer a decentralized distributed system collect, store and manage key service information of each individual cargo being shipped and this system is proposed in this paper using a containerized vehicle as a scenario. Individual BLs along with specific cargo information, with such distributed block of information potentially create a secure, shared record of transactions for the service. The proposed system is explained in the following sections, including, the types of actors at the port of loading and discharge, how they register and access information in the network, and how data entry is validated, stored and authorized.

6.1 BC Ready Port Supply Chain

Figure 2 is an illustration of proposed application of BC in port supply chain systems. The method proposed comprises of a BC system that uses a decentralized distributed technology to collect, store and manage key cargo information of each cargo throughout its service life cycle. This creates a secured and shared record of exchange for each cargo along with specific cargo information. As cargo moves through its service life cycle (movement of cargo from port of loading to port of discharge and delivery to consignee), it is possessed by a number of actors, for example, the shipper, shipping line (owners or agents of ships or vessels), customs, port authorities, terminal operators, regulatory authorities (e.g., Food and Drugs Authority, Environmental Protection Agency and, Standards Authority), freight forwarders, customs house agents and the final consignee (customer). Each of these stakeholders or actors play an important part in this system, logging in key

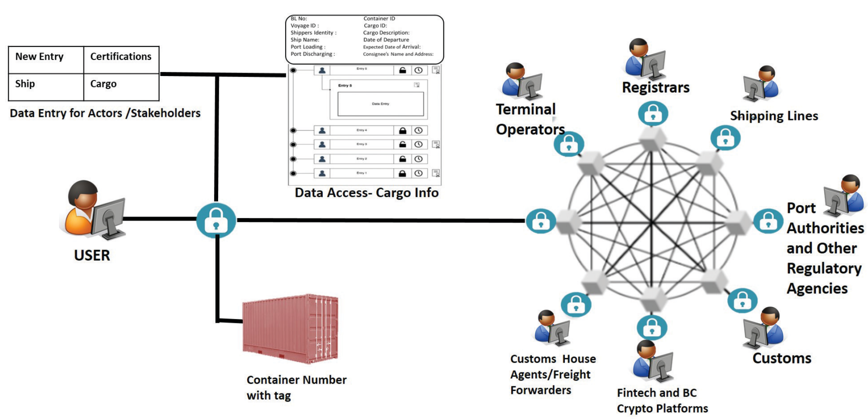

Figure 2 Overview of the proposed port BC concept.

information about the cargo and its current status (current location of the cargo whether on terminal or on ship) onto the BC network. Each cargo listed on the BL would have a unique digital profile containing all related information, populated during various stages in the movement of the cargo. This scenario is based on the entire port logistics and transport supply chain from the port of loading to the port of discharge including all processes to ensure that cargo is delivered to the consignee.

Each voyage (movement of a ship from a port of loading to a port of destination) would have a unique transaction code (voyage ID), representing a unique digital cryptographic identifier that links a voyage made by a ship to specific cargoes to its identity on the network. It is very instructive to note that containers are used as enclosures to hold the cargo on board a ship in the scenario used as specified earlier. These containers would also have same unique digital cryptographic identifier (RFIDs, barcode etc.) that links the container (based on its type: either 20 or 40 feet) to its cargo. It is presumed that each cargo in a container with a BL number could be a type of product which has its own information tag with specific unique digital cryptographic identifier (RFIDs, barcode or QR Code) from a manufacturer.

This virtual identity is offered on the system software as a part of the cargo digital profile within the service cycle. Stakeholders or actors upon registration on the system can also maintain their own digital profile on the network. This profile displays information such as their cargo ID, cargo description, BL No., container ID, shipper's identity, ship's name, port of loading, port of discharging, date of departure, expected date of arrival, certifications (Regulatory authorities) associated with the cargo. A cargo that has been signed or handled by an actor (shipper, customs, regulatory authorities etc.) would have a link from the cargo profile to the actor's profile. The system allows actors to change the privacy of their profile to different types of actors. Actors are registered on the system through a registrar with details that provide the role of the actor in the service cycle. Actors who intend to remain anonymous in the system, must, however, be certified by a registered certifier or auditor to establish trust in the system.

The system provides accreditation services and a unique identity to the system actors through registration of themselves on the network by a registrar A public and private cryptographic key pair are generated for each actor upon registration. The public key is used to identify an actor within the network whilst the transactions of the actor is authenticated by a private key in the system. Transactions can be executed with the network by actors by cryptographically authenticating themselves by means of their private

Table 2 Actors/stakeholders and their roles in the port supply chain network

Registrars	Register and provide unique identities to actors on the network as well as certification of the actors to participate in the network.
Shipping Lines	Carrier who move cargo from the port of loading to a port of discharging based on predefined rules (SOLAS conventions etc.)
Port Authorities and Regulatory Authorities	Define standards' schemes for cargo and ships (such as Fairtrade, protocols for ship arrivals and departure, IMO Standards, SOLAS Conventions)
Terminal Operators	Handle ships and cargoes in a safe and secured manner based on predefined regulations by the port authorities.
Customs	Responsible for collection of import duties and taxes on cargo
Customs House Agents/Freight Forwarders/Consignees	Act as agents to consignees to facilitate the clearance of cargo through predefined processes at the port of discharge. Most of the initial data entries to start the transaction are initiated by them on the BC network
Fintech and BC Enabled Crypto Platforms	Provide platforms for actors to use to facilitate payments of goods and services.

unique keys. This allows each cargo and its voyage to be digitally signed by the actors when being moved from one port to the other or added to further down in the port supply chain. Table 2 above illustrates the types of actors/stockholders and their mandated roles in the proposed system.

This system provides each actor to access a specific network of BC using a user interface. A specific digital profile of a cargo used by an actor can be configured by the application software. Parties trusted in the port supply chain network (such as port authorities, customs etc.) develop the system software and make them accessible for registered organizations and stakeholders to download and run on their systems. Consignees and custom house agents would have customized versions of the user interface to access data about a cargo they are associated with. The system software facilitates the access to existing data and new entries. The system is run on a BC that offers programmable code to be executed, for example, Ethereum BC [14].

Anyone running the system software with an appropriate authentication can access all data stored on the BC network. However, access to data by actors would be based on their types and positions in the port supply chain network. How the actors are to interact or transact business and share data on the network with the system are pre-defined by these rules (type and position). Actors cannot change these rules which therefore guarantee integrity and the prerequisite for the validity of data. As far as these rules are defined and stored on the BC system, they cannot be altered without notifications to all nodes and verifications by key actors. Fairtrade or FSC which are standard and certifications programs, for instance, can be implemented on the system [29, 62]. Certifiers and auditors in the network will visit the ports and terminals to inspect if the rules for standard programs are being met. As soon as confirmed by the certifiers, the actor's profile and its cargo can be digitally signed by the certifiers and standards organization, to show their certification. All actors are inspected by the certifiers to verify their identity. The certifiers are required to disclose all actors' identity to the network through a registrar. The purpose is to enhance the transparency of system elements, while at the same time maintaining the security and integrity of data.

6.2 Data Entry

To enable trades and updating of cargo profile, each physical cargo in the proposed system has to be presented digitally on a BC network, to ensure direct access of the cargo profile by stakeholders responsible for such updates. For instance, the shipping line should have direct access to the cargo profile to be able to update the type of ship and location of the cargo on the BC system. Applying the digital identities of the actors and cargoes, enables the possibility for a "smart contract" to be created for each cargo in the form of rules, so that only the parties with the correct digital keys have access to that cargo.

At a given time, a cargo is 'owned' by an actor (for example at the port of loading, the shipper owns the cargo and at the port of discharging the consignee owns same). Only this actor has the authorizations to enter new information onto that cargo's profile or initiate a transaction with another party. Therefore, when the cargo is moved from a port of loading to another actor at the port of discharging, both parties must sign a digital contract to endorse the exchange. Once all parties have signed the contract, the particulars of the transaction will be added to the BC. The network will process this data and update the position of that cargo profile, depicting its new parties. This presents the network to establish an unquestionable record of ownership for each cargo. When the transaction is completed, the system updates the authorizations such that only the new owner can establish a new entry and update the cargo's particulars. Meanwhile both parties must demonstrate their identity by signing with their individual private keys, the particulars entered onto the profile is guaranteed to have been entered by the individual party.

Table 3 Types of cargo and description

Types of Data	Description
Ownership data	Orderly list of all previous owners of the cargo or entity in the BC network including the current owner. Each time the cargo is exchanged between two parties, a new entry is created by the system recording the details of the transacting parties and is added to the cargo's profile. The transacting parties are referred to by their digital identity. Thus, enabling the system to assign data entry authorizations to the correct party. Moreover, this enables implementing a controlled level of transparency amongst related parties.
Location data	Where the cargo has been (port of loading, port of discharging, container freight station, etc.) and where is it now currently, are recorded using the location data. Meanwhile, the system has location details of all the registered actors; it can record the location of a cargo anytime an actor effects a new entry. The location information may be simply a unique location ID, or dynamic GPS data, which could be implemented for other supply chains.
Time stamping	When a new entry is created on a cargo's profile, the system automatically records the exact time of that entry. This allows the network to establish a logical order of entries related to that specific cargo. Time cargo is loading on board the vessel, sailing time, arrival time and discharge time of cargo are all recorded.
Cargo specific data	This is the key information that is specific to a cargo (cargo details). This information can be used to prove certain attributes of the cargo or provide performance data as feedback to shipping lines, regulatory authorities, customs, and the terminal operators.
Environmental impact data	Provides additional information regarding the environmental impact of the cargo. For instance, dangerous cargos (chemicals, explosives, etc.) are handled with predefined safety standards.

By using the private key data, this could be added manually or automatically to connect the network.

A platform is provided to the actors through the software application to create a new consignment. The system can collect a range of data, depending on the type of cargo, status of the cargo, and the standards that are to be implemented for this cargo. When the transaction is initiated (when cargo is moved by a ship from a port of loading to a port of discharging), the records are updated automatically. Furthermore, cargo specific information is added by the owner of the cargo when they are given access to generate a new entry. In Table 3 above are several types of data that can be collected on some types of cargo.

Some types of cargo could be configured to transmit their performance data to the BC system during their shipment period from one port to the other. For instance, a refrigerated cargo could update information about the temperature of the cargo during movement on the high seas and at the terminal before it is finally delivered to a consignee. This information could then be accessed by the respective manufacturers, shippers, shipping lines and terminal operators and regulatory authorities, to improve their services based on such feedback. Another example of this would be a dangerous cargo class 1 (explosives) that is connected to the Internet, which automatically uploads conditions and environmental effect data to the BC system whilst in transit through the entire port supply chain activities. Future shippers and of explosives will have access to these historic performance data to make informed decisions as well as manufacturers and designers of explosives.

6.3 Data Access

All actors in the port supply chain use the cargo digital profile as the primary source of accessing cargo information. Figure 3 illustrates an example template of a cargo profile. Each entry is time stamped and digitally signed by the actors. The certifications (registrars, regulatory authorities etc.) affiliated with the cargo are also recorded in the digital profile of the cargo (see Figure 3). To establish control over users' access, the information within a profile, including the specific cargo details and identities of actors and specific rules would be embedded into the cargo's profile. All actors must use their respective private keys to authenticate themselves when accessing the profile of the cargo. This allows the system to display the profile, according to the permissions set to that actor. Figure 3 shows the access as a locked or unlocked entry for each actor, which signifies the level of authorizations allowed for each different user accessing this cargo profile.

For example, a vehicle cargo such as a van would have a profile that contains details like Brand name, year of make, chassis number, engine capacity, horsepower, displacement etc. A consignee importing that vehicle would have access to these details but not the specific names of the manufacturers. Meanwhile, a distributer or quality controller would have access to more information such as the manufacturing warehouse and details of the parts and other quality control information that are required to pass the standards required.

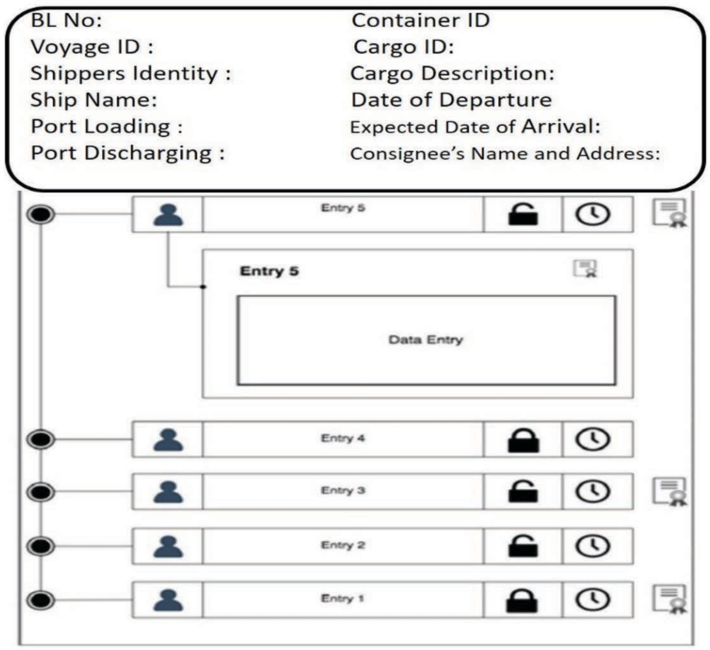

Figure 3 Example template for a BL cargo profile.

7 Application Scenario (West Africa Seaport Process)

In this section, we use an example of an application scenario to explain and better clarify the potential for the proposed concept. The application of the BC ready port supply chain is considered for the shipment of a containerized vehicle from a port of loading to a destination port (port of discharging). There are numerous actors involved in the transportation of the cargo on the high seas. The application of BC in this instance could extend to other transportation supply chain network of other products. The scenario focuses on a branch of the port supply chain (seaport), which includes the movement of containerized cargo (vehicle) from a port of loading to a destination port stage as depicted by Figure 4. Through the BC system, all actors mentioned in this scenario, have registered themselves through a registrar service, and have been assigned their own unique identity on the network, including an actor profile. The system software created for the actors in the industry provides an interface to interact with among themselves. In a BC ready containerized cargo scenario, the following business processes would be involved:

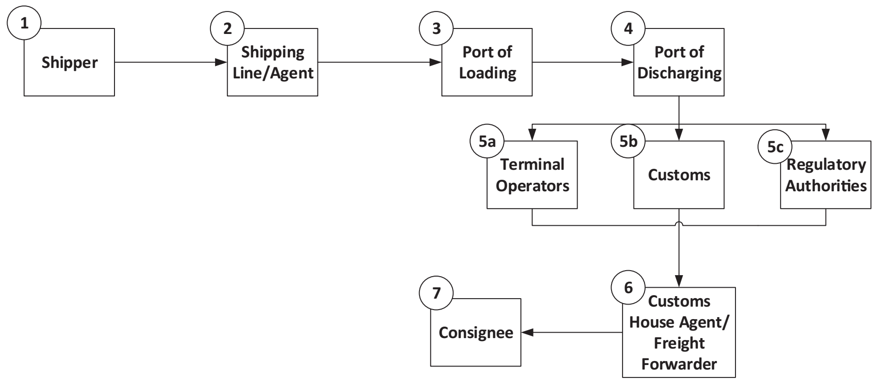

Figure 4 Port supply chain of movement of containerized vehicle from port of loading to port of discharging.

1. **Shipper:** The vehicle to be exported is entered with specific details (type of vehicle, make, year of make, engine capacity, weight, consignee name, address and port of destination, etc.). A new trade is initiated between the shipper and the consignee, where cargo is exchanged, after signing of a digital contract stored on the BC (data entry could be through a handheld device or a desktop computer). The registrar appoints the certifiers to do physical checks if regulations have been complied with as indicated on the system. The certificate is then displayed on the shipper's profile with digital signatures of both the certifiers and standard organizations (regulatory authorities).
2. **Shipping Line/Agent:** The shipper selects a shipping line on the system and signs a digital contract with the shipper after cargo has been physically moved to the terminal of the shipping line. The shipping line enters additional information on the cargo by indicating ship details, details of the container (Container Number, Weight, Size, etc.) and moves cargo to the port for loading/destination after signing a digital contract with the port authority to perform cargo works. This information is also displayed on both the port authority's and shipping line's profile on the system.
3. **Port of Loading:** The port assigns a specific berth and yard to the shipping line to berth ship and stack cargo for loading activities to commence respectively. This transaction is made possible after a digital contract is signed between the shipping line and the port authority. In instances where duties and taxes would have to be paid on exported cargo, cargo is blocked in the system unless payment is made and

a customs officer physically validates that physical cargo at the yard matches the features specified and a digital signature of the officer added to the shipper's profile. When cargo is loaded on the ship, the port tally clerks indicate the movement of the cargo at each stage in the yard to the ship to show which equipment handled the cargo before it was stacked on the ship. This gives time stamp records of every activity at the port. If a ship departs as scheduled, the shipping line indicates that on the system, however, if there are any delays, a new expected time of departure is indicated by the shipping line, and all actors on the system are notified accordingly.

4. **Port of Discharging:** Prior to arrival of a ship at the destination port, the system gives a platform to all actors with GPS capabilities to view the location of the ship and the status of each cargo on board. The destination port (port of discharging) assigns berth and yard space for the ship before its arrival and this data is entered on the cargo profile by the officer at the port of discharging. Every activity on the cargo is captured by the assigned officer using a handheld device based on the permission level.
5. a. **Terminal Operators:** Most often cargo at the berth at the port of destination is transferred to an off-dock terminal where processes for delivery of the cargo are executed. Some ports operate as terminal operators. Cargo is moved from the port of destination to a terminal yard after a custom officer display's the container movement report on the cargo profile on the BC system indicating that location of cargo has changed. An officer at the off-dock terminal receives the cargo and gates-in the cargo into the terminal with a handheld device indicating the condition of the cargo at the time of receipt, and this data is added to the cargo profile.

   b. **Customs/Regulatory Authorities:** At the port of destination or the off-dock terminal, duties and taxes must be paid on the cargo before it is delivered to the consignee. The customs house agent performs physical activities on behalf of the consignee to obtain a release for the cargo. Duties and taxes to be paid are already known on this system through an inbuilt algorithm on the BC platform which classifies cargo based on the WCO classification nomenclature and respective duties and taxes are automatically calculated after the shipper initiates the first entry on the system. Similarly, fees and other levies (penalties) to be paid by a consignee to comply with the required standards are built through similar algorithms as executed in the case of duty calculations.

Certifiers confirm in the terminal that all requirements have been adhered to and display a digital certificate on the cargo's profile. These data also form part of cargo risk profile for the shipper and the consignee. The system groups these risks into three categories (Red-Bad, Yellow-Fair and Green-Good) indicating levels of severity. It is instructive to note cargo can only be released on the system when customs and regulatory requirements have been met.

6. **Customs House Agents/Freight Forwarders:** The movement of cargo from the shipper's location to the terminal (port of loading or port of discharging) is facilitated by a customs house agent or a freight forwarder. In the same manner, the delivery of cargo from the discharging port to the consignee is facilitated by customs house agent or the freight forwarder. These practices where agents facilitate import and export processes for consignees are prevalent in most African seaports and normally enshrined in the regulations of customs. In this wise, a customs house agent uses a private key to access the system after a digital contract has been signed between the consignee and the customs house agent. This contract gives the customs house agent the authorization to facilitate all processes in import or export of cargo. In ports, where customs house agents are not actors in the supply chain network, the consignee performs these activities directly with the shipping lines, customs, regulatory agencies and the terminal operators.
7. **Consignee:** The consignee at any point in time can access the platform to ascertain the status of cargo transactions. For instance, number of releases made, pending releases, duties and taxes paid, terminal handling charges, cargo turnaround time and every detailed historic information about the cargo. The consignee receives cargo from the customs house agent and indicates receipt of cargo by updating the cargo profile on the system. An inbuilt Fintech and crypto BC platform will thus enable seamless financial transaction to be executed without any intermediary.

8 Conclusions

The role of BC technology plays in transforming many existing traditional systems to a more secured, transparent, distributed, collaborative system to empower users cannot be over emphasized. In this paper, the authors reviewed some of the main features of the BC technology and deliberated potential application discipline. The focus of the paper was pitched on the application of the technology within the port supply chain network using a containerized cargo scenario transportation from a port of loading to a port of discharging.

A conceptual vision for a BC ready port supply chain was proposed using same scenario within the context of West Africa seaport where port processes appear to be similar. In this paper, a concept has been proposed to demonstrate potential benefits and stimulate further research and subsequently development of the concept into a BC application platform. The authors fully comprehend the cultural and technical difficulties ahead. Nonetheless, it is believed that the numerous potential benefits to actors in the network in facilitating port and maritime trade should provide adequate impetus to adopt this technology.

The port authorities can report comprehensively on detailed statistics about cargo handled within a certain time horizon at various stages (sea, terminal, delivery point) of cargo movements. Non-compliance cargo can easily be detected in the system and as a result owner of such cargo (shipper and consignee) could be blocked from the system due to bad risk data attached to cargo profile.

The integration of smart contracts into this system can enhance the security of transactions as each cargo can only be received by the consignee who has signed the relevant contract with the shipper; permitting the system to identify duplicated transactions or misplaced cargoes. Furthermore, it would replace the laborious task of always sending manifested information by the shipping lines through EDIs or other data exchange platforms to actors in the network or the calculation of customs duty based on classifications. Conversely, this technology requires some level of IT infrastructure in place for all actors, such as access to the Internet, which may not be feasible in areas where there is unstable or nonexistent Internet connectivity.

The digital profiles of cargo need to be updated regularly by manual or automated devices such as simple or RFID tags. Users of the system should derive incentives using smart contracts embedded to enable BC to govern progress of a business transaction and process. In some cases, performance capability of such secured system may be seen to be a bottleneck for the implementation of proposed solution.

9 Recommendations

The proposed system will facilitate the collection of large amount of data about cargo and its actors in the port supply chain network, which can demonstrate to be beneficial to a number of stakeholders (government, organizations, investors, producers, retailers, shipping lines, consignees etc.) For example, this allows consignees (consumers) to readily access accurate data specific to any cargo that has been transported through a BC enabled port supply chain, thus allowing them to make better shipment decisions. Companies engaged in the design, manufacturing and production can derive an improved understanding of how their products are repackaged and transported along the seaport supply chain. This degree of feedback can be leveraged to improve on their production, marketing and technology strategies.

It would be necessary that the large ports and maritime originations be involved in championing the potential benefits of the proposed port supply chain systems. Some may be reluctant initially to features such as lead times of cargo, transparency and automated payments (digital currencies) as sporadically these are used as a business leverage. Nevertheless, the experience from digital currencies and large financial institutes have demonstrated that big industrial and governmental organizations will realize the potential and endeavor to remain unbiased towards this technology.

Future studies will look at the possibility of using transactions generated from the port BC ready system to be integrated into a public BC platform that allows for multiple coins, smart contracts and distributed applications to be built and mined. Extensive research is needed to develop this concept to the next level for port industry to be deployed on a large scale with close collaboration between research, port and maritime industry, and governmental institutions.

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