Current Status and Challenges of Enhancing Security Management on IT-Enabled Supply Chain

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Abstract: This exploratory investigation aims to show an explicit summarization of applying current information technologies, such as data-provenance, Internet of Things, cloud computing and blockchain, to traditional supply chain systems for enhancing its security management and improving various security-related properties, i.e. transparency, visibility, accountability, traceability and reliability. It introduces general histories and definitions, in terms of information science, of the supply chain and relevant technologies which have been applied or are potential to be applied on supply chain with purpose of lowering cost, facilitating its security and convenience. It provides a comprehensive review of current relative research work and industrial cases from several famous companies. It also illustrates complementary relationships among those technologies while working on supply chain, discusses the applicability about why they are suitable and efficient for establishing a trust supply chain management. Finally, this paper concludes several potential or existing security issues and challenges which supply chain management is facing.

Keywords: Supply chain; Security management; Information technologies

1. Introduction

Supply chain has a long history as a traditional supply-demand model from manufacturing raw materials to process and produce, then selling final products to end customers. Traditional supply chain system can provide services to human's life within a relatively safe environment, however, it's not much easy to satisfy ever-increasing diversified types of goods and complicated customers' demands which require supply chain to high-efficiently and less-costly work within a more complex consuming information network. Moreover, for making decisions coordinately in a timely manner, all supply chain participants should have an ability to share and gather all process and product's information and status efficiently cross the whole supply chain network.

By enabling technical methods to the traditional supply chain's daily management work for gathering, processing, analyzing, storing and sharing large amounts of information in a real-time, information technology (IT) has become a necessary component of supply chain management system for information collaborating and performance improving (Smith et al. 2007). IT-enabled supply chain is designed proving the authenticity of goods received by customers, and efficiently tracking transportation status or items' condition (especially factors like temperature, power and light for cold or food chain) in real-time. Various IT techniques, i.e. internet of things (IoT) technologies for information capturing and processing; cloud computing for big data processing; blockchain for transportation visibility and data-provenance for activities and responsibility tracking, have been applied to traditional supply chain management system by many companies to achieve the management system's maximum-efficiency and minimum-cost.

The reminder of this paper is organized as follows: section 2 introduces general histories and definitions, in terms of information science, of the supply chain and related technologies which have been applied or are potential to be applied to supply chain management systems with purpose of facilitating its security and convenience; section 3 provides a comprehensive review of current relevant research work and industrial cases from several famous companies; section 4 demonstrates limitations of the traditional supply chain system and requirements of IT-enabled supply chain systems, as well as analyzes security issues resulted by applyin current information technologies; section 5 illustrates complementary relationships among those technologies while working on supply chain with the applicability about why they are suitable and efficient for establishing a trust supply chain management; section 6 discusses potential or existing security challenges to which supply chain management is facing; section 7 concludes a brief discussion on the perception and future work about IT-enabled supply chain systems.

2. History and Definition

2.1 Supply chain

Supply chain has long history over than 100 years. A supply chain can be regarded as a network of all individuals, organizations, resources, activities and technologies involved in the creation, delivery and sale of a product (Janvier-James 2012). A supply chain is linked together through physical flows, which involves the production, transportation, movement, and storage of goods and materials, as well as information flows, which allows the various supply chain members to coordinate their long-term plans and control the daily flow of goods and materials up and down the supply chain (Zhou and Piramuthu 2015).

2.2 Data-provenance

The term "provenance" has a long history over than 300 years with the original definition in works of arts as the chronology of

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a historical object (Zhang et al. 2012). Provenance can be given different kinds of definition in terms of different domains (Simmhan and Gannon 2005). Data-provenance is much similar with another concept "data-lineage", which refers to a data life cycle including data's origins, activities and where it moves over time. Bunaman et al. (2001) described data-provenance as the origins of a piece of data and the process by which it arrived at a database.

Syalim et al. (2010) and Hasan et al. (2007) described data-provenance as a causal relationship between objects, processes and process executors who was able to control processes and objects, which could also be regarded as an evidence recording of objects and processes' activities. For example, in the hospital information recording system, data-provenance describes causal relationship among medical records (object), medical diagnosis (the process), and the physicians (the process executors).

2.3 IoT

The first idea of "network of smart devices" was applied on Carnegie Mellon University's modified Coke machine which was able to report its inventory and whether the loaded drinks were cold or not in 1982. However, the first proposal of "Internet of Things" was formally proposed by MIT's Auto-ID Center in 1999 (Madakam et al. 2015).

Benabdessalem et al. (2014) defined IoT as a network of objects within which all objects were able to be identified by certain trustful mechanisms and connected, either with each other internally or to the internet externally through combining with IoT's necessary technologies like RFID, sensors, GPS chips and mobile phone to provide integrated services.

2.4 Cloud computing

The term "cloud" was firstly proposed by General Magic and AT&T as platforms for distributed computing to describing their Telescript and PersonaLink technologies as early as 1993, while "cloud computing" became popular sine Amazon's Elastic Computer Cloud released in 2006 (Qian et al. 2009).

Cloud computing refers to a super calculating model to distribute computing tasks into a remote data center with thousands of computer and servers connected to the computer cloud to assign different resources, like storage space, computing power and all kinds of software services, for various computing requirements (Jun and Wei 2011).

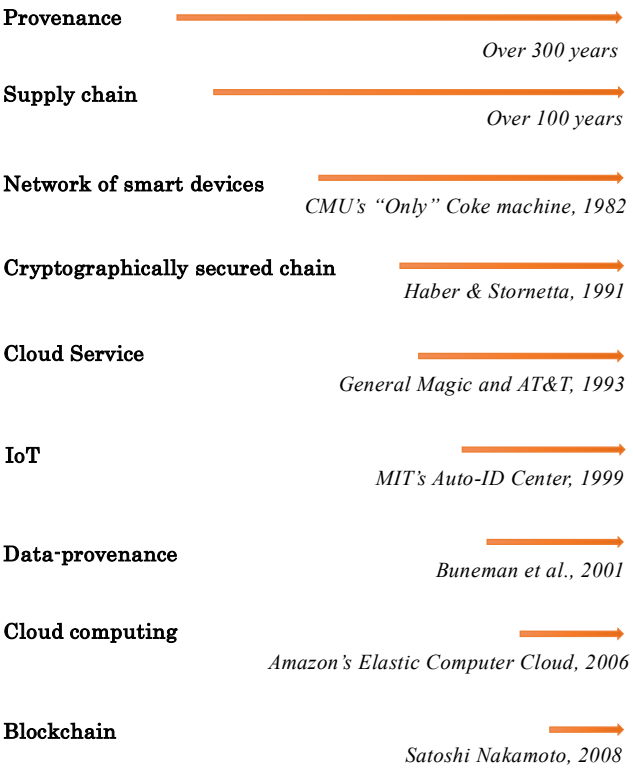
2.5 Blockchain

Haber and Stornetta (1990) firstly proposed the idea of cryptographically secured chain architecture for their tamper-proof timestamp mechanism in 1990. Blockchain was formally proposed by a person or a group named Satoshi Nakamoto in 2008 as a core component of his cryptocurrency system "bitcoin" (Nakamoto 2008).

Blockchain refers to a decentralized architecture consists of increasing numbers of cryptographically linked blocks each of which stores the hash value of previous block (Bocek et al. 2017). Blockchain was able to protect the information among the network against any breached or vulnerable device through verifying identities and rejecting malicious parties by other members. The data stored in a block is immutable which is extremely hard to be tampered (tamperproof) which means that hackers must manipulate all blocks' data until the head block to achieve cyberattacks, which is impossible in a real blockchain world.

Figure 1 shows the general history of traditional supply chain and enabled information technologies.

Figure 1: History of terminologies



3. Related Work

3.1 Supply Chain with Data-Provenance

Data-provenance have been worked in many research domains such as healthcare management for information navigating, tracing, monitoring and management. Data-provenance issues can also be researched with other related technologies such as IoT, blockchain and working in cloud environment, in various research or industrial domains as tracing evidences of objects or processes, especially working on food supply chains. Zhang et al. (2013) proposed a smart sensor data collection strategy for IoT, which aims to improve the efficiency and accuracy of provenance with the minimized size of data set at the same time by modeling IoT system structure for food supply chains, as well as algorithms from big data and self-correction strategies.

Some researchers have researched on data-provenance with related technologies but not focus on supply chain system, which would have research space for further research work by extending them to supply chain systems. Ramachandran and

Kantarciogly (2017) researched on developing a system which was for recording immutable data trails according to smart contracts and open provenance model, to facilitate the collection, verification and management of trustworthy data provenance based on using blockchain as a platform. Javaid et al. (2018) provided a system architecture which could enforce data provenance and data integrity to work in IoT environment based on using Physical Unclonable Functions and Ethereum, as well as a blockchain variant with smart contracts.

3.2 Supply Chain with IoT

One of the most necessary and important properties for IT-enabled supply chain is to achieve its high-efficiency traceability in some fields, i.e. cold chain, food supply chain, health care, and pharmaceutical industries for preventing against some transportation or production's condition accidents like food poisoning which could cause some serious health effects on consumers (Zhou and Piramuthu 2015).IoT plays an important role on combining supply chain management system with information technologies regarded as a basic platform providing tracking and internet-connecting services. Thus, early research works should focus on facilitating the convenience and traceability by utilizing IoT technology.

The combination between IoT and supply chain would enhance the traceability especially in cold chain and food manufacturing. Mousavi et al. (2002) proposed a practical system framework, which could trace the whole process of meat producing from the individual animal to individual prime cuts in the boning hall, with technologies such as bar code scanning and RFID. Regattieri et al. (2007) provided a practical system framework for food manufacturing supply chain traceability with tracing functions, which could identify products' self-information, track products' status and data by utilizing traceability tools and route relevant information. Abad et al. (2009) demonstrated an example of using RFID tags for tracking products' status and conditions in the fresh fish cold chain in which multiple sensors were enabled to capture the real-time information in terms of temperature, humidity, power and light. The information thus collected are stored and can be further analyzed.

3.3 Supply Chain with Cloud Computing

Information sharing problem of supply chain management system have been an important research topic in areas of information integrity and security. Cloud computing could provide supply chain management providers an opportunity to take advantage of new processes related to ethereal space (Markim 2015). With applying cloud computing on supply chain management system, the inventory information would be updated instantly without users having to wait for central organizations or servers to populate information across a supply network (Gray 2015).

Jain and Dhaka (2015) researched on supply chain management in cloud computing environment and divided the history of supply chain into three parts, which were focused on administrative processes, core and rather complex processes covered in cloud. For industrial cases, Maziliauskaite (2015) demonstrated companies could use cloud computing for real-time data sharing of inventory and products sales information which would allow the supply chain management providers get more integrate information and improve the ability of data analysis across whole supply chain members. Cao et al. (2017) studied on a managerial perception in terms of using cloud computing technologies in supply chain management, especially on how cloud computing impacts information sharing among supply chain partners, the impact of trust in cloud information sharing and the impact of cloud computing on supply chain performance. Moreover, they also used a kind of structural equation model to analyze the results of this study and the analysis provided empirical support based on managerial perceptions regarding cloud computing, information sharing and supply chain performance. The data provide evidence on the impact of cloud computing in enhancing information sharing.

3.4 Supply Chain with Blockchain

Blockchain's architecture of distributed ledger can ensure a decentralized and transparent transaction mechanism in supply chain management system in industrial and business. Blockchain can help supply chain organizations and consumers to track products origins and whole processes during the whole transportation. Abeyratne and Monfared (2016) proposed an architecture about how blockchain can manufacture supply chain system with factors of registrars, standards, certifiers, producers and consumers.

The application of blockchain in supply chain has been employed in industrial area widely by business companies. Alibaba worked with AusPost, Blackmores and PwC to explore the ability of combining blockchain with food supply chain for food fraud fighting such as selling low-quality foods. The purpose of their team is to develop a "Food Trust Framework" to improve the integrity and traceability on the global supply chains (Kshetri 2018). Walmart built a system for providing a service to monitor the pork production in the U.S. and China with blockchain enabling the digital tracking on individual pork products in a few minutes compared to many days taken in the past (Kshetri 2018).

3.5 Hybrid Industrial Cases

IBM's Watson Supply Chain applied artificial intelligence on their supply chain system, and trained in supply chain through machine learning, to provide comprehensive, end-to-end visibility and insights. They provide a personalized dashboard with 360-degree viewing angle for easy understanding and prioritizing critical issues in real-time. Users can use Watson to rapidly assemble the right team to collaborate and manage incidents and resolve disruptions quickly. Watson provides an open integration platform for connecting and harmonizing disparate data, silos and systems to provide deeper visibility and insights. For information security and privacy, they scale and adapt quickly to manipulate business needs without compromising security, privacy or risk levels with the IBM Cloud platform.

Wal-Mart's integrated supply chain is the key enabler of its growth from a small retailer to a global leader. Wal-Mart has become the leading retailers because of having a powerful decision-making system that relied on data analysis through a barcode scanning system, a point-of-sale system, and real time data collection through current RFID technology. They enabled some advanced inventory technology like automated recording system for real-time data recording to the database. Wal-Mart was the first retailer that experimented central database in the mid-1980s. When combining with the use of barcodes, employees were able to gather and analyze real-time inventory information. According to above information, they could forecast customer's demands by analyzing the real-time utilizing data quickly.

Cisco began to process its supply chain digitization initiative eight years ago. For the first three years, they focused on their systems and processes foundation. They upgraded their enterprise resource planning (ERP) and product data management (PDM) systems. Cisco also combined multiple processes and systems into a single system. During the following three years, they were focusing on their data and analytics foundation. They used technology such as collaboration, internet of things, mobility, big data and cloud services, to provide real-time visibility. Cisco also process their work to focus on orchestration by using machine learning and automated decision-making system.

4. Why IT-Enabled Supply Chain

4.1 Limitations of Traditional Supply Chain

Traditional supply chain is placed on a structure with a set of linear nodes, that means it would be difficult to connect or communicate with skipping nodes, they can only share data with their neighboring nodes. IT-enabled supply chain uses technological enablers like a network of sensors and social technologies through the central control organization over the whole supply chain.

The limitation of information collaboration results in the low speed of information sharing or exchange and decisions-making in traditional supply chain. IT-enabled supply chain management system could improve the performance of information collaboration and flexibility for making decisions across all supply chain participants.

The most obvious difference between traditional supply chain and IT-enabled supply chain is the transparent view. The traditional supply chain only provides a limited view of the supply chain; however, IT-enabled supply chain provides a complete and comprehensive view across the whole supply chain system while information sharing among any pairs of nodes.

Responsiveness cannot be provided from traditional supply chain management system, which should be also important for a high-efficient supply chain management system to improve the speed of making decisions or react to any emergency. In the IT-enabled supply chain management system, real-time responses can be implemented on planning and execution level.

Figure 2 introduces the information delivery process of traditional supply chain which is in a linear architecture without any interconnection between nonadjacent members. Figure 3 describes a kind of distributed architecture of IT-enabled supply chain management system with information sharing and connection between any two nodes.

Figure 2: Traditional supply chain

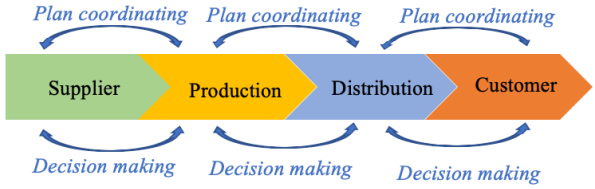
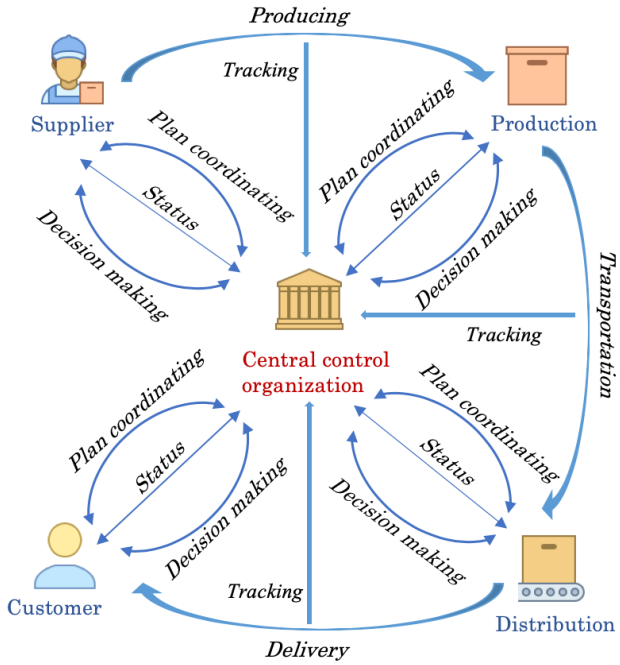


Figure 3: IT-Enabled supply chain



4.2 Requirements of IT-Enabled Supply Chain

4.2.1 Traceability

Traceability is a core feature an efficient supply chain management system should own for tracking products status and conditions in a real-time, especially in cold, food and agriculture chain in terms of temperature, power, storage and light. High-efficient traceability was able to allow supply chain members to make decisions and coordinate plans flexible and fast. A high-efficient traceability can also help organizations to manage their whole transportation network with lower cost.

4.2.2 Transparency

Transparency refers to the ability of determining such information as what actions and the time as well as locations cross the whole supply chain life cycle. True transparency allows auditing and inspecting of data sets in real-time refers to a level of transparency which makes activities and operations highly visible (Abeyratne and Monfared 2016).

4.2.3 Accountability

For some unexpected incidents, the ability of tracing back to the responsible members or processes, by analyzing the evidence record of their activities, would be much useful for problems solving. Supply chain system can work normally with accountability whenever the incident happened.

4.2.4 Big Data Processing

The increasing scale of world-wide-crossed supply chain systems caused large amounts of products, manufactures, retailers and consumers' information part of which would be sensitive and need efficient privacy protection. The need of powerful data calculating, and information processing was able to allow the whole supply chain system to work safely against some information leakage risks.

4.2.5 Cost Control

The first important purpose of enabling IT technologies to traditional supply chain system is to lower its cost as much as possible in an economic manner. For instances, gathering and sharing information through IoT devices or cloud computing server could reduce time cost spent on communicating in circuity way including sending messages through many middle nodes and waiting for a long time, as well as money cost by improving the whole chain system performance in terms of speed of processing, transforming, decision making and plan coordinating.

However, it is difficult to achieve true lower-cost with enabling IT technologies, especially the money cost. Perhaps more would be spent due to employing third parties' services or devices with high operating cost. Hence, how to achieve true cost reduction is one of current important research problems on supply chain area.

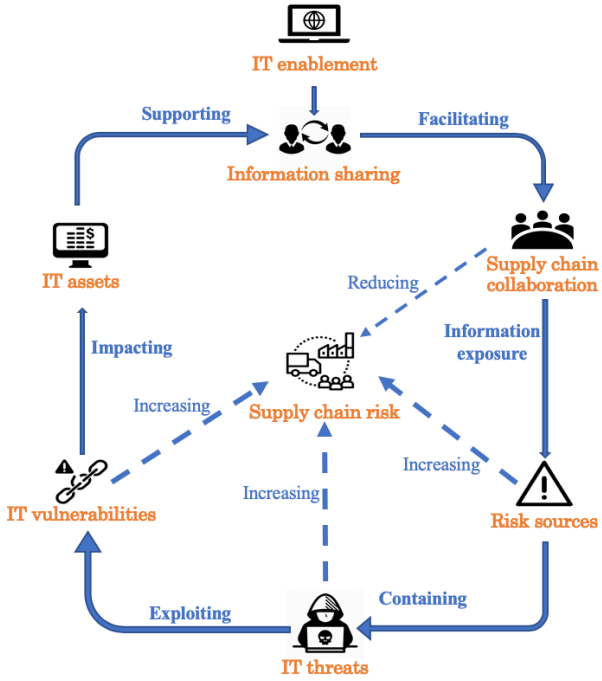
4.3 Security Issues with IT-Enablement

One of the most important part of preventing against security issues is how to preserve necessary security properties such as confidentiality, integrity, availability (CIA), authenticity and authority which could be vulnerable to diversified cyberattacks, like virus, malicious code injection, DDoS, covert channel, malicious intrusion and misuse.

While the enablement of information technology can provide an efficient information collaboration for supply chain networks, it also reduced or removed the protection barrier of traditional supply chain system. Traditional supply chain system was separated from external unstable cyberattacks environment due to its disconnecting with the internet. Connecting with the internet would allow various external or internal risks to enter into supply chain system resulting in unexpected problems.

Although enabling IT technologies could improve the performance of information sharing and reduce supply chain risks by facilitating its information collaboration, risk sources could be exposed at the same time and increase supply chain risks. In this way, system flaws and vulnerabilities, especially from devices provided by third party providers like IoT devices or cloud computing server, would be exploited by cyber attackers to also increase supply chain risks. Those attacks would be dangerous for system assets, including both system data and processes which could be regarded as supporters for information sharing.

Figure 4: Flow of supply chain information security risks



Smith et al. (2007) defined a supply chain information security risks flow model, shows as figure 4, to illustrate relationships, in terms of increasing, facilitating, supporting, reducing and impacting, between information technology enablement and security risks. Information technology enablement could be regarded as the source of a series of security impacts and actions.

5. Security Management

Security management refers to a protective method to achieve the high-level system security by enabling related security methods such as identification, authentication, access control and defining security policies. Security management plays an important role in information technology environment for reliable data fusion and mining, as well as enhancing users' privacy and information security, which allows systems to overcome perceptions of unexpected situation or risks.

The definition of security management on IT-enabled supply chain management system refers to manage potential risks such as privacy leakage and malicious members manipulation, which could happen to any part or process, appeared with enabling information technologies on supply chains.

5.1 IoT

Traditional tracking methods, such as periodic bar code scanning and check points, provide segmental information, that is incomplete. IoT technology is a kind of new technology which

can enable supply chain traceability with complete information that traditional information technology cannot achieve. In recent years IoT technologies, such as RFID, enables an automatic supply chain tracking capability with the lowest operational cost. For example, many companies have started using RFID technology to track real-time inventory information and to monitor human resource activities (Zhou and Piramuthu 2015). Moreover, RFID could be used by retailers to facilitate the speed of returns, to manage warranty claims by manufacturers and improve the performance of post-sales support. Especially in pharmaceutical supply chain management system, RFID could cut down the counterfeiting of pharmaceutical drugs and insure the integrity of products purchased by consumers. RFID could also be used in the food supply chain to ensure that the foods are fresh by tracking food products' real-time status and condition. Consumers can use RFID information to check all nodes of supply chains, especially in the cool supply chain. That is to say, goods attached by RFID would be traceable in the supply chain (Shen and Liu 2011).

Yan et al. (2014) defined objectives of trust management on IoT systems, which could be applicable on IoT-enabled supply chain system, with regard to trust relationship and decision, data perception trust, privacy preservation, data fusion and mining trust, data transmission and communication trust, quality of IoT services, system security and robustness, human-computer trust interaction and identity trust. To provide a trust environment of a supply chain management system, IoT technologies and services enabled on supply chain should be enforced as many as better to achieve above objectives as standard measurement of IoT trust management systems.

5.2 Data-Provenance

Data-provenance can work with IoT technology as a kind of history and evidence record for tracking products and processes' activities. Unlike using RFID's traceability in terms of environment or conditions, the data-provenance could be produced by processing information, i.e. all participants' activities, physical and information flow, captured by IoT sensors.

The application of using IoT to trace data-provenance in supply chain system indicates the ability of products' information safe protection, especially in food supply chain for food's safety protection. IoT can also work with some existing mature data-provenance security methods such as applying its hash/signature chain architecture for integrity protection and access control policies for confidentiality protection, to solve those security issues come with IoT-enabled supply chain for achieving other efficient management features.

5.3 Cloud Computing

The centralized cloud server architecture of cloud computing can manage and collaborate collected information between different systems in an efficient way, which could improve the performance of information sharing and collaboration across the whole supply chain system. While traditional supply chain management systems only focused on physical, in-person information management methods, cloud computing environment provided the on-demand access to information vital for procurement practices, store shelf optimization, sales and operations planning (Cao et al. 2017).

To achieve the trust management of supply chain under a cloud service environment, cloud service providers provide many technologies such as standardization technology, virtualization technology, data management technology, platform management technology (Jun and Wei 2011). The standardization technology can be applied to provide an interface which is for accessing cloud service providers and relating to alliance master formed real information interchanges on supply chain. The central cloud server could be regarded as a middleware which is in service and server cluster to provide the management service. The virtualization technology providers of cloud computing services can provide a same virtual software interface for different supply chain enterprises or systems who own different phy sical interfaces, in order to improve the efficiency of information collaboration, program collaboration and interface collaboration.

5.4 Blockchain

Blockchain as one current hottest research topic currently, its trustworthy architecture with distributed and decentralized ledger, as well as cryptographically linked blocks, can also provide an accurate way for measuring products quality during whole transportation on supply chain. For example, stakeholders in a supply chain can gather the location information about whether the product was in a wrong place or the whole journey from source to destination by analyzing collected data on the travel path and duration (Kshetri 2018). Other utilizing cases of this kind of capability are applying blockchain technology on cold supply chain for food products environment monitoring, especially for temperature, and on food supply chain for food healthcare which could lead to serious health risks without enough attention.

Kshetri (2018) demonstrate blockchain's roles in achieving the various strategic supply chain objectives. For general performance dimensions of supply chain, for instance, blockchain can reduce or zero costs of enterprises if technologies such as IoT have already been applied to detect, measure, and track key supply chain management processes (Mehring 2017); the response speed can be increased by digitizing physical process and reducing interactions as well as communications according to blockchain's digital signature storage and transmission which can validate the identities of individual and assets to minimize the needs of physical interactions and communications. Blockchain can also play an important role on improving the performance of trust management by reducing the risk possibility since blockchain need to validate the identities of individual participating in transactions, which means only members who are mutually accepted in the network can engage in transactions.

6. Challenges

For current IT-enabled supply chain management systems, an important security challenge is how to face those security risks which are also rigorous for enabled information technologies. While enabling above technologies on supply chain systems, some inherent security problems within themselves or between collaborations with each other would be long/short-term challenges for IT-enabled supply chain system in terms of improving efficient trust management.

IoT devices still face the unstable or untruthful internet environment with unexpected cyberattacks, so the information collaboration between IoT and data-provenance would be vulnerable to such risks. In addition, how to preserve the integrity and confidentiality of data-provenance in terms of producing and storing to ensure IoT's traceability needs more deeply research work.

The limitations of blockchain would limit the development on supply chain as well, i.e. the global supply chain operates in a complicated environment which requires various parties to comply with diverse laws, regulations and institutions (Kshetri 2018). Increasing storage space for blockchain technology is also an emergent problem. Many researchers have worked on combining blockchain with cloud storage service to achieve storage space reducing and information accessing timely. However, this kind of application reduced blockchain's security due to cloud service's centralized architecture.

Big data is another important factor for IT-enabled supply chain for appropriate data gathering, processing, storing and sensitive information protection, which could be consumer or retailer's privacy, with the increasing scale of world-wide supply chain management system. Inefficient data processing and storage would allow some risks like sensitive information leakage to malicious parties.

Another considerable issues about current digital supply chain management system should be the "trust" problem. Trust issues have been researched for not a short time, however, not any efficient solution proposed yet. Whatever between users and service providers, or among users themselves, the trust problem is the most important aspect users care about. How can users trust the service provided by third parties, how can service providers trust identities submitted by users, or how can downstream firms trust the service provided by their upstream firms, high-efficient method should be proposed.

Moreover, trust doesn't mean security, security also doesn't mean trust. More advanced solutions or solving plans, with regard to design a secure and trust supply chain management system, should be researched on.

7. Conclusion

This paper discusses current situation and environment of supply chain management systems with various information technologies enablement for improving the performance corresponding to diversified demands. While working advantages of those information technologies, supply chain must face various security risks and challenges which are needed to be solved in the future research work. That would not be a short-term work to enhance the trust management of supply chain management system.

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