Blockchain technology in Supply Chain and Logistics

by

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FEBRUARY 2018

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To my parents, who inspired me to dream big

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Abstract

Blockchain technology is a peer-to-peer infrastructure based on distributed databases and smart contracts as the business logic. The distributed ledger technology eliminates the need for intermediaries disrupting the ownership model. It can have a tremendous impact on cross-organizational process automation when combined with other innovative technologies such as machine learning and additive manufacturing.

Over the past few years as the blockchain technology concept has increasingly attracted many industries. The logistics and supply chain management industry have also realized its potential applications in enabling transparency, efficient information sharing, and food safety. Several companies have identified possible use cases that could benefit from blockchain over existing IT solutions.

Thesis report provides an overview of current state of blockchain adoption, its technology architecture, review of how blockchain technology and smart contract works, and the benefits and challenges involved. Further, provided a deep dive into the problem of food safety, and the food supply chain and logistics ecosystem drivers. Highlighted, the current use cases of blockchain technology in supply chain and logistics along with critical success factors that companies consider essential for blockchain technology adoption. In the interviews conducted, digital innovators and senior executives are fairly positive about the blockchain technology and its benefits. However, factors such as under-developed ecosystem, lack of governance model and regulatory uncertainty impact its adoption. The proposed framework consists of a hybrid architecture of private and public blockchains, enabling immutable record sharing and monitoring while maintaining selective data privacy.

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Acknowledgements

I am grateful to several people who have supported me throughout my academic journey and encouraged me to put my best foot forward in my endeavors.

First and foremost, I wish to thank my advisor, Prof. Christian Catalini, for his infinite patience. He has been a constant source of inspiration, insight, and enlightenment since day one when I began working on this thesis. Throughout the process, he remained very accessible and gave me timely input to steer me in the right direction. Blockchain technology is still new and evolving field. I found his work on blockchain technology closest to my research topic. It served as a building block for my work and made me inquisitive to pursue this topic as my thesis.

I am also grateful to Prof. Joan S Rubin, and the entire SDM staff for making my SDM experience so valuable, rewarding and memorable. I would like to thank my MIT friends, who have been like family to me at MIT. I am grateful for all their help and guidance, and for their words of encouragement during this 16 months journey. Their involvements have enriched my MIT experience, and I feel lucky to have had the chance of working with them.

Special thanks to my dear husband Atul, for believing in me. I could not have done this without his constant support and encouragement in every phase of my life. Without his love and sacrifice, I would not have been able to dream of pursuing my second Master's degree at MIT.

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1 Introduction

1.1 The advent of blockchain technology

The idea of blockchain technology started in 2008 when a pseudonymous person or persons named Satoshi Nakamoto published a whitepaper on Bitcoin. Since the early days, people have trusted banks to keep their deposited money safe. However, the financial crisis of 2008 exposed the breach of customer's trust when the banks lost their customer's money by giving out risky loans. To deal with this problem the government printed more money, reflecting poor planning. The people lost trust demanding a currency that would not be controlled by a central authority [1]. According to Satoshi Nakamoto, "the root problem with conventional currency is all the trust that's required to make it work. The central bank must be trusted not to debase the currency, but the history of fiat currencies is full of breaches of that trust" [2].

Bitcoin is a protocol for "an electronic payment system based on cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party" [3]. The underlying technology behind the bitcoin is called the blockchain. The blockchain is a secure, trustworthy and publicly available distributed ledger that contains the transaction history of every bitcoin in circulation, and stores the proof of who owns what at any given point in time. It has the potential to eliminate the need for a trusted third party such as financial institutions or payment providers [4].

In 2009, bitcoin hardly had any mindshare. It did not have any economic value. When the first block of bitcoin blockchain the 'Genesis block' was created, no one apart from a few crypto enthusiasts knew about bitcoin. Gradually, after the bitcoin market was established, bitcoin began gaining the critical mass of early adopters [5] (see Figure 1). The bitcoin now has a huge market cap between USD 100 – 120 billion and is used in growing payments market [6].

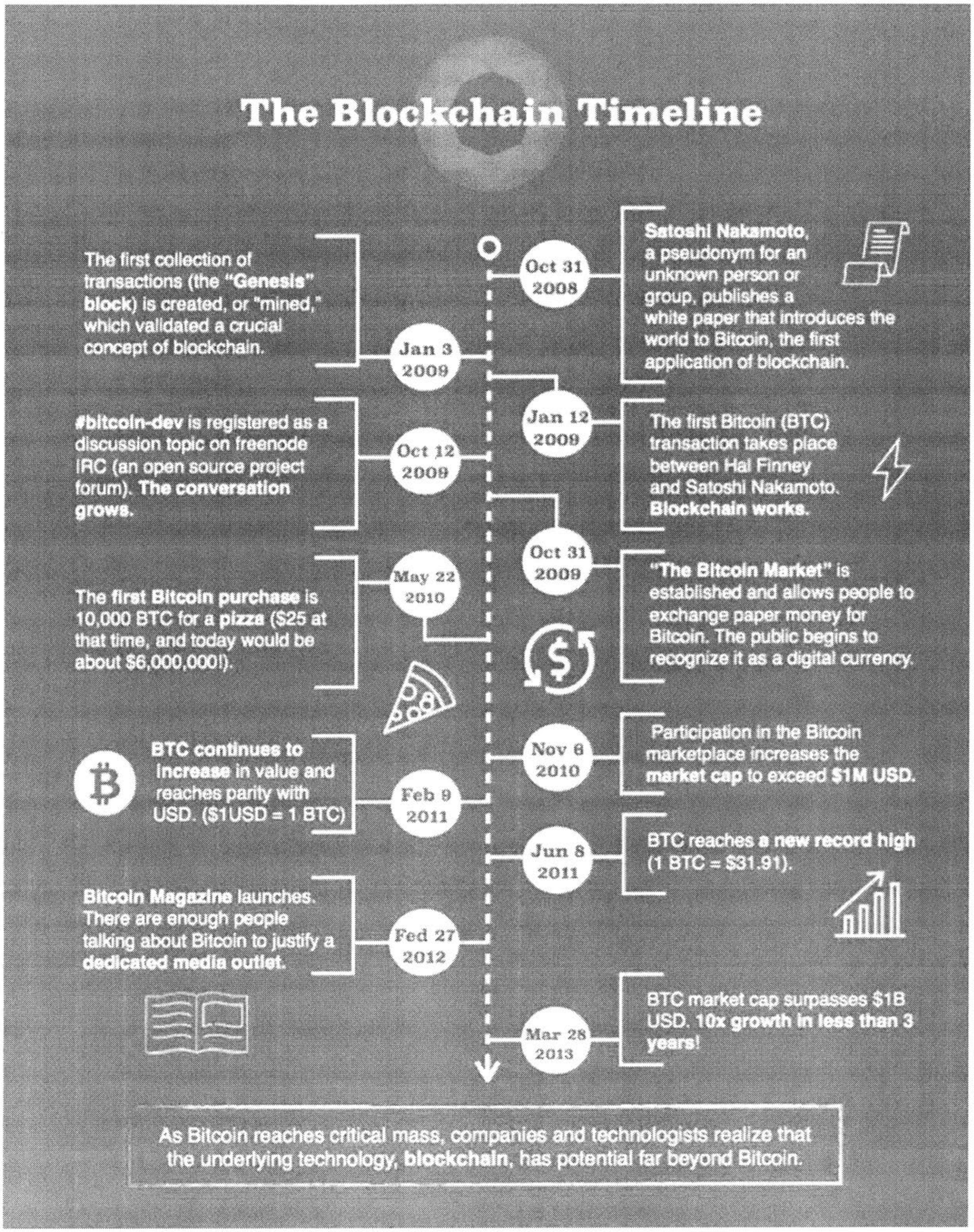

Figure 1: The blockchain timeline (Source: [7])

1.2 Trends driving the blockchain technology

A single concept is not driving the blockchain technology. Blockchain technology has evolved into a way of thinking about how to improve the customer experience, drive customer journeys or end-to-end value, and eliminate inefficient operations. There are several enablers behind its evolution:

- **Increasing popularity of open source blockchain 'Ethereum Smart Contract' platform.** In 2015, the blockchain technology garnered greater interest when a Russian-Canadian programmer, Vitalik Buterin realized a new level of functionality for blockchain apart from bitcoin and created the Ethereum blockchain. Technology enthusiasts saw the potential in blockchain as an open software that allows to securely exchange value by building decentralized applications such as smart contracts. Ability to democratize the ownership of transaction records without single point failure makes Ethereum blockchain likely to have widespread economic and social implications. Smart contracts are "small computer programs built directly into blockchain that allows financial instruments, like loans or bonds, to be represented, rather than only the cash-like tokens of the bitcoin, thus driving greater value" [7]. The Ethereum smart contract platform has gained large adoption as several new projects by both the incumbents and new players in multiple industries are under proof of concept. Ethereum now has a market cap of around USD 31 billion (as of 11.18.2017) (see Figure 2).

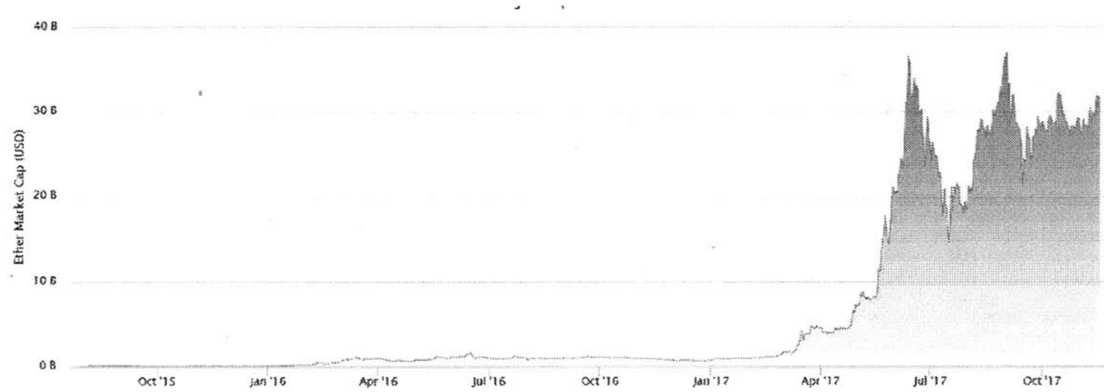

Figure 2: Ethereum historical market capitalization chart (as of 11.18.2017) (Source: [8])

- **The shift from the Internet of information to the Internet of value.** Internet was designed to enable sharing of information. However, the core design for sharing information is dependent on the intermediaries. Most of the value is captured by big internet players, making it difficult for small players to grow and sustain. In contrast, Blockchain is a network of trust designed for exchanging value in a decentralized fashion where the value creation can be traced back to the original value creator [9]. According to digital visionary Don Tapscott, "blockchain is likely to transform some important industries that rely upon third-party assurance by providing a secure, direct way of exchanging money, intellectual property and other rights and assets without the involvement of traditional intermediaries like banks, utility companies, and governments" [10]. The sharing economy has created demand in the world where every participant has an equal opportunity to participate. Blockchain features such as transparency and immutability can be a strong force in the fight against bribery and corruption. Moreover, blockchain is likely to disrupt global supply chains, which have several intermediaries and change the way consumers buy products. As per the survey report from the research and event company Eyefortransport (EFT), more than 16 percent of the 300 companies surveyed believe the most prominent use cases for blockchain technology in the supply chain will be data interchange, visibility and tracking [11].

- **Convergence of blockchain with emerging technologies.** Automation and shared economy have given rise to new business models. There is a paradigm shift from human-facilitated physical systems to online and automated networks. The peer to peer or shared economy has created a platform ecosystem, which has given rise to improved efficiencies and new opportunities. These trends are driven by the combined effects of existing and emerging new technologies. These technologies are SMAC (Social, Mobile, Analytics, and Cloud), Artificial Intelligence (AI), Internet of Things (IoT), Autonomous Vehicles, Drones, Robotics, Virtual Reality (VR), Augmented Reality (AR) and 3D Printing. As the industries like retail, banking, healthcare, logistics, and agriculture are digitizing, a vast amount of data is captured and analyzed, and as a result, the processes are automated to make them more efficient. The future competitive advantage will lie with the players who would own this valuable data, and apply the insights from this data to create the better customer experience. As per the report published by Outlier Ventures Research, "Blockchain technology has potential to provide the foundation for a scalable and secure data management layer for new economic models. It can allow decentralized aggregation of vast amounts of data from the Internet of Things, and ensure the benefits of artificial intelligence are shared broadly across society" [12] (see Figure 3). Several new AI startups such as SingularityNET have already adopted open, decentralized blockchain network to incentivize value creators to share the data and reward players [13].

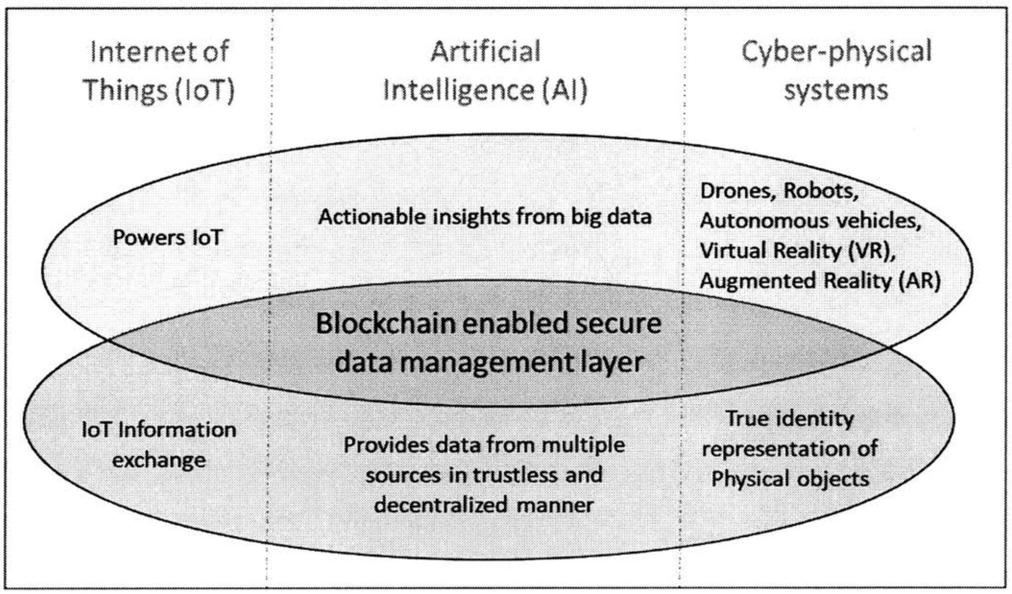

Figure 3: Blockchain based network for interoperable technologies

1.3 The outdated global supply chain management

The digital world has changed the way people buy and consume things. Consumers demand customizable products tailored to their needs, simplified buying experience and transparency in the real value of goods. These needs have created both the new opportunities and challenges in the current supply chains. The challenges lie in better demand management, process optimization, building better supplier network, and tracking or investigating the provenance of a product in the geographically dispersed supply chains which are extremely fragmented and complex. According to Ben Dickson, "Customers and buyers have no reliable way to verify and validate the true value of the products and services they purchase because of the endemic lack of transparency across supply chains, which effectively means the prices we pay are an inaccurate reflection of the true costs of production" [13].

The old technology of supply chain management, which is deeply rooted in the physical world cannot efficiently meet the changing market needs in time, and also manage the risks and costs of operations. Agility has become an equally important characteristic of a supply chain. The new age manufacturers and suppliers need to invest in multi-purpose tools and services for managing inventory, fulfilling orders and channel distribution. The new technology adopted must be designed to operate in a silo-less environment, such that businesses can track their inventory throughout - from multiple suppliers or outsourced packagers to numerous points of sale, and have the supply chain agility to meet the demands [14].

1.4 Research motivation

At the time of writing this thesis in 2017, there is a growing interest in blockchain technology and its applications. The interest is primarily for two reasons. Firstly, the need for a trusted decentralized environment to enable value creators to enjoy the benefit of services provided instead of the costly intermediaries. Secondly, immense success of anything, anytime, and anywhere connected platforms all over the world, which created awareness and reach for consumers. Moreover, the costs of computing, storage and bandwidth are all coming down on one side, and processing power is continuing to increase on the other hand. Growing capabilities have enabled different stakeholders to conduct proof of concept experiments to validate the technology effectiveness and business case for blockchain.

The rate of adoption of innovative technologies such as artificial intelligence, virtual reality, and the internet of things is also rising. Numerous startups in various sectors including financial services, social inclusion, intellectual property, and the Internet of Things (IoT) have emerged that are working on blockchain innovation. Blockchain technology provides promising opportunities for companies and customers to complete value exchange with each other in real time and without any third party intervention. In addition, it enables business operation managers to make processes more efficient and transparent. However, to benefit from blockchain technology, both large organizations and emerging startups need to overcome several challenges. The uncertainty remains with regards to the readiness of organizations and the impact of adoption. This uncertainty exists because while blockchain adoption offers promising opportunities, on the one hand, there are several unresolved challenges on the other hand. These are still early days for blockchain technology, and there are several key questions to be answered:

- What are use cases of blockchain besides cryptocurrencies?
- What are the key drivers for blockchain and smart contracts' adoption?
- What is supply chain management organizations' stance towards blockchain adoption?
- Are supply chain management organizations ready for blockchain adoption?
- How does blockchain integration impact an organization's business model?
- How does blockchain adoption impact the organization's strategy?
- What are likely barriers to blockchain adoption in the supply chain logistics industry?
- Frameworks and tools for blockchain implementation process

The purpose of this research is to analyze the blockchain and smart contracts, and trends in global supply chain and logistics. Further, evaluated the problems in ensuring food safety in the supply chain, and some opportunities to address them using blockchain technology. This analysis will help in recognizing latent opportunities that blockchain presents today, and also the challenges that come along with these potential opportunities. The answers to above questions about supply chain and logistics industry have been discussed in various sections of the report. The end goal is to develop a framework to enable trust and traceability in global food supply chain through blockchain and smart contracts. It would help in understanding drivers of mainstream blockchain adoption in food supply chain, possible business models, and strategic considerations.

1.5 Approach and organization

For my thesis report, I did extensive primary and secondary research. Under primary research, I interviewed senior business executives and technology evangelists, who are playing an important role in deciding blockchain adoption strategy for their respective companies. Some of the interviewees are blockchain consultant, who are providing blockchain technology solutions to their clients. These people have shared their professional experiences that have helped me understand the business case for blockchain and identify core issues in implementation. Most of the interview questions focused on the value proposition of blockchain technology, learnings from current proof of concepts, critical success factors for adoption and implications on organization's business strategy. It involved a lot of qualitative inputs to get a comprehensive understanding of the subject at hand. For secondary research, I have referred to research material and books available through MIT library and also referred to online available white papers, blogs, & articles.

The rest of the thesis is organized as follows –

- Chapter 2 and 3 provide an overview of current state of blockchain adoption, its technology architecture, review of how blockchain technology and smart contract works, and the benefits and challenges involved.
- Chapter 4 and 5 provide a deeper understanding of trust and traceability in supply chain network, the problem of food safety, and the ecosystem drivers.
- Chapter 6 highlights current use cases of blockchain technology in supply chain and logistics along with critical success factors that companies consider important for blockchain technology adoption. It also throws light on the interview insights.
- Chapter 7 presents a new framework that was developed from the research findings and discussed potential business models and strategic considerations.
- Chapter 8 summarizes the findings and conclusions drawn from the research.

2 Blockchain Technology

2.1 What is blockchain?

Originally developed for Bitcoin, the Blockchain is a decentralized transaction and data management technology that allows consumers and companies alike to store and exchange value without the need for traditional intermediaries. It is an innovative technology that has potential to disrupt existing economic and social systems and create more transparent, efficient, and secure systems. Blockchain technology is founded on a globally distributed ledger that leverages the properties of a large peer-to-peer network to verify and approve transactions [15]. The distributed ledger contains chronologically ordered, cryptographically signed and immutable transaction records, which are accessible to any participant in the network. Since copies of blockchain are globally distributed across the network, the historical records cannot be altered without the consensus of the majority of the network. Immutable distribution increases the trust in the network. Moreover, the value store in transactions can be viewed and traced by specific users as well as larger network participants with access rights, making the value exchange decentralized and transparent. The cryptographic signing of records ensures the data security of the transactions information stored on the blockchain [15] (see Figure 4).

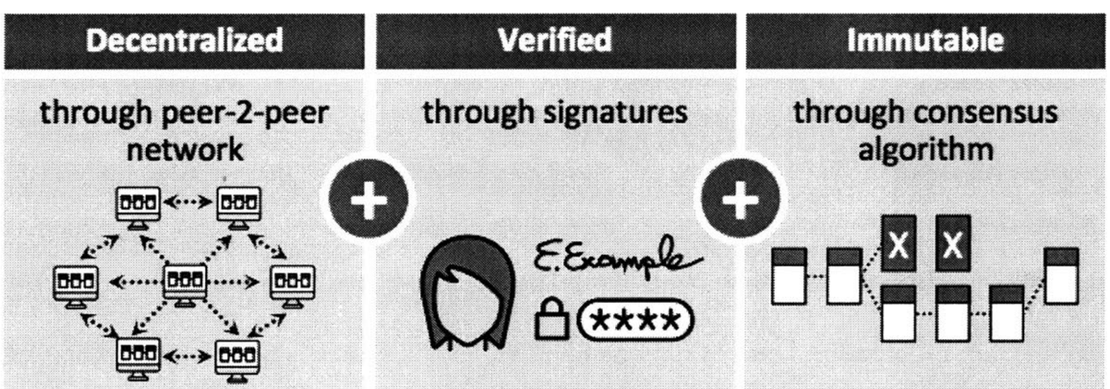

Figure 4: Basic value proposition of Blockchain (Source: [16]*)*

According to their research published in Gartner Research Journal, Valdes and Furlong have defined following key characteristics of the blockchain technology that are common across all blockchains [17], [18] –

a) Dynamic and fluid value exchange

The blockchain ledger serves as a permanent record of transactions that take place peer-to-peer or between consumers and an organization. The type of information stored as the blockchain transactions is not solely limited to a monetary value such as Bitcoin currency exchange but can span to several use cases such as provenance of goods and services, intellectual property rights, user identity data, carbon credits, asset ownership data, location data, etc. There are several varied applications of blockchain that are still in concept. "Beyond recording transaction data, the blockchain platform can optionally record additional state information, essentially key-value pairs that collectively define the state of the system." [19]. This characteristic of blockchain value store can make blockchain technology highly customizable for different applications in multiple industries.

b) Distributed resilience and control

The blockchain ledger is not controlled by any single organization or entity. Blockchain with its distributed database eliminates the need for trusted third parties to verify transactions. It acts as a shared database to provide a secure, verified and single source of truth that is accessible to all members of the network. "Essentially it creates trust between parties by eliminating the need for trust" [16]. It increases transparency and thus confidence in the system. In addition, distributed database increases efficiency by creating standardized data formats, allowing the frictionless exchange of data across organizations and process integrity. As the transactions are verified in real time by the network participants, it improves audit compliance and risk of error or fraud [20].

c) Decentralized network

The blockchain ledger directly connects the individual consumers to the organizations without any central intermediary. The digital transaction data is shared in real time within the blockchain's peer-to-peer network. All members of the network keep their local copy of the ledger on their computers and send information to other nodes [16]. It eliminates the need for central authorities, such as banks, as well as trusted intermediaries, such as brokerage firms for value exchange. It also reduces friction in current transaction processes and makes the value exchange faster in near real-time while reducing costs. Moreover, due to massive replication of ledger across several participant nodes, it makes the system more robust as it eliminates a single point of failure in case of any malfunction or collusion. It improves quality, reliability, and availability of services [19], [20].

d) Transparency with pseudonymity

The blockchain enabled transaction system is highly transparent as every transaction value is visible to every network participant with access rights. It makes illegal transactions very difficult to execute. However, the participant in the network can choose while initiating a transaction what information related to their identity they are willing to divulge to rest of the network thus providing pseudonymity. For this purpose, each participant node in the network is provided a digital signature called private key that is proof of identity of the node and is used to verify the transaction. The private key should not be disclosed to others. It is used to generate the public key, which is an alphanumeric code shared with others in the network for transactions.

e) Irreversibility of records

Blockchain uses consensus algorithm to verify a group of transactions and add them to the blockchain as a block. It leverages the power of the peer-to-peer network to reach consensus. Only, when the majority of participants in the network validate a block of transactions, it is added to the blockchain. If any single party tries to change the ledger, it is unlikely to succeed as the change needs to be verified by a consensus. Also, each new block is tied to the previous block, and as soon as a new block is updated all nodes in the network are updated with the latest copy of the ledger. Thus changing the previous block would be difficult and costly. It makes it hard to change records on the blockchain, making it immutable.

f) Security and modern cryptography

Blockchain uses public key cryptography, and digital signatures approach to prove node identity and ensure data security. This approach helps in protecting identities, and preventing data tampering by hackers, reducing the risk of fraud or theft. Also by eliminating centralized third parties, the technology does not result in a single point of failure in case of a compromise [21].

g) Programmable logic

Blockchain transactions are digital, which allows these transactions to tie to conditions written in code. The computation logic can be built only to allow value exchange when certain pre-defined conditions between the seller and the buyer meet. It allows the transaction to be automated, documented and yet controlled [16]. It is the basis for smart contracts in blockchain technology.

2.2 Blockchain technology Concept of Operations

As blockchain technology is in proof of concept phase in many industries, it does not yet have any accepted architectural approach. However, the design goal for a wide variety of blockchain technology enabled use cases is based on the core value proposition of achieving trustless, immutable, and efficient operations. An overview of underlying functional components and design parameters of blockchain technology are as follows -

1) Blockchain

Blockchain is a decentralized data structure, which stores a group of transactions and related data transparently and securely in a distributed network. Network participants can access all historical transactions and their value including the time of creation of block at any point in time. The blockchain as the name suggests constitutes of a chronologically ordered chain of blocks. Each new block consists information of addresses entitled to receive the exchange value and also contains the digital address (hash) of the previous block [22] (see Figure 5).

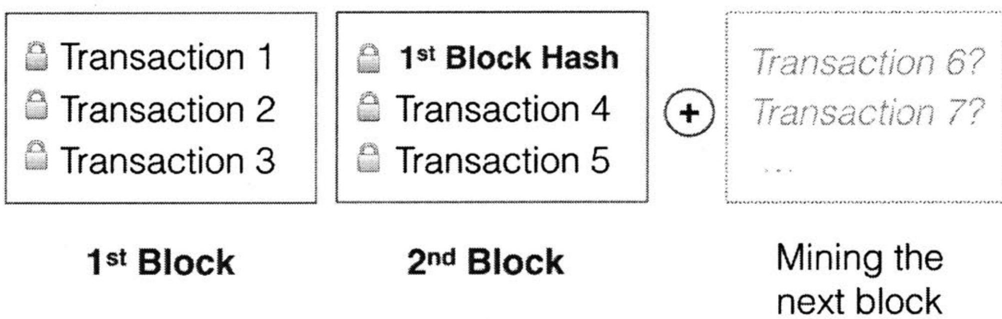

Figure 5: Data structure of blocks in a blockchain (Source: [22])

If anybody tries to change or tamper with the transaction information recorded in a block, the hash for that specific block would be altered, and it would no longer point to the hash of previously verified block. Thus it makes blockchain easily auditable in near real time and making it difficult to tamper with records without achieving consensus in the network [22].

2) Public blockchains and Private blockchains

Bitcoin was designed to be completely decentralized and permissionless, allowing anyone in the network to participate in the proof of work mining process and access the copy of ledger. However, this method of governance was inefficient as it did not meet economies of scale in processing. High risk of a single pool of miners forming a majority in consensus posed a threat to the integrity of the trustless consensus process. Private or permissioned blockchains are created with a different value proposition than the bitcoin or public blockchain. Private blockchains are useful in cases where the integrity of audit trail is not most important, and there is a need to standardize data sharing across industries for efficient operations and new market structure [22].

In public or permissionless blockchain, anyone can participate in any capacity. It allows anyone to approve new blocks during the mining process, whereas in a private or permissioned blockchain, only certain parties can take part in the network. It restricts processing or mining to only selected members or organizations in the network. While zero cost of verification benefits it, the cost of networking remains significant as private blockchain still depends on the trusted parties [22] (See Figure 6).

	Public blockchain	Hybrid/consortium	Private blockchain
Overview	Fully decentralized with no central authority; "proof-of-work" or "proof-of-ownership" is used to ensure record authenticity	Quasi-centralized where a consortium of entities controls the record authenticity	A central authority acts as a trusted intermediary to control and ensure record authenticity
Permission	Permissionless—anyone can read and write	Permissioned—selected participants can make changes	Permissioned—write permissions are centralized to one entity
Transaction verification	Records are verified by majority of the "miners" reaching consensus on the authenticity	Transactions are verified by the consortium	Central authority verifies transactions
Data storage	Records are distributed; a copy of the entire record is available to all users of the peer-to-peer network	Records are distributed throughout the consortium	Records are stored by the central authority
Transaction cost	Low cost for transactions	Transaction cost agreed to by the consortium	Transaction cost dictated by one entity

Figure 6: Common types of blockchain (Source: [23]*)*

3) Decentralized database

The decentralized and secure database of blockchain technology is impacting the way the data is shared over the internet. The blockchain database allows sharing data directly from machine-to-machine as opposed to the current centralized system over the internet such as Gmail or

Dropbox, etc. The encrypted communication protocols allow data exchange in a more secure and distributed manner without the risk of the intervention of intermediaries such as government which created rules for data censorship. Beyond data management, another use case of the decentralized database is to allow people all over the world to vote from their mobile devices securely. These votes can be securely traced or audited. Blockchain's decentralized and secure database has potential to become the foundation for the broad adoption of Internet of Things. The blockchain database can be the central repository of transactions or value exchange between billions of devices connected to the internet, thus providing a private, secure and trustless machine-to-machine coordination [24].

4) Proof of Work and 'Mining'

The 'proof of work' (PoW) is network security protocol used as a consensus mechanism to validate transactions and add new blocks. It helps in ensuring the credibility of blockchain ledger by maintaining consensus enabled data integrity and making the blockchain tamper-proof.

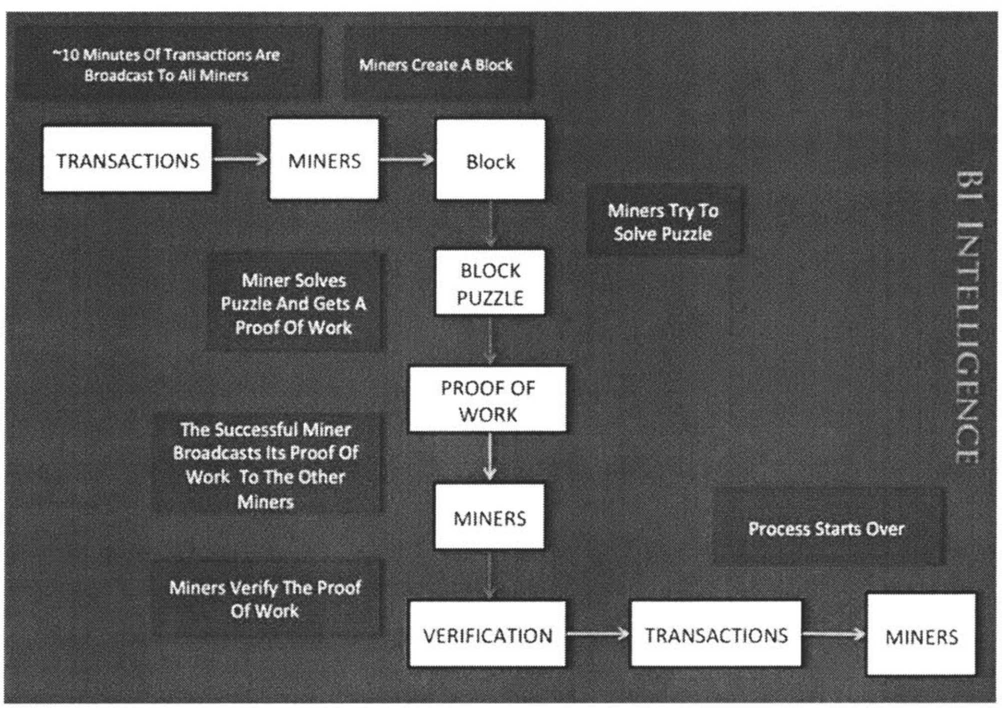

Figure 7: Proof of Work blockchain mining process (Source: [25])

The participants in the network help in broadcasting and verifying 10 minutes of transactions on the blockchain to all miners. Miners perform the computationally intensive task of "creating a block, and then assembling new, valid blocks and committing them to the shared blockchain ledger." The miners need to participate in a lottery based on their computing power to win the right to add the next block on the chain. The miners try to solve the complex puzzle and the miner who solves the puzzle first broadcasts its proof of work to other miners. The new block is verified and added when a majority consensus of more than 50 percent is achieved [22] (see Figure 7). According to Catalini and Gans, "Each time a miner commits a new block to the chain it can assign a pre-defined amount of the crypto token to itself as a reward (coinbase transaction). This reward, combined with the transactions fees participants may have included in their individual transactions to incentivize miners to prioritize them over others in the construction of the next block, serves as an incentive for miners for the work they perform" [22].

5) Proof of Stake

Extreme computational power required and rewards based system required in the proof of work network protocol makes it very costly for the miners. For this reason, the blockchain community is transitioning from Proof of Work to Proof of Stake network protocol for mining the transactions on the blockchain. In proof of stake network protocol, the miner of the new block is chosen in a deterministic way based on the stake in the network. There is no reward system for adding a new block. Instead, the miners take the transaction fees. Less amount of computing required for proof of stake method is a cheaper form of achieving distributed consensus as it requires lesser electricity [26]. There may be a future possibility of combining both network protocols to form a hybrid Proof of Work and Proof of Stake protocols to "encounter the issue of centralization as the stakeholders with large stake holdings (in Proof of Stake protocol) could attempt to display a level of domination over the network" [27].

6) Smart Contracts

Smart contracts are code snippets containing contract terms or data-driven business logic that can be added to a blockchain. The smart contracts work on "if-then-else-that" logic and are capable of automatically enforcing themselves without a third party between individual participants in the peer-to-peer network [28]. It signifies that smart contracts are important as they are decentralized and distributed, and operate without any third party. Further, they enable blockchain to verify not only financial transactions but all-purpose digital assets such as carbon credit, property, energy, provenance, etc., thus broadening the use of blockchain across multiple industries. In addition, smart contracts increase trust in the parties that agreed upon terms are executed automatically, reducing the risk of error and manipulation [29]. Smart contracts are explained in detail in section 3.

2.3 Blockchain platform architecture, and flow of operation

The blockchain platform architecture has several components. The implementation and the interaction between these components increase the complexity of the flow of operations. The main components of the blockchain architecture are as follows [30] (see Figure 8)-

- **The Wallet** is the user repository of a public key and private key. It is an external system which is the primary user interface to the blockchain system. It allows users to "propose and accept cryptographic records that represent value transactions carried on the network" [30].

- **The Network Node** represents the computer client on the peer-to-peer blockchain network. It participates in the transactional activities in two ways. First, it contains the distributed ledger copy of permanent records of historical transactions. The chain of transactions called blockchain is replicated across all nodes ensuring that records are tamper proof. Secondly, the nodes broadcast the list of all transactions proposed by the wallet over the network for miners to validate and add as a new block.

- **The Miners / Validators** - the validators in the network generate a new block every 10 minutes by grouping and validating the broadcasted transactions. The miners compete to add the new block in the chain by becoming the first one to solve an extremely difficult cryptographic puzzle also known as proof of work problem. The winner receives the reward of 12.5 newly minted bitcoins and a small transaction fee for adding a new block. After a block has been added and committed by the miner to one copy of the ledger, it replicates across the network [30].

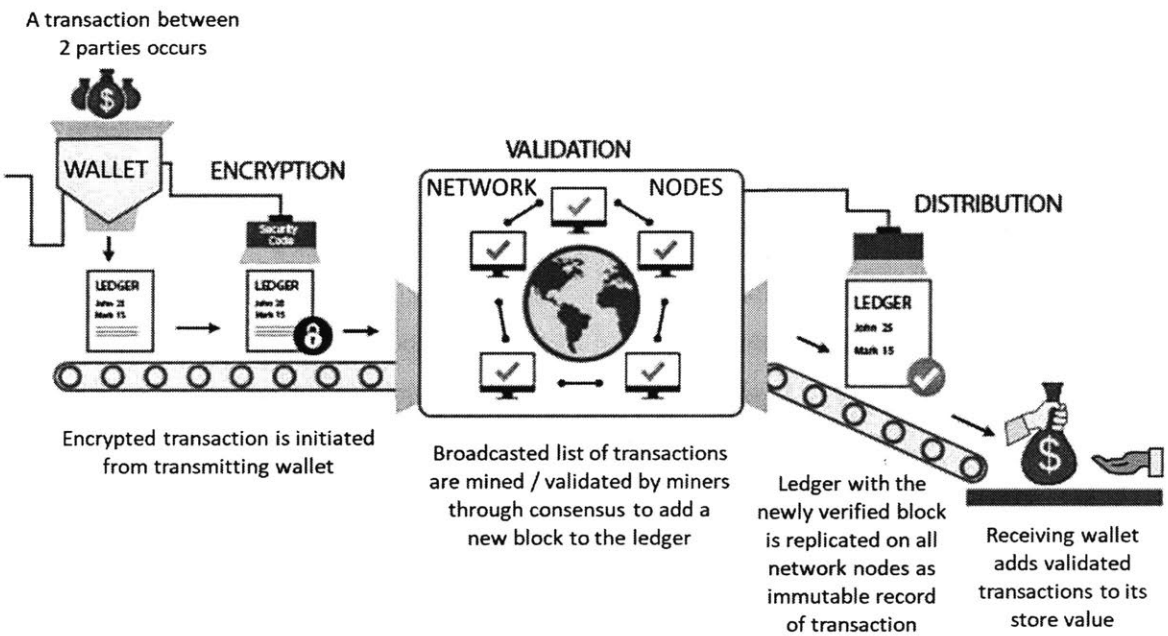

Figure 8: Flow of operation on blockchain platform (Adapted from Source: [31]*)*

Farahmand mentioned in his research published in Gartner Inc. Research Journal that in a general flow of operations in a blockchain network, "a transaction is initiated from a wallet which contains the digital signature of the user who proposed the transaction. The transaction is verified in the wallet before being broadcast to all full nodes. The validated transaction is broadcasted to all full nodes. The transaction is executed and validated to compute the future states of the participating accounts (associated with assets). The new states of accounts are stored in full nodes' respective live blocks. A full node is selected to add its block to the blockchain. The live block is stored and synchronized in the blockchain at the end of a period. The transaction is confirmed to the wallet account" [32].

2.4 Advantages of blockchain technology

The characteristics of blockchain technology mentioned above give rise to several new applications across industries, and the potential to disrupt and create new business models. The adoption of blockchain is increasing as several corporations and startups are together building and testing proof of concept for different use cases. Following are some of the advantages of blockchain technology as mentioned in the Gartner research [17], [22], [32] -

a) Reduced transaction costs

Catalini and Gans explain two keys costs in current business models that are affected by the blockchain technology – the cost of verification of transactions and the cost of networking for value exchange of good and services in changing the economy.

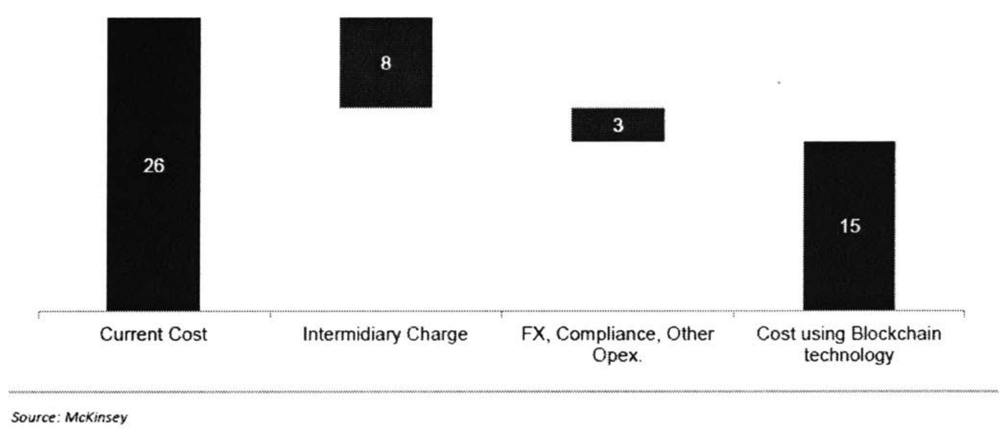

Figure 9: Cost savings due to blockchain in cross-border payments (Source: [33]*)*

Blockchain allows settling transactions in a distributed manner without any intermediaries. These intermediaries such as financial institutions or ride sharing platform such as Uber charge transaction fees for providing verification services. In the report published by AMC Wanhai Securities ltd., the application of blockchain technology in the cross-border payments space would remove the third-party financial institutions, thus reducing the transaction costs incurred by banks. "McKinsey estimates that the application of blockchain will reduce the cost of each cross-border business by about 42%" (see Figure 9) [33].

The cost of networking is reduced by combining the blockchain ledger with tokens allowing to crowdfund development of a decentralized marketplace. The tokens act as an incentive for people to contribute resources to grow the platform. It removes the need for the costly central actor to build and maintain the platform.

b) Business process acceleration and efficiency

Blockchain technology enables higher effectiveness, efficiency and transparency in multiparty business processes such as supply chain management, through granular trust control of the distributed ledger. Currently, each participant maintains their version of truth for the records in silos. These are more often than not redundant and inconsistent with the actual environment. The ledger brings efficiency by bringing standardized data formats, increases the speed of exchange between multiple parties by reducing time delays and ease of integration, and increases effectiveness by providing an audit trail in real time and higher process quality. The cost also reduces by eliminating the siloed ledgers and reconciliation tasks. As explained by Catalini and Gans, "in music industry the artists that license their music to Apple or Spotify could track how many times their songs are played by consumers, or seamlessly receive royalties from other artists for remixes that include parts that provide a shared view of truth for participants" [22].

c) Fraud reduction

The blockchain technology enables strong verification for the transactions initiated by the user. Each time a transaction initiates, the user identity is verified, authorizing whether the user is eligible to initiate the transaction. Moreover, the identity is verified through the cryptography enabled public keys identification instead of social security number or other personal documents, which can be leaked or stolen through the intermediary. Blockchain enhances privacy and reduces chances of fraud. Moreover, due to digital transactions verification on the blockchain, it is possible to track attributes of goods and services offered. It increases the ability to verify properties, provenance, integrity or status of any asset coded on blockchain as a token, providing reliability, proof of ownership and ability to trace it. In a nutshell, blockchain technology acts as a complement to current intermediaries who provide verification services to reduce fraud.

d) Reduced systemic risk

In current third-party verification based business models, there are risks of data privacy issues and intermediaries becoming a single point of failure. All data resides with these centralized parties. If they are prone to attacks, entire business value chain gets affected. The decentralized network and distributed ledger of blockchain technology reduce this risk and enhance system resiliency by eliminating a single point of failure. Secondly, blockchain reduces the counterparty risk in multiple partner businesses. It creates a trustless environment by creating an immutable, permanent record of goods and services offered and delivered. The decentralized identity reduces heavy reliance on the centralized third party to provide service ratings or building reputation for the participants such as sellers. Instead, ratings can be generated using verified transactions completed by the seller. Moreover, this lowers the barrier to entry for small players to enter the business and reduced the risk of monopoly by big players.

e) New business model enablement

The decentralization enabled by blockchain is disruptive for many business models and the underlying regulatory and operational framework. Firstly, Blockchain technology can remove inefficiencies in current business models across industries by providing standardized, faster and automated workflows, and also reduce current costs and fees in businesses. Secondly, blockchain can give rise to decentralized marketplaces which will remove intermediaries' ability to retain control over the current ecosystem. The participating nodes would be able to create marketplaces by bootstrapping through crowdfunding. The role of intermediaries such as Uber or Airbnb is likely to change from settlement and reconciliation to providing new types of applications and services. Though the first wave of the business model evaluation focused on financial sector and payments, currently there is increasing interest in identifying blockchain enabled use cases in supply chain management, legal, healthcare records, identity management, intellectual property rights, insurance, etc.

f) Application rationalization and redundancy

Decentralized tracking of assets provides the foundation for sharing information in a standardized format within and across organizations. It can help in removing redundant and non-value added applications and IT systems, thus freeing up the future budget of various departments in an organization for building new business-critical systems.

2.5 Limitations of blockchain technology

Although blockchain technology has a lot of strengths and potential to disrupt the way we exchange value, there are a few weaknesses and challenges that limit its widespread adoption. Following are some of the general weaknesses of blockchain technology enabled platform as explained by Farahmand in Gartner Research [32] -

a) Scalability, efficiency and maintenance issues

By design, blockchain requires participant node in the network to come to a consensus to verify a transaction to deter fraud. The consensus algorithms such as proof-of-work used to add a new block are computationally wasteful by design as every node performs the same task, and a huge amount of resources and energy is wasted. Also, it reduces the throughput as part of the random selection thus reducing the capacity of the system to verify the number of transactions per minute. It makes blockchain enabled system less efficient than current centralized transaction processing. Moreover, as the size of blockchain grows, the time required for verification increases and more storage capacity is needed, requiring more resource commitment. It is a concern both from network traffic and data management point of view. This computational scalability, efficiency, complex data management and blockchain maintenance issues need to be overcome for before blockchain can become a mainstream technology.

b) New-technology risk: Blockchain

Blockchain is a fairly new technology, which introduces the challenges of lack of understanding of how its functions and components. It requires more investment and exploration to develop a better design and implementation. Also, since this technology is distributed in nature, it creates the most value when organizations across industries work together. However, most of the organizations are working in silos to implement blockchain use cases. Individual work has led to the creation of more than 70 blockchains leading to wasted efforts and delay in adoption.

c) Regulation and governance uncertainty

Blockchain technology is so transformational that it requires a total shift from current ways of doing things. It has made it difficult for regulatory authorities to introduce any standards addressing the governance challenges or multi-stakeholder cooperation opportunities. As a result, the organizations are exposed to compliance, legal and regulatory uncertainties in implementing blockchain enabled use cases. It will also lead to more integration and interoperability problems in future adoption of the blockchain.

d) Security vulnerabilities and new attack vectors

The value of blockchain platform is driven by its security as well. The blockchain platform is not completely immune to security vulnerabilities and breaches. The public blockchain such as Bitcoin allows anyone to read or write transactions provided they show sufficient computing power and achieve consensus. According to Berke, "because anyone can read and write transactions, bitcoin transactions have fueled black market trading." Further, the need for high resource investments has made mining viable only for a small number of players. As a result "the majority of miners/validators operate in countries with cheap electricity, leading to network centralization and the possibility of collusion" [34]. In addition, the user private keys are just like any data that can be stolen to siphon bitcoins from the wallet. Currently, there no regulations to recover the stolen bitcoins or a way to distinguish stolen keys from legitimate transactions.

3 Smart Contracts

3.1 What are smart contracts?

According to the legal definition of 'Contract', it is a "voluntary arrangement between two or more parties in which there is a promise to do something in return for a valuable benefit known as consideration." This promise is a written agreement in specific terms enforceable by law as a binding legal agreement [35], [36].

Contracts have been core to managing business relationships, defining the terms and conditions of how to do business. For e.g., E-commerce shopping sites facilitate online transactions by providing terms of service on their website. Shoppers must agree to these terms to purchase goods or services. The customer trusts the e-commerce platform or the merchant to provide fair services in exchange for the payment made. The merchant, on the other hand, trusts the bank or the credit card issuer to bear the risk of non-payment. The level of verification for both parties involved in this value exchange is very low. The entire transaction takes place by trust in the brand image of the merchant and credit score of the customer verified by the trusted third party such as Visa or MasterCard [37]. In case of a breach of contract or trust, all parties involved can visit the legal jurisdiction courts to settle the dispute. The settlement process is expensive, tiresome and may take several days.

The term 'Smart Contract' was first proposed in 1996 by Nick Szabo, a computer scientist, legal scholar, and cryptographer. He defined smart contract as "a set of promises, specified in the digital form, including protocols within which the parties perform on these promises" [38]. It means that smart contracts are digitally signed agreed upon business rules between two or more parties, and the terms of the agreement are specified electronically by writing lines of code. Smart contracts not only replace many traditional paper contracts with computer code, but when integrated with a blockchain platform such as Ethereum also facilitate, verify, and enforce the negotiation or performance of a contract.

The smart contract is 'smart' for it its ability to automatically self-execute complicated multi-party agreements, which is beyond the capability of any singular organization [37]. It makes the settlement process low-cost, automated and faster. Furthermore, it makes the business relationships trustless, giving each party an equal playing field in the digital economy. This distributed blockchain ledger provides an immutable operating system upon which smart contracts are executed. Everyone in the network sees the same proof of events executed by the smart contract along with the ability to audit the tamper-proof timeline history. It increases confidence in the verification and integrity of the smart contracts, making it synonymous with the present day adjudication process [39].

The blogger Antony Lewis, summarized smart contracts in the context of blockchains and cryptocurrencies, as following [40]:

- **pre-written logic** enabled through computer code,
- **stored and replicated on a distributed storage platform,** e.g., Ethereum blockchain,
- **executed and run by a network of computers** through protocols such as proof of work or proof of stake, running consensus based validation on the blockchain,
- **and can result in ledger updates** by value transfer in the form of cryptocurrency payments, dictated by pre-defined contract

"If blockchains give us distributed trustworthy storage, then smart contracts give us distributed trustworthy calculations" [40].

3.2 How smart contracts work

The main purpose of smart contracts is to enable free market economy by allowing people to do business with strangers without the needs of trusted third parties. Digitizing assets into blockchain transactions by encoding them through programmable logic, allows verification and settlement of contractual promises without human intervention. According to BBVA research, "smart contracts are an evolution of the legal system and not its replacement. The role of lawyers might shift from adjudicating individual contracts to producing smart contract templates on a competitive market" [41].

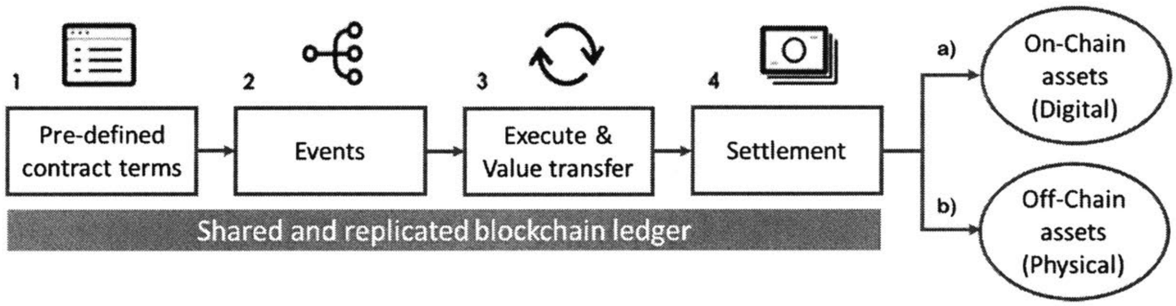

Figure 10: A flow chart for applying business logic with smart contracts (Adapted from Source: [41]*)*

Smart contracts are autonomous scripts stored in blockchain ledger at a particular address. Any business logic related to the exchange of goods or services can be coded. As explained in BBVA research, the following is the process flow of how smart contracts works to execute business logic (see Figure 10) [41], [42]:

1. Pre-defined contract terms

The counterparties involved in a business transaction agree on the desired outcomes for each party. The terms such as variable interest rate, the currency of payments, currency rate, etc. are established. Obligations and settlement instructions are also specified. Both physical and digital assets involved in a transaction are put under the custody of smart contracts by creating electronic scripts. It contains conditions for execution based on the logic 'if-then-else-what.' For e.g., If the variable interest rate on a certain date exceeds a pre-decided number then certain agreed condition should be executed. These smart contracts scripts are stored in the blockchain at a particular address. This address is determined when the contract is deployed to the blockchain.

2. Events

An event can refer to a transaction initiated by any party or any external information received. When an event pre-defined in the script takes place, it triggers the smart contract execution on the blockchain.

3. Execute and value transfer

The smart contract is executed on the shared, replicated and immutable blockchain ledger. The pre-defined terms of the contract (related business logic) dictate the movement of value. The movement of value is based on the conditions met. After an event is triggered, a transaction is sent to the pre-defined address, and the distributed nodes in the network execute the script's clauses using the data shared with the transaction.

4. Settlement

The values associated with the asset are settled by making respective transfers to intended recipients. The transfers are controlled by contract terms. The changes to accounts of associated parties are reflected on blockchain ledger, as an auditable and immutable permanent record.

1. For digital assets on the chain such as a cryptocurrency, accounts are automatically settled through wallet transfer.

2. For assets represented off the chain such as stocks and fiat, changes to accounts on the ledger would match off-chain settlement instructions. Central authorities such as regulators and

auditors may be needed to keep a tab on the blockchain ledger. It would help in keeping the records synchronized.

3.3 Smart contracts use cases

The ability of smart contracts to automatically and securely execute contracts, and also store a permanent record of business transactions, make it valuable for implementing multiple use cases across industries. Several big corporates and new startups are currently exploring smart contracts use cases. As per Deloitte report, growing popularity of smart contracts is evident from $116 million worth of smart contract venture capital-related deals done last year. These deals account for 86 percent of total blockchain venture funding. In addition, an Ethereum-based organization the Decentralized Autonomous Organization (D.A.O), has raised more than $150 million to experiment with and develop smart contract-driven applications [43]. Most of the smart contract applications are still in the proof of concept phase. Following are a few examples of smart contract use cases across multiple industries [43], [44]–

1. **Financial services**

Blockchain technology is generating significant interest in the financial services industry. Currently, most of the smart contracts enabled use cases are being explored in the financial services industry. The financial services industry operations have several intermediaries, along with manual paper-based cumbersome processes. Smart contracts can be used in trade clearing and settlement to manage approval workflows between counterparties, instantaneously calculate trade settlement amounts, and transfer funds automatically based on the contract terms. The Australian Securities Exchange (ASX) has already announced that it would replace old trade settlement and clearing system with blockchain to reduce the cost for its customers [45]. Smart contracts are also being explored for securities and over-the-counter (OTC) derivatives trading. Delaware based smart securities company Symbiont has already issued first smart security on the blockchain, allowing users to issue, manage, locate and trade financial instruments more efficiently [46]. Smart contracts can also be useful for financial data recording. It can help in reducing accounting fraud and reducing costs associated with managing accounting data.

2. Insurance

The insurance industry is heavily dependent on third parties to validate claims, and the current insurance process is disjointed and cumbersome. Insurance can benefit from smart contracts. Smart contracts can be used to automate the claims process by facilitating agreements, automating the underwriting of policies, faster validation of claims, and self-verification of the state of assets coded on the contract. In the auto industry, the insurers can provide innovative insurance products and services by equipping cars with sensors, and store all policy information in smart contracts. In case of an accident, the damage can be assessed and settled within hours instead of weeks or months.

3. Life sciences and healthcare

The medical industry requires patient's trust in managing and sharing sensitive health records. However, the industry operates on collaboration between several stakeholders, making it difficult to control data privacy and seamless exchange of information. For e.g., clinical trials or medical research involves sensitive agreements related to data privacy of people participating in the study. Smart contracts can help in automating and tracking patient consent, streamlining the exchange of data with specific parties, and increasing transparency. These benefits can be a strong force in bringing a positive change in the clinical trials community, and furthering the medical research in various fields.

Smart contracts can also be used for personal health tracking. Through the integration of wearables with blockchain, person's health-related actions could be stored as a permanent record. Smart contract can execute in case of action and automatically generates rewards based on specific milestones

4. Government - Digital Identity Management

Currently, the digital identity of a person or an entity such as reputation, data, and digital assets is recorded in the database of a centralized third party. These trusted intermediaries could be a source of data leakage or a single point of failure in case of cyber-attack. Smart contacts can allow users to own and control their own digital identity. They can decide what level of information to share on a need basis. IBM and SecureKey technologies have already announced an initiative that will enable digital identities of people to be shared with companies and government agencies on a blockchain. Smart contracts would be used to “enforce privacy and contractual agreements among parties involved in peer-to-peer data sharing and transactions” [47].

5. Supply chain management

The global supply chains have become complex value chains. The data is captured in silos and shared with limited parties due to a competitive threat. Moreover, there is no standard format to share the data across the organization. These challenges give rise to supply chain blind spots and data incompatibility issues. Smart contracts can simplify the complex multi-party value chain by enabling tracking of product provenance and history. Blockchain can enable the Internet of Things connected devices to be smart, independent agents that can interact with other machines autonomously, trace the inventory location and ownership in near real time, and automatically settle payments between multiple parties if the delivery meets the conditions specified in the contract. It would enhance the confidence of consumers in the provenance of the product and reduce the risk of fraud. Everledger and IBM are already exploring blockchain for supply chain visibility to track the provenance of diamonds, and food items respectively.

6. Real state - Land title recording

'Property transfer' and 'land title ownership' verification processes are manual, complex and unreliable. Getting consent from multiple parties in multistep processes, and permanently recording those agreement terms requires a lot of security, coordination, and trust. Smart contracts can ease property transfers to improve integrity, efficiency, and transparency. If combined with Digital identity, this solution can also help eliminate shotgun mortgage fraud. Some countries such as Sweden, Georgia, and Ghana are already coding land registries on the blockchain.

3.4 Organizational benefits of smart contracts

In previous sections, various advantages of smart contracts such as automation, economic efficiency, trust, transparency, and privacy have been highlighted. In this section, some of the potential benefits that can be obtained by the organizations by deploying smart contracts are presented [27]. A smart contract enabled system ensures that the value is exchanged only when the terms of the agreement are met. It allows buyer organizations to remain anonymous while the other party is still guaranteed to receive the payment in exchange. It safeguards the identity of participants, protecting them from the risk of identity theft or fraud.

Value is exchanged only in the way pre-determined by the parties involved in a transaction. Moreover, smart contracts can automatically execute the contract based on an event and allocate resources autonomously. Therefore, no central party has to be paid as the trust model is clear before the flow of value from one party to another. As smart contracts are programmable scripts integrated on the blockchain, the cost of changing the contact rules is extremely low. The redundancy ensured through a local copy of the contract on all nodes in the network reduces the risk of single point of failure.

The smart contract scripts stored are permanent with a history of linked and traceable transactions, helping faster settlement in case of dispute. The immutability doesn't allow the script to be changed, reducing the risk of fraud. In addition, since all transaction blocks are time stamped, no two operations can interfere with each other, providing synchrony. The atomicity of transactions based on reward for mining ensures an entire operation runs or nothing does. Last but not the list, smart contracts do not interfere with communication or transactional anonymity developed for blockchain platforms. It is additional functionality on the blockchain.

3.5 Challenges in implementing smart contracts

Despite several potentials advantages of smart contracts, some real-world challenges need to be addressed for mainstream adoption. Some of the challenges are discussed as follows [27] -

- **The complexity of the business ecosystem**

For smart contracts to execute accurately and successfully in a stipulated time period, the key requirement is that all control actions performed by the code need to be successfully integrated into the same platform. Sometimes due to technical or external difficulties of the platform, these actions may not be successful. In such case variations enforcement would be required to complete the value exchange. Secondly, due to the complexity of the business ecosystem, it is hard to determine all aspects of the contract terms negotiation at the onset of a business deal. In the real world, contracts are often imprecise, and conditions change after an agreement, leading to a revision of contract. Smart contracts do not have mechanisms to allow parties to amend their agreements when mutually desired.

- **History of Hacking**

The security challenges related to the code of smart contract is the biggest limitation in its adoption. These limitations were exhibited by the attack on the Distributed Autonomous Organization (DAO), a venture capital fund designed to run on Ethereum (blockchain platform) was exploited to siphon $53 million from its funds. The changes had to be made in the code to restore the funds. The DAO is an early-stage investment fund where the funds are managed through smart contracts instead of a manager. The investors vote for the projects to fund, and the event triggers the software to initiate value transfer based on the terms in the smart contract.

The DAO has promoted itself as a smart contract that is programmed from immutable and undisputable computer software, operated without any governmental or member intervention. The fund transfers during the attack exploited the weaknesses in the computer code. The DAO software code was incomplete as it did not anticipate the attack. The security risk of implementing smart contract is that the code underlying the blockchain can be exploited to "inject malicious immutable codes in the blockchain data structure" [32]. It can slow down the network, affect operations and worse can cause substantial financial losses. The blockchain transactions are hard to reverse, which builds the confidence of the user in blockchain ledger. As explained by Berke, the decision to reverse the transactions for DAO was controversial [34]. Although the problem in the code was fixed and the lost transactions were reversed, this has reduced the confidence in blockchain's feasibility as an immutable and secure platform.

- **Smart Contracts' Code**

Many roles in the current business ecosystem would need to be transformed to implement smart contracts in actual transactional environments. The lawyers need to learn how to write a contract using programming language, and the judges would need to learn to interpret those codes or rely on the third party to interpret them. The developers would need to understand contract law and bring best techniques to market for code development. Devising and reviewing a smart contract could be time-consuming and frustrating for a lawyer, who does not have prior programming skills. The new model of smart contract enabled contractual relations varies from the traditional understanding of contract law and dispute resolution. As of now, most of the lawyers look at smart contracts as a marginal improvement over traditional legal agreements. Whereas, the developers consider numerous smart contract applications without understanding the intricacies of traditional legal agreements. It will take significant advancement in web application developments before the smart contracts formation process can become easier and reliable.

- **Dispute Resolution Complexity**

There is currently no clear governance framework for smart contracts. A substantial number of low-intensity disputes originating in simple and anticipated scenarios are easier to govern and resolve through smart contracts and blockchain. However, more complex disputes such as the dispute over the quality of a product are subjective and are open to interpretation. They cannot be simply automated and settled through technology. Possibly, regulatory authority is needed to classify such different categories of disputes which cannot be resolved by use of technology, and layout a new dispute resolution framework. Moreover, there should exist guidelines which define the circumstances in which transaction records on the ledger could be reversed legally. Currently, the legal and regulatory authorities are way behind in devising any simple solution exploring the idea of smart contract enabled dispute resolution.

4 Supply Chain Management

4.1 Overview of supply chain management

Supply chain comprises of the flow of products, information, and money. How the related decisions and activities are managed greatly affects any organization's performance. Following schematic illustrates key components of any supply chain:

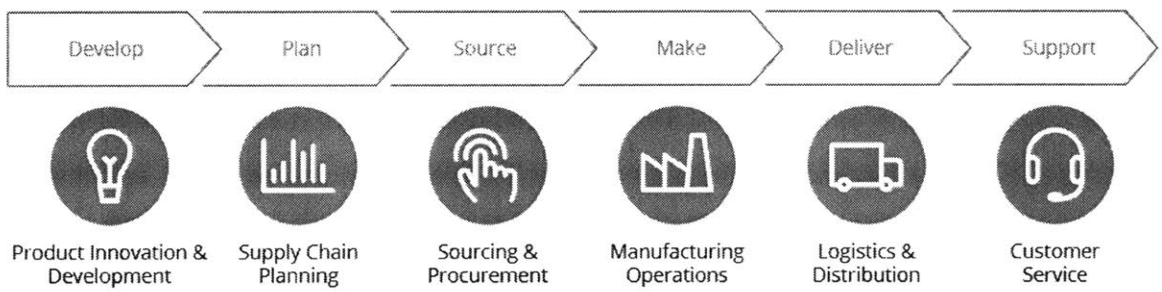

Figure 11: Supply chain and operations (Source: [48]*)*

Supply chain management (SCM) is a process of managing various components of the supply chain. According to the Council of Supply Chain Management Professionals (CSCMP), supply chain management encompasses planning and management activities involved in sourcing, procurement, manufacturing, distribution, and logistics.

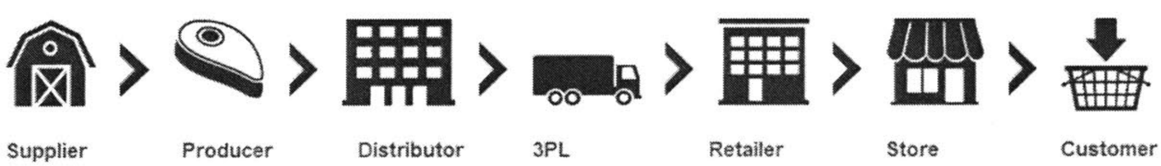

Figure 12: Stakeholders in a Supply Chain (Source: [49]*)*

Supply chain management also includes coordination and collaboration with channel partners, which may be suppliers, manufacturers or producers, intermediaries, third-party service providers, and the customers (see Figure 12) [50]. The term 'supply chain management' was first coined by Keith Oliver in 1982. However, the concept was of great importance long before, in the early 20^{th} century, especially with the creation of assembly line. Many movements are observed in the evolution of supply chain management such as globalization, outsourcing, supply chain management as a service and most recently SCM 2.0.

The supply chain today is largely discrete and comprise of decisions taken in silos through marketing, product development, manufacturing and distribution, and finally into the hands of the customer. Forecasting remains an ambiguous activity and the data it depends on can be inconsistent and incomplete. Typically, manufacturing operates independently from marketing, from the customers, and from the suppliers and other partners. Lack of transparency is leading to poor coordination among various links in the supply chain. The orderly flow from marketing to the customer seems to be disrupted somewhere [51].

According to a research report published by Strategy&, "Digital technology can help bring these walls down, and the supply chain can become a completely integrated ecosystem that is fully transparent to all the players involved – from the suppliers of raw materials, components and parts, to the transporters of those suppliers and finished goods, and finally to the end customers" [52]. While the goal of a fully integrated and transparent supply chain sounds ambitious, but organizations have no other route but to make progress to deal with increasing complexities.

4.2 The increasing complexity of supply chains

Supply chains are continuously evolving and becoming increasingly complex. Primary drivers are evolving customer requirements, changing the competitive environment and industry standards, and lack of technology adoption by various supply chain stakeholders [53]. These drivers are further accentuated by organizations' need for globalization as geographic separation reduces the visibility of key dependencies.

The most important driver of complexity is the changing customer requirements and the desire of businesses to develop an appropriate supply chain to meet customer needs. Be it fashion, consumer electronics or traditional industries such as power generation the customer preferences are changing. Shorter, more responsive product lifecycles are leading the way regarding developing agile supply chains that can deliver new products every few months or new clothing styles virtually every week [54] (see Figure 13).

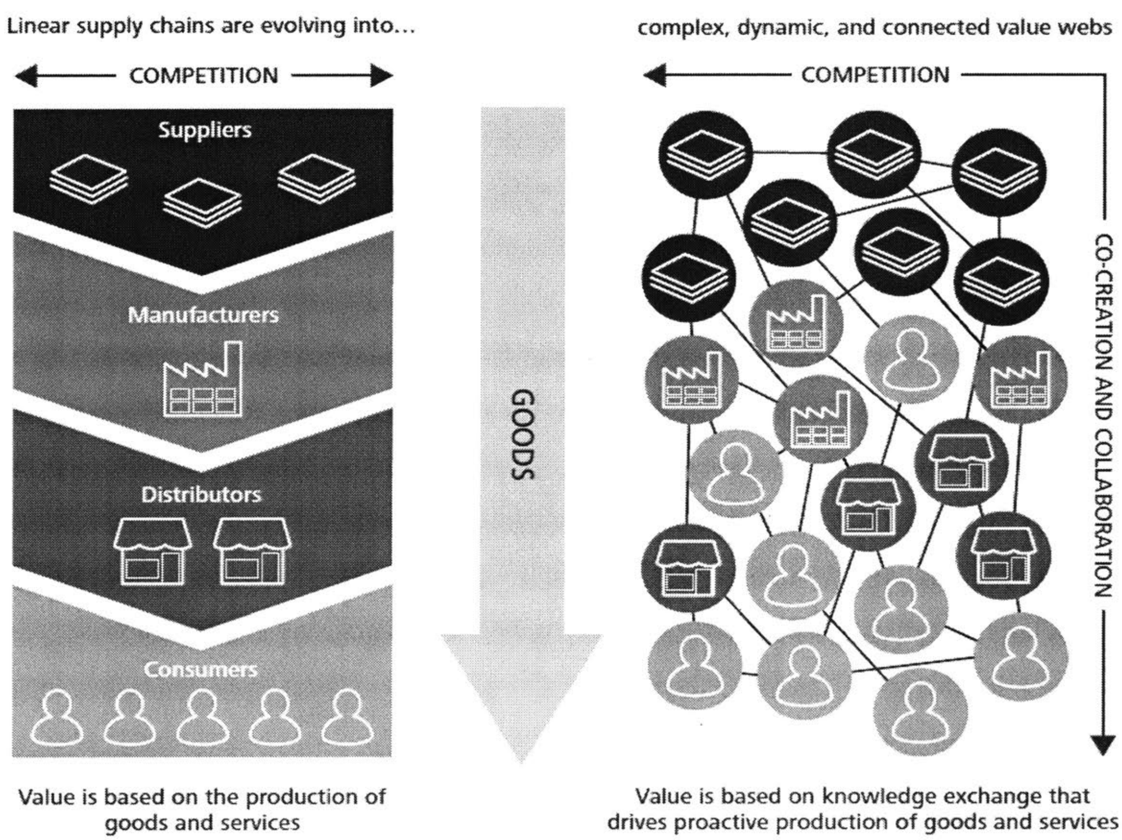

Figure 13: Supply chains evolve into complex value webs (Source: [55]*)*

Active M&A (Mergers and Acquisition) environment, modal shift, nearshoring, and evolving regulatory standards are driving changes in the competitive environment and industry standards. It impacts product price points, customer and vendor contracts structure, distribution channels, branding and customer service standards. Organizations need to customize their supply chain to manage these changes on a continuous basis to stay competitive.

Business and technology innovations such as 3D printing, blockchain, digitization, Internet of Things (IoT) are constantly revamping the way we think about supply chains. 3D printing is paving the way for manufacturing goods near to the customers. Blockchain and digitization are reducing paperwork and making information flow across supply chain more efficient and dynamic. Similarly, many other emerging technologies are demanding various supply chain stakeholders to adapt to the challenge continuously.

Increasing supply chain complexity makes it harder to maintain confidence in either the resilience or ethical nature of supply chains [54]. Extending supply chains around the world accentuate the problem of developing confidence. It is hard to be confident when you do not fully know who is in your supply chain at lower tier levels.

4.3 Trust in the supply chain

Trust is central to business interactions. It connects both internal and external supply stakeholders. Internally, cross-functional success is dependent upon establishing and maintaining trust within the organization. Externally, various supply partnerships are held together through trust. Trust's role in supply chains emerged in the 1990s. It became obvious how important trust was as a pre-condition for sharing information and assets, which then again was essential for the success of a strategic partnership [56].

There have been many studies characterizing trust and its importance in the supply chain. Nelson, Mayo, and Moody in their book published in 1998 contend that "long-term relationships require dedication and trust, skills that take years to develop and nurture" [57]. According to Tyndall et al. (1998), "effective supply chain management is built on a foundation of trust and commitment. Trust is conveyed through faith, reliance, belief, or confidence in supply partner and is viewed as a willingness to forego opportunistic behavior" [58]. Poirier in his book says that "the single greatest obstacle to advanced supply chain improvement is a lack of trust among the parties who will most benefit from cooperation in pursuing mutual gains" [59].

According to Maister, Green, and Galford, following are the four basic steps driving trust in business relationships [60] –

- **Credibility** – The supply manager and the supplier must have some 'common ground' on which to base the relationship
- **Reliability** – The purchaser and the supplier must see each other as dependable, consistent, and predictable
- **Intimacy** – People should be recognized as individuals and hence understanding their feelings, emotions, and dealing from a genuinely caring perspective becomes important
- **A lack of self-orientation** – A selfless approach that caters to the concerns, needs, and behaviors of other parties in supply chain system is key to trust formation

In reality, trust is an amalgamation of credibility, reliability, intimacy, and a selfless orientation. While most stakeholders in the supply chain (manufacturers, suppliers, distributors) recognize the importance of trust as an operational and strategic tool, they fail miserably at integrating trust into the buyer and seller relationships. Managers fail to use the information to close behavioral gaps in supply chain associations. Lack of information linkages can be attributed to ineffective systems, poor integration of systems and processes, and unwillingness to share required information. While there is much discussion about trust in supply circles, the implementation and operationalization of the trust construct are lacking [61].

4.4 Traceability in the supply chain

A recent study at the Stanford Graduate School of Business revealed that while most participant companies had systems in place for internal operations, less than a third had similar structures to monitor the practices of their immediate and extended supplier network. Companies today face intense scrutiny of their supply chain practices including workers' rights, product safety and integrity, and environmental responsibility [62].

Previously, physical distance separated various stakeholders of the supply chain. Now technology can make downstream stakeholders – consumers, business customers, news media and regulators aware of upstream risk almost instantly. The dispersed nature of today's supply chain across more jurisdictions, with different types of business practices and varying cultural norms, has also increased risks for multinational businesses, making traceability both critical and complex.

Nestle made a voluntary admission in 2015 that slave labor was being used to produce its seafood sources from Thailand. This step revealed many US and European companies buying seafood from Thailand are exposed to the same risks of abuse in the supply chains. Though Nestle is not a major purchased of seafood in Southeast Asia, it took a pioneering step to end slavery in the Thai seafood supply chain [63].

Unfortunately, most manufacturers don't know how ethical the supply chains that support their business are. Research from the supply chain visibility specialist Achilles shows 40 percent of businesses, which are buying only in Britain have no information on second-tier suppliers, while one in five companies have no information about their tier-two suppliers across the world. Additionally, just 51 percent of manufacturers regularly audit their tier-one suppliers [64].

5 Analysis of Global Food Safety problem

5.1 Global food supply chain ecosystem

A food system encompasses the interdependent set of people, enterprises, regulatory authorities, institutions, processes and relationships that collectively govern, develop, and deliver material inputs to the farming sector, produce primary commodities, and subsequently handle, process, transport, market, and distribute food and other products to consumers. Food systems differ regionally and culturally depending on the nature of processes and relationships between entities. A robust food system delivers the desired outcomes such as reducing food waste, improving food safety, affordability and supply chain worker's livelihoods, while a failing system delivers unintended consequences through environmental and socioeconomic feedbacks (see Figure 14).

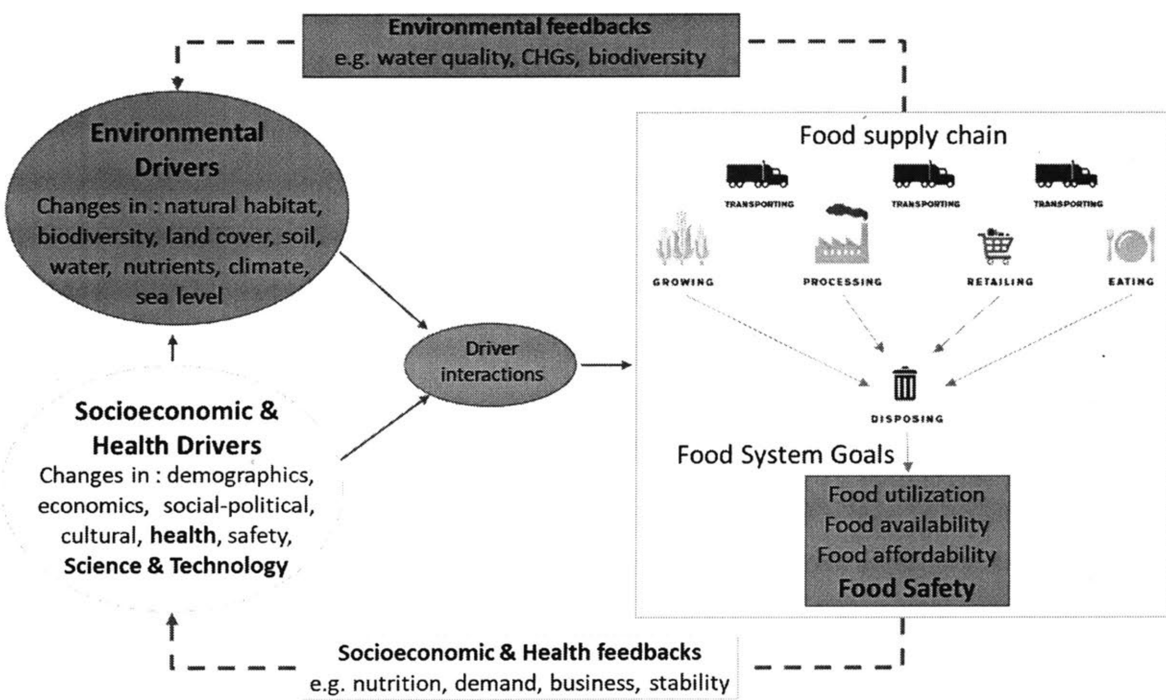

Figure 14: The Global Food System (Adapted from Source: [65])

Environment, health, social and economic are four important domains in a food system that help to accurately assess the system's effectiveness in meeting the end goal of food utilization, availability, affordability, and safety. The stability of each domain is mainly dependent on the system's ability to meet these goals successfully, and thus increasing end consumer's confidence in the system. Within each domain, four dimensions of effects – 'quantity,' 'quality,' 'distribution' and 'resilience,' help in measuring the success of a food system in meeting its goals [66]. Table 1 provides a sufficiently broad range of potential outcomes of an agricultural food system, and how the four dimensions can measure the food system effects for each of these outcomes.

	Domains		
Dimensions	**Health**	**Environment**	**Socioeconomic**
Quantity	Sufficient calories consumed for good health, but not obesity	Plentiful food production from agricultural land and water	Rising disposable income for consumers and/or food system workers
Quality	Safe working conditions and/or availability of food that is safe and meets recommended dietary guidelines	Biodiversity and quality of natural environment in agricultural setting	Variety of affordable foods across income levels
Distribution	Access to a variety of foods for all groups in population	Distribution of agrochemical runoff risks across diverse landscapes	Cost of meeting dietary needs as share of household income at different income levels
Resilience	Recovery of trusted food safety level after contamination event	Recovery time for agricultural production after drought or flood	Community retains viability after loss of a major employer

Table 1: Four dimensions to measure food system effects (Source: [66])

The global food system currently sustains 7.6 billion people and their livestock across the world. The system seems to work by meeting the environmental, health, and socioeconomic food needs of the consumers. However, it is currently facing many challenges. From farm to fork, perishable goods are handled at many steps and transported for long hauls. It creates a global food industry consisting of several stakeholders working at low margins. The consumer expectations have been reset by the retail e-commerce experiences of receiving goods anywhere and anytime. There is an increased desire for immediate consumption and increased pressure to produce high-quality food at low cost and faster pace. With growing population, changing diets and increased demand, it is expected that in 40 years agricultural output will need to increase by 100 percent. Assuring sufficient, nutritious and affordable food for all people must be achieved sustainably by conserving our natural resources [67].

The growing complexity of globalized markets with many stakeholders and the consequences of misaligned incentives in our global supply chains are also of great concern. The intense competition and increased demand have caused numerous food scandals worldwide. In recent year, there have been several instances of consumable products that have been fake, contaminated or of low quality. In most of the cases, such products have caused significant health concerns and even death to consumers. As per IBM report, almost 1 in 10 people in the world fall ill after eating contaminated food every year, and about 420,000 people of those 600 million who fall ill, even die.

Food incidents are increasing instead of stopping. As per a 2015 study, the total cost of foodborne illness in the U.S. alone is about $93 billion a year. The average cost of food recall to the company is $10 million, excluding brand damage and lost sales [68]. With instances such as the Chinese milk scandal in 2008, European horse meat scandal in 2013, the most recent papaya salmonella outbreak in 2017, genetically engineered contaminated eggs, counterfeit wine, incorrect product labeling, sustainability and ethical issues in sourcing, etc. – the food industry is facing many challenges. Such cases have led to customer distrust in food and concerns in regulatory verifiability of processes involved in the production of food products. There are severe negative impacts of consumers distrust on food industries involved. After the Chinese Milk scandal in 2008, Chinese consumers had lost faith in locally produced goods, and as a result, the entire industry was outsourced to foreign producers. It led to closing down of shops of local dairy producers in China. Consumers want to know more about the food they are eating. They no longer trust the honesty of centralized parties, which regulate and approve products.

As per the Deloitte survey in 2015 of 5,000 consumers nationwide, 51 percent consumers signaled distrust in the food industry and mentioned an additional set of attributes driving their food purchase decisions. The value drivers for consumers' purchase decision not only include price, taste, and convenience, but now also include health & wellness, safety, social impact, and transparency. Another important insight from the survey confirms that the consumers' attributes for safety overlap significantly with that of health & wellness and transparency. When thinking about food and beverages, consumers consider a safe item to be free of harmful elements, have clear labeling, and detailed information on product contents [69]. Table 2 lists the key insights gained from the Deloitte consumer survey and presents potential opportunities to increase revenue and customer loyalty further.

Purchase Driver	Key Consumer Insight	Key Food Industry Opportunity
Health & Wellness	• The most important driver in food purchase decision • Consumer's willingness to pay is more for organic production and all-natural ingredients	• Increase customer share of wallet, promote consumer health, build positive brand image by signaling quality of food products
Safety	• Considered in both short-term and long-term • Applies to absence of allergens in food and accurate labeling	• Build ability to identify infected source and recall it quickly • Build resilience in supply chain operations and reduce losses due to product recall
Transparency	• Consumers want to have access to product attributes (e.g., clear labeling, certification by trusted third parties) and company attributes (e.g., reputation, trust), and ability to verify it in real time	• Build public database containing product information from farm to fork • Promote trust and increase customer loyalty by providing consumers access to all relevant product information
Social Impact	• Social impact such as sustainability, animal welfare and fair treatment of employees is an important driver	• Provide customers ability to track reputation of global supply network • Provide access to all sustainability and ethical practices information

Table 2: Consumer's purchase decision drivers and opportunities (Adapted from Source: [69])

5.2 Key stakeholders and activities in the agriculture-food supply chain

The agriculture-food system is effectively a global food network that links farm production inputs to food consumers. Both positive and negative - health, environmental, social, and economic effects occur all along the food supply chain processes from source to make and deliver. During the product lifecycle, the management of food system is affected by the changes in the ecosystem comprising of natural resources, cultural context, market economics, policies, technologies, organizations and information flow.

As seen in section 4, the supply chains are complex and diverse. The food chain is managed by several entities with competing interests and goals. The key stakeholders in the agro-food supply chain are primarily involved in agricultural activities, raw material production, food processing, distribution, transportation, and consumption. There are a number of other secondary stakeholders such as feedstock suppliers, agro-chemical manufacturers, suppliers of food additives, machinery and equipment manufacturers and sellers, and waste processors. The entire agriculture chain is also greatly influenced by the legal and regulatory requirements. It is important that multiple processes and relationships across the food supply chain are managed properly to ensure the success of the global business.

To better understand various processes and value exchange involved in a food supply chain, interviewed India based agriculture food suppliers and processors. Accordingly, created a stakeholder value network of an agriculture food supply chain. The stakeholder value network helps in understanding the needs and goals of different stakeholders to manage all of the processes from farm to fork. Figure 15 shows the stakeholder value network analysis in which multiple exchanges take place between the stakeholders. These exchanges are related to the policy regulations, money, information, knowledge, and the goods and services provided. The value chain can vary significantly about the levels of value providers across the supply chain depending on the goods or services provided. The following stakeholder value network analyzes the process involved in producing, buying, making and selling 'pulses and derived products.'

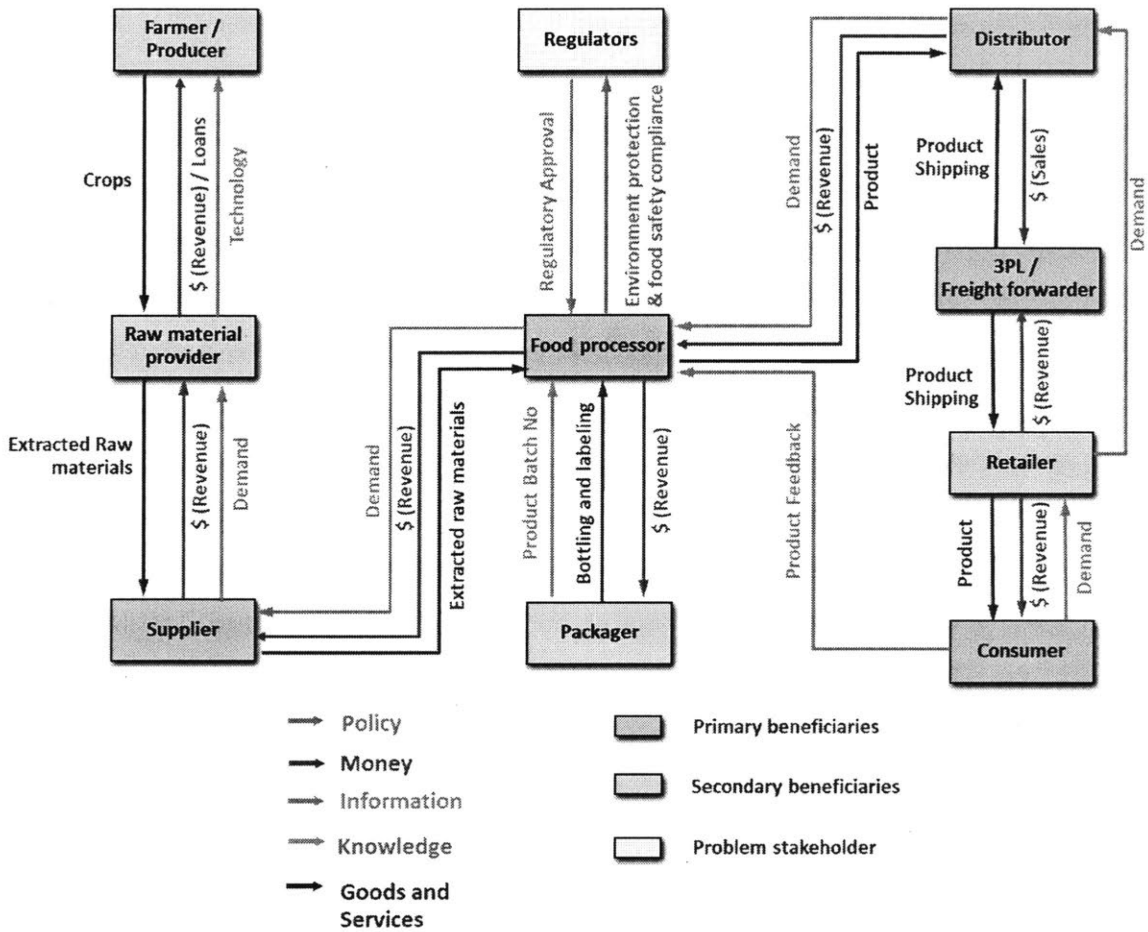

Figure 15: Stakeholder value network for agriculture supply chain

1. **Farmer / Producer** – The food producers need technology and information to improve quality, increase crop and animal output and reduce post-harvest losses while conserving resources and minimizing the impact on the environment. Producers also need loans to buy improved seed varieties, employ efficient farming practices, better animal and disease management, efficient irrigation system and post-harvest systems for the delivery of more diverse and healthy crops.

2. **Aggregator / Raw Material Provider** – The harvested crops are transported to the mills. Crops are extracted and transformed into raw materials in mills. The raw material providers

aggregate farm products and facilitate market access through brokers or suppliers. They have access to farm origination data and information on crop growing conditions.

3. **Supplier** – Supplier makes links between the aggregators and the food processors. It is responsible for providing raw materials required in manufacturing of the end product. Its goal is to meet the demand by providing sufficient quantity and quality of raw materials at competitive prices. At the same time, it has to ensure that it doesn't store too much supply of inventory as it would lead to high inventory holding costs.

4. **3PL (Third party logistics)** – Freight brokers and forwarders are responsible for safely transporting materials and products to and from different stakeholders. Due to globalization, the distances have become larger. As a result, transportation needs more robust systems for bringing food to consumers that can ensure safe storage temperatures and humidity conditions. The third party logistics services not only provide a faster way of transport but also ensure an efficient and continuous supply. Improper or careless handling of food items during transportation can lead to food spoilage or contamination. Usually, the shipping data is captured in silos and is shared with other stakeholders only on need basis.

5. **Food processor and packagers** – They add value to the raw materials to produce the end-product. Mostly, the processors have great market power to specify food requirements. Food companies realize that strong brand name that is synonymous with high quality and food safety is critical to build customer loyalty and increase the market share. In case of food contamination, it is difficult for the processors to immediately identify the source since most of the data points in the value chain are stored in silos. The losses are huge in such cases. Food processors need to appraise relationships with key raw material suppliers to guarantee constant supplies of high-quality raw material. They can also get the direct customer feedback on their products through online marketing channels. The food regulations require the food processors to provide batch numbers and expiration dates on each product for ease of traceability and reduce the risk of counterfeit.

6. **Distributor** – The distributor receives the final packaged product in batches from the food processor. They distribute the product to various retailers with the help of third-party logistics. The goal is to manage the inventory supply with the market demand and at the same time managing the inventory costs. The distributors maintain strong relationships with the retailers for re-orders. It provides an estimate of product demand to the food producers.

7. **Retailer** – Traditionally, food supply and distribution comprised of wholesale merchants and retail operators including small shopkeepers, market retailers, and street sellers. Nowadays, the rising income and diversification of diets have led to many new forms of retail such as supermarkets. The goals of the retailers are to ensure profitability, business continuity, and high-quality end product. Further to increase the perception of food safety amongst the consumers, and know the customers' needs better. It is beneficial for the retailer to have good relations with the distributors to assure a constant supply of high-quality end products. It can also provide feedback to the food producers on the customer demand. The quality and management demands of retail buyers can be met by distributors with better demand forecasting.

8. **Consumer** – Meeting expectations and needs of the final consumer of the product are paramount in the value chain. As consumers become more affluent and health conscious, they seek more fruits, vegetables, meat, fish, dairy, poultry, and processed products. These needs give rise to the opportunity for agricultural producers and processors to grow and capture the value of higher-priced goods.

9. **Regulatory authority** – The regulators play an important role in providing guidelines for ensuring food safety, and minimizing the risk of contamination and counterfeit. The goal of the authorities is to ensure that food processors and other stakeholders are following the guidelines for food safety through all stages of raw material production, procurement and handling, manufacturing, distribution, and consumption of the finished product. It is

compulsory for the food processors to get regulatory approval before they can launch a product in the market.

5.3 Challenges and pain points in managing food supply chain

The stakeholder analysis showed multiple relationships between stakeholders and business processes in an agriculture supply chain. Often these relationships become more complex to manage as the chain grows into a network. This complexity gives rise to several challenges associated with the supply chain management. These challenges include product demand planning, coordinating, and information sharing, and ensuring food safety. Most of the relationships in the value chain are managed by trust between farmer, supplier, processor, distributor retailer and the end consumer. In the following section, existing challenges and problems in the food value chain have been discussed. Current challenges include [68], [70]:

1. **Traceability and visibility across the value chain**

In supply chain management, food traceability is part of logistics management that checks the food at all stages in the food supply chain for safety and quality control. Traceability in a supply chain is defined as the ability to follow the movement of a food product along with the associated information in both upstream and downstream directions respectively. The backward follow-up of the products is called tracing, and the forward follow-up of products is called tracking. The drivers behind food traceability are food safety regulations compliance, safety and quality concerns, declining consumer confidence, and perceived economic benefits. Food traceability can play a critical driver in improving business performance through better product demand planning, improved coordination, enabling collaboration, decreased response time to product recall and better food crisis management.

However, the food supply chains have limitations in traceability of the physical movement of the product, complete product history information, and the product quality for the consumer safety.

The challenge arises due to lack of a fully integrated traceability system across the organizations involved in the production, storage, distribution and selling processes of a product. There is a discontinuity of information flow at each stage as the information is stored in silos and is shared only on need basis. Different organizations have different or incomplete data (see Figure 16).

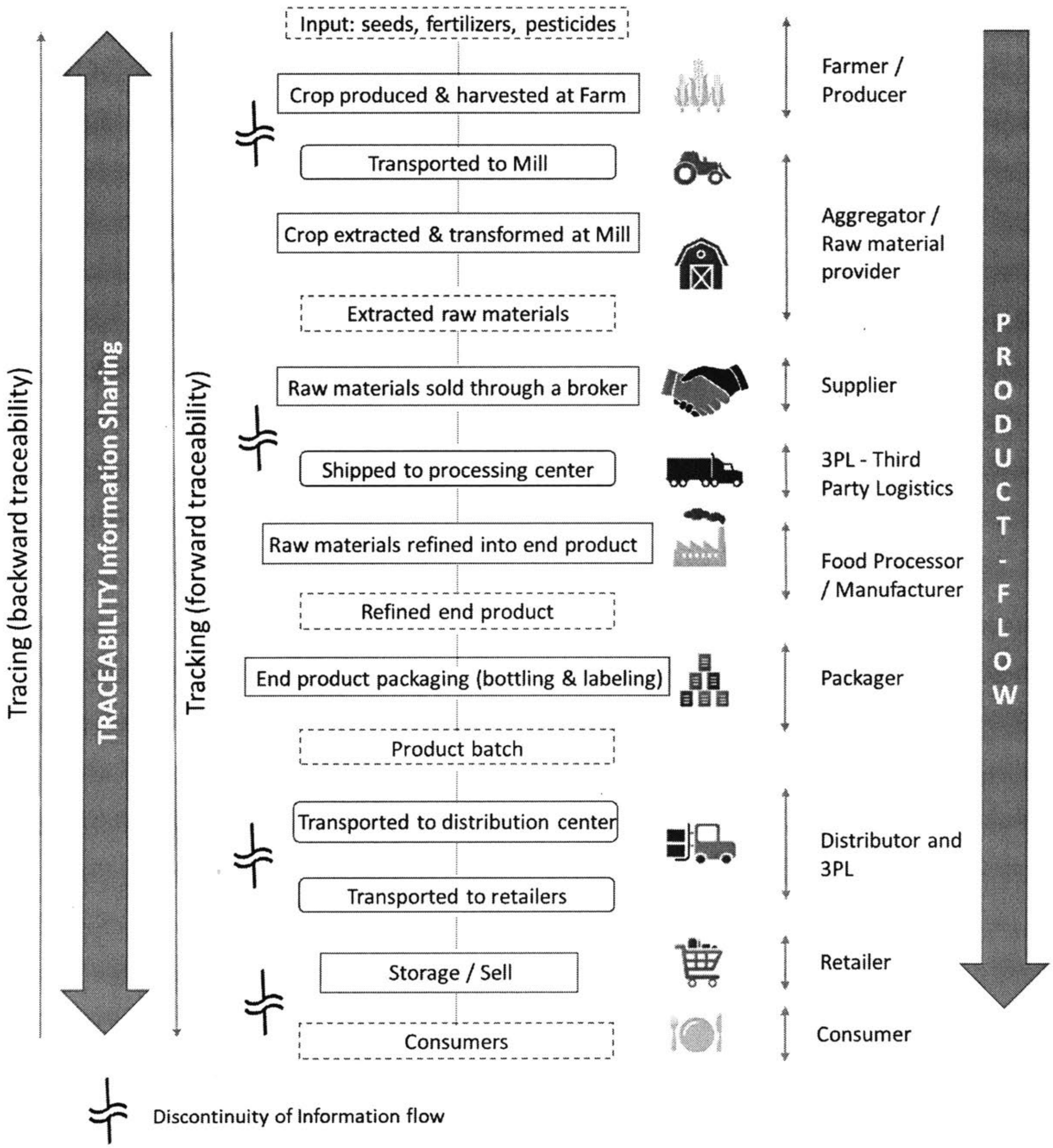

Figure 16: Material and traceability information flow in agricultural food supply chain

Moreover, there is lack of uniformity in implementing traceability systems. Every company uses different standards in information exchange, making it difficult to integrate systems across the value chain. Another challenge in implementing traceability system is the resource and capacity limitation. Implementing a traceability system is also resource intensive especially for small and medium businesses (SMEs). Gathering and analyzing product information at each level requires much administration and paperwork which places a burden on small producers of food. In addition, there is difficulty in allocating cost and benefits of traceability system among the stakeholders at different levels of the food value chain. The current operational challenges at each level of an agriculture food value chain are highlighted in the table below-

Stakeholder	Current Process / Paperwork
Farmer	• Limited technology know how to capture accurate harvest conditions and to timely share the information
Supplier	• Difficult to certify the origin and conditions of the raw materials • Ownership changes multiple times with short-term storage • Individual document transfer is a cumbersome process
Food processor	• Limited technology to control and verify product requirements (e.g., quality & quantity) and regulation compliance coming from suppliers • Cumbersome paper-based transfer process • Difficult to get end-user sales data to get insights into product demand for inventory planning
3PL / Freight forwarder	• Reliable but one-sided transportation conditions and GPS tracking system • Limited certification ability and complex tracking of temperature, pressure and humidity conditions
Distributor	• Difficulty in certifying the origin and path of the goods bought and sold • Difficult to get end-user sales data to get insights into product demand for inventory planning
Retailer	• Difficult to verify fraud and counterfeit products • It takes 3-4 days to identify the source of food contamination • Recovery of trusted food safety level after contamination event is difficult
Consumer and Regulators	• Difficult for customers and regulators to verify products' origin, composition, and compliance

Table 3: Operational challenges at each level of an agriculture food value chain

2. Lack of trust and consensus between suppliers, manufacturers, distributors, and retailers

The stakeholders gain trust by fostering business relationships and maintaining a good reputation in the market. The suppliers and distributors have to prove over time that they can produce high-quality food materials, and regularly meet the demand. The increasing transactions volume and speed of the business have led to a highly disputed business environment. Gradually, the trust is eroding among the stakeholders. For example, a food producer must have the assurance that raw materials supplied are satisfactory and that the freight forwarder delivering the end product would not spoil the product by storing them at unacceptable conditions.

Lack of trust leads to inefficiencies in the supply chain as additional resources are wasted on verification and inspection. Moreover, this makes it more difficult for new players and small-medium businesses (SMEs) to enter the market or get access to affordable credit as they don't have past orders to signal themselves as dependable, consistent, and predictable.

3. Unsustainable and inefficient use of resources and distribution of goods

"Opaque supply chains are devastating environments and compromising the wellbeing of people, animals, and communities" – Jessi Baker, Provenance founder

Adoption of advanced agricultural technologies and better production practices have resulted in significant productivity gains. However, the challenge is to continually improve environmentally sustainable practices, expand those practices for equitable economic growth and keep pace with the growing needs. As consumers are becoming more environmentally conscious and governments are getting more involved, they worry that large companies are involved in irresponsible practices harming the state of the environment. There is lack of transparent information on factors such as CO_2 emission, consumption of resources for production and waste production. There is need to collect, share and analyze such information to minimize the environmental footprint.

4. **Technological concern**

Global supply chains today have become more complex than ever before. Emerging technologies have connected companies and manufacturers from different corners of the world, creating a web of supply chain operations. The need for cutting-edge systems is apparent, but not all organizations are utilizing the latest and greatest technology to their advantage yet.

In a study conducted by supply chain management consulting firm JDA Software in 2015, found 58 percent of manufacturing and retail industry respondents had prioritized implementing a best-in-class S&OP (sales and operations planning) process in that year. 46 percent of respondents reported that their strategic priorities included “increasing agility in production planning processes” [71]. Further, the survey participants considered the actions “improving service levels” and “moving inventory closer to demand” as the top priorities for optimizing inventory management. A majority of respondents agreed to the increasing complexity in global supply chains, however, admitted that they were relying on outdated processes and ineffective technological solutions to keep pace with growing international demand [72].

Today, innovation is rapidly changing the supply chain space. Many technological advances such as artificial intelligence, machine learning, blockchain, 3D printing, cognitive computing, virtual and augmented reality, and the Internet of Things (IoT), are critical for SCM. These advances would allow SCM to adjust to changing the market and consumer demands, create more efficiency, drive profitability, and outpace the competition [73].

6 Learnings from blockchain early proofs of concept in supply chain industry

The food industry experts see potential in blockchain and are currently validating business case, the benefits and the limitations of blockchain technology. Reviewed currently published case studies to better understand the details of business use cases, their drivers, and benefits and limitations. Also, conducted interviews with senior executives and employees from five organizations at different levels of the supply chain about their industry's and organization's motivation for blockchain technology adoption. It helped in getting more insights into the case studies as well. In addition, discussed the critical success factors for successful blockchain technology adoption and its implications on their business models and strategic decisions. Following sections summarize the primary supply chain use cases, case studies on early proofs of concept, and key observations from interviews.

6.1 Blockchain applications in supply chain and logistics

"Blockchain technology has the potential to streamline and simplify the supply chain and logistics, especially in contexts where multiple entities are involved, and the overall supply chain is complex and geographically dispersed." – Christian Catalini, Principal Investigator, MIT Digital Currencies Research Study

a. Facilitate origin tracking

Problem identified: In the food supply chain, foodborne outbreaks are a huge problem for retailers. They have to identify the source of food contamination quickly, get a quick overview of where that food item came from and also identify which other food products were affected and needed to be removed from the store. Delay in the identification of contamination source can have a serious effect on the consumer's trust in the retailer's brand. The retailer may lose its valuable customers to competitors.

Present challenge: It can take "weeks" to identify the precise point of contamination, causing further illness, lost revenue and wasted product.

Proposed benefits of blockchain solution: The food supply chain would have increased trust of the customer and also trust among the stakeholders. Traceability would allow rapid identification of the source of compromised food, reducing illness and cost of the recall. Additional benefits would include product accuracy, reduced fraud, and process optimization. It could improve product flow and shelf life while reducing waste.

Early proof of concept - **<u>Walmart & IBM 'Food Safety' Project</u>**

Walmart is a retail giant in the United States of America. IBM is a pioneer in blockchain space and has made several attempts to improve supply chain management using blockchain.

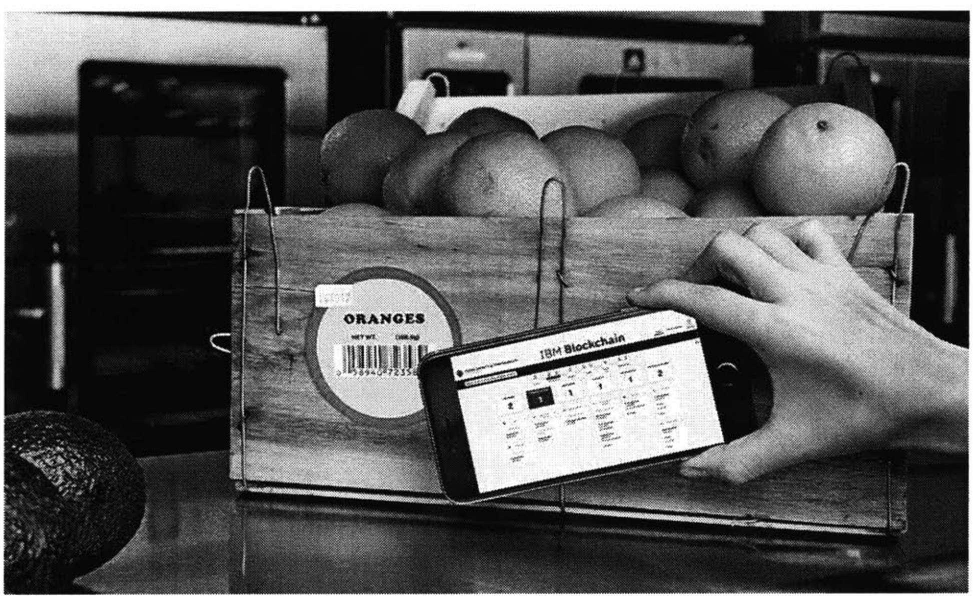

Figure 17: Crate of oranges scanned as part of a food safety blockchain (Source: [[74]])

Since October 2016, IBM and Walmart have been working together on a pilot study to demonstrate the benefits of tracing food products on blockchain. In a published interview, Frank

Yiannas, VP of food safety for Walmart revealed that the initial trial had helped trace origin of a food item in 2.2 seconds. This process took almost seven days using previous methods. This efficiency will help reduce response time when contamination is discovered as well as make it possible to perform selective recalls. August 2017 onwards Dole, Driscoll's, Golden State Foods, Kroger, McCormick and Company, McLane Company, Nestlé, Tyson Foods, Unilever, Walmart, and others have come together with IBM to help further identify and prioritize new areas where blockchain can benefit food ecosystems and can positively impact global food traceability. The project uses IBM blockchain platform developed through open source collaboration in the Hyperledger community, including the newest Hyperledger Fabric v1.0 framework and Hyperledger Composer blockchain tool, both hosted by the Linux Foundation. Blockchain holds the history of food items through entire supply chain providing traceability of food from "farm to fork." Permissioned blockchain creates the trust necessary to address the core problems of data visibility, process optimization and demand management in any supply chain [74].

b. Identify counterfeit products

Problem identified: The new age consumers who are empowered by the digital technology demand both lower prices and higher quality for products. There is an increased demand for product authenticity especially for high-value items such as diamonds, watches, wines or handbags. More conscious customers want proof that their vegetables were grown on an organic farm, and are not just attached to organic label and premium price. Secondly, there is increasing pressure from counterfeiters, who steal sales and damage the brand's value by flooding the market with fake copies. Counterfeit goods account for 2.5% of global trade or $461 billion. Recently, UGG footwear maker discovered around 3,660 pairs of fake UGG products [75].

Present challenges: The provenance of high-value items usually is based on paper certificates that can get lost or can be tampered. Moreover, continuously reinforcing and proving product authenticity entails significant recurring costs for retailer, manufacturers, and regulators.

Proposed benefits of blockchain solution: The solution has potential to provide retailers with a tool to share reliable information with customers, who increasingly base their purchase decisions on product contents, origins, purity, and authenticity. Consumers are also more health conscious would be willing to pay a premium for higher quality food sources which can provide assured proof of product origin and purity, as well as the accuracy of ingredient listings.

Early proof of concept – <u>BlockVerify 'Trustless system of Transparency'</u>

BlockVerify is a startup founded in 2015. It has about ten employees and is headquartered in London. As of Dec 2017, it has raised about $53K [76]. BlockVerify offers a blockchain enabled an anti-counterfeit solution for pharmaceuticals, luxury items, diamonds, and electronics.

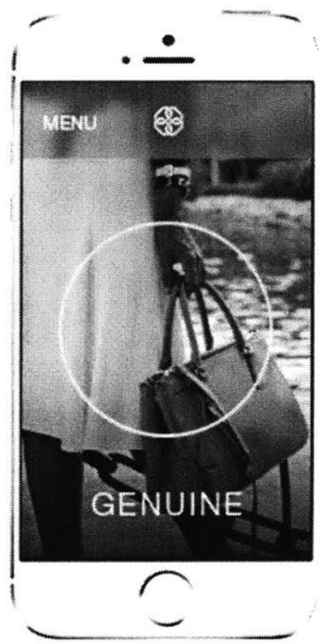

Figure 18: BlockVerify process to ensure product authenticity (Source: [77])

The solution can verify counterfeit products, identify if a product was diverted from its original destination and track fraudulent transactions. In addition, it can also trace and locate stolen merchandise. The BlockVerify platform runs on global, digital ledger that gives the ability to track goods throughout the entire supply chain. Each product is labeled with BlockVerfiy tag, and each product is verified along the supply line. As the platform is built on the hybrid technical model using private blockchain simultaneously with the bitcoin blockchain, it allows supply chain to become transparent to the extent desired by the business. BlockVerify uses consumer-level authentication and track-and-trace (TnT) technology to record changes in ownership of a product. When consumers purchase a product, they would be able to verify that the product is genuine and activate it. Even retailers can use mobile devices for verification. They can be assured that the goods they receive are genuine. Each product has a recorded history permanently recorded in the blockchain. It can provide verified history for each product for transparency and audit purposes. Block Verify has been testing solutions in pilot programs with both a Swiss pharmaceutical company that has a UK presence and a London-based beauty company [78].

c. Enable supply chain visibility in ocean shipping industry

Problem identified: Global trade process involves a lot of paperwork. It is a huge problem for stakeholders as the process is costly, time-consuming and inefficient. According to the firms, 90% of goods in global trade are carried by the ocean shipping industry each year. Currently, most of the shipping transactions involve a big number of papers, such as sales contracts, charter party agreements, bills of lading, port documents, letters of credit and others related with the vessel and the cargo. These documents are important as they affect the payments as well as the carriage and delivery of the cargo. Several stakeholders are involved in these business decisions starting from shipper at load port to the receiver. The paperwork alone costs the industry billions of dollars. In addition, the paper-based freight documents such as the bill of lading are prone to get lost, tampering, and fraud.

Present challenges: The container shipping market has not seen any transformative change during digital revolution. Shipping remains a traditional industry with manual processes. Usually, the paperwork and approval procedure is so lengthy and time-consuming that the vessels to arrive at the discharge port before the bills of lading. It significantly increases cost, risks of fraud and complexity of trading.

Proposed benefits of blockchain solution: Blockchain and smart contracts together have potential to establish transparency among parties and efficiency of delivering goods globally. It could lead to massive savings for the shipping industry and could also reduce the cost of goods for consumers. Moreover, it would help reduce fraud and errors, reduce the time products spend in the transit and shipping process, improve inventory management and ultimately reduce waste and cost [79].

Early proof of concept - **Maersk & IBM 'Cross-Border Supply Chain' Project**

Ocean freight is one of the oldest professions by humankind. While the ocean freight business eco-system has come a long way, processes still require manual paperwork. As per Danish transport company Maersk, a simple shipment between continents requires stamps and approvals from 30+ people and organizations comprising of shippers, customs authorities, agents, transporters, freight forwarders, etc. The process included more than 200 different communications among these stakeholders.

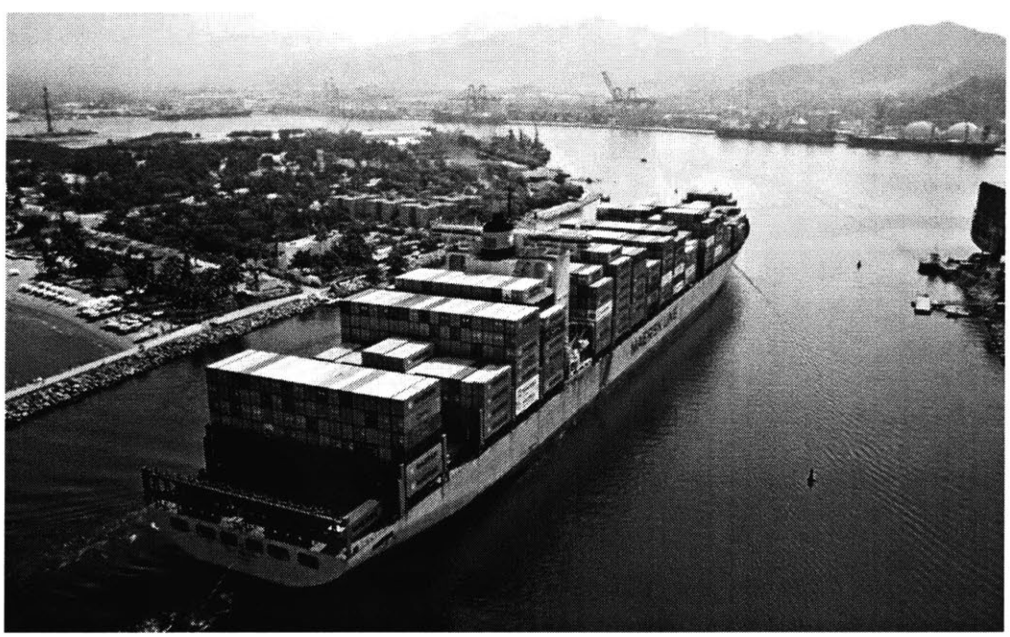

Figure 19: Blockchain enabled solution for digitizing paperwork in ocean freight (Source: [79])

IBM and Maersk joined hands to tackle this complex problem via blockchain technology. The partnership is targeted to develop a solution that will digitize and manage the paper trail of shipping containers across the globe. It would also enable the real-time exchange of original supply chain transactions. While implementation details are yet to be revealed, the structure is expected to be as follows [79]:

- Blockchain will provide a transparent shared network with high level of security
- Each participant (shippers, trading partners, freight forwarders, ocean carriers, ports and customs authorities) can view the progress of goods through the supply chain along with status of customs documents, bills of lading and other data
- The platform will also enable real-time collaboration and exchange of documents
- Participants will require consensus from others in the eco-system to edit any record

Stena Bulk & MIT Sloan project - 'Blockchain Technology use-cases in the shipping industry.'

Stena Bulk is a Swedish tanker shipping company. It has offices in eight countries. The company has a controlled fleet of about 80 tankers. Stena Bulk is part of the Stena Sphere with more than 20,000 employees and a turnover of 6.5 billion USD. Stena Bulk hosted MIT Sloan project during spring 2017 to investigate how Blockchain affects the tanker industry. The project aimed to recommend short, medium and long-term approaches for Stena Bulk to consider.

d. Facilitate SME (Small Medium Enterprises) financing in supply chains

Problem identified: In most emerging markets, small and medium enterprises, or SMEs, lack access to the credit and liquidity they require for their daily working capital needs, primarily for their domestic and international trade operations [80]. According to the International Finance Corporation (IFC), small to medium-sized enterprises (SMEs) in developing countries face a financing gap totaling over $2 trillion. In China alone, the vast majority of the 40 million SMEs remain unserved by existing financial resource [81].

Present challenge: In any supply chain it is difficult for small businesses and suppliers to enter the market or receive loans as they don't have trusted tools to signal their commodities, accounts receivables, equipment, land, etc. to retailers and financers. Furthermore, onboarding new suppliers and integrating them with existing processes is a challenging task. Also, it is difficult to align incentives among different stakeholders due to information asymmetry.

Proposed benefits of blockchain solution: Blockchain solution has the potential make global trade more accessible to a much larger number of players from both emerging and developed countries. Digital identity solution and transactions history would help SMEs to signal for quality and viability to bigger retailers and financers by giving visibility into supply chain cash flow, and their inventory. It would help in creating a more inclusive and transparent market. In addition, this solution would help banks extend working capital finance to SMEs by leveraging blockchain enabled the trustless network to assess, measure and manage their risks of extending financing. It can also help large corporates improve their working capital management and decrease supply chain disruptions [80].

Early proof of concept – <u>Eximchain</u>

Eximchain is a startup founded in 2016. It provides supply chain finance solutions on a secured public, permissioned blockchain hybrid enabled through smart contracts. The blockchain for small-and-medium enterprise (SME) buyers and suppliers act as supply chain optimization tool and helps gain access to affordable capital sources to grow their businesses. The smart contracts allow SMEs to implement customized SCF solutions quickly. The solution is based on Ethereum blockchain, consensus protocol and quadratic voting based governance model to provide practical, finite time security guarantees on their public, permissioned blockchain hybrid model. Eximchain enables businesses to connect, transact, and share information more efficiently and securely. Using blockchain technology, Eximchain eliminates traditional supply chain barriers and integrates actors big and small into an inclusive, transparent, and secure global network [81].

6.2 Interview excerpts

The summary of interviews conducted with senior executives and employees of different organizations and research groups have been captured in the form of key observations below. These observations informed the framework, the analysis, and recommendations presented in this thesis. The names of the interviewees have been anonymized to maintain confidentiality.

a) Key observations from my discussion with Vice President, Blockchain Solutions, and Research at IBM –

<u>Context:</u>

IBM is solving the food safety problem for the entire industry. Walmart is the sponsor helping answer the right questions and making sure this product meets needs of the entire industry.

<u>Challenges:</u>

If we want to have a blockchain food safety solution for the industry, there are three main challenges that we face today – **Technology maturity, Ecosystem complexity,** and **Governance of running the solution.** Blockchain is a ubiquitous general purpose technology, but it is just two years in making. Therefore there will be some time for this technology to mature enough. Blockchain Technology is constantly improving in performance over time. The ecosystem is important for food safety solution to be successful. An ecosystem can be 'Founder led' or 'Consortium' led. The solution of food recall cannot be given if the entire industry is not involved. That is a big issue for blockchain solutions.

Multiple parties are coming together when everybody benefits is a huge challenge. However, it is the business model. There are the whole set of questions on governance rules required for managing blockchain technology solutions. Few questions that need to be addressed are: Who can join the network? Who can operate the network? Who can see the data? Who decides if there is a dispute within the ecosystem, how is it resolved? Who governs management questions around the ecosystem?

Solution:

Blockchain and smart contracts can be used in present systems. Some of the data can be critical information that companies don't want to share with their competitors. Blockchain makes sure people have selective visibility of the data shared. Blockchain is a purely shared databased where you can share data and at the same time be sufficiently comfortable that privacy and confidentiality of data are guaranteed. In addition, smart contracts are digitized documents. Therefore, the food safety certificates issued by the government can be stored electronically on blockchain along with the digital signature. It can mitigate the risk of counterfeiting. The blockchain technology can also be very helpful in resolving disputes as for every transaction that goes in multiple parties have to sign it. As a result, all transactions history is verified before it is stored on the blockchain.

b) Key observations from my discussion with Director, Product Management at TraceLink –

Context:

Pharma industry shares a common goal of ensuring medications are delivered safely to patients. The rise in counterfeiting and diversion has made this task difficult. TraceLink is a cloud-based pharma traceability solution's company connecting the Life Sciences supply chain and eliminating counterfeit drugs from the global marketplace.

Present solution:

Tracelink is a platform that provides its serialization technology for identifying each product uniquely, allow information sharing among trade partners, managing serialization in the warehouse, and meet compliance requirements. The platform is hosted on Amazon web services cloud infrastructure as a service. Data authenticity, reliability and availability are important key value propositions for their customers. Ease of integrating with new partners, systems integration, data aggregation, data accuracy, and interoperability are important drivers for customers to join their platform. TraceLink relies on Amazon cloud services for their business continuity and scalability and is satisfied with their platform performance over the cloud.

Challenges:

Tracelink's management is observing blockchain use cases for traceability from a distance, and at present their likeliness of adoption of blockchain is low. However, they agree that if blockchain is implemented industry-wide, then it would radically transform their business model. High-level reasons for current lack of interest in blockchain adoption are blockchain's unclear benefits, lack of acceptance in the industry, and presence of comparable cloud-based competing solutions.

c) Key observations from my discussion with Advisor at MIT Media Lab, leading the research, projects, and publications around Blockchain and Supply chains –

Context:

The interviewee is a contributor to Blockchain Research Institute's project - Additive (3D printing) manufacturing and blockchain for creating efficient supply chains for Moog. Moog is a global designer, manufacturer, and integrator of precision motion control products and systems focused on the aircraft industry with its razor-thin margins. She provided insights into the way blockchain, and additive manufacturing can be used together to transform supply chains radically.

Challenges:

Regulated industries are currently facing the challenge of complex processes, uncertain tracking mechanisms for the provenance of supplies, and conflicting data sources.

Inefficiencies and counterfeits in the products, parts, or supply chains can delay projects, compromise the integrity of critical systems, and endanger human lives. The cost of noncompliance is very high. Any changes in design data for any part or a supplier's failure could increase notices of non-compliances by almost 10 percent. There is a need to encourage innovation, ensure security, preserve intellectual property rights and enhance supply chain visibility within a high-stakes / low-margin supply chain industry.

Solution:

Supply chain industry is the best application for blockchain as there is a common interest among stakeholders to sell more, but they don't particularly trust each other. Moreover, Blockchain is an enabler for other technologies. A blockchain platform that combines technologies such as 3D printing, and analytics, with regulatory bodies, and suppliers can overcome supply chain inefficiencies and counterfeits. The platform could also become a marketplace and a reputation management system as all stakeholders' information, system integrations and transactions history would be available in one place. Vendors' performance and user experience could be traced from transaction history. It could factor into vendor ratings, which would be visible to all platform participants. It could contribute to existing vendor management system scorecards and future re-orders based on past performance.

d) Key observations from my discussion with Stena Bulk Project Manager for the Stena Bulk & MIT Sloan blockchain project –

Context:

The interviewee is Business Intelligence Manager for StenaBulk and also the project manager for MIT Sloan blockchain project. The project details are discussed in section 6.1. As a Business Intelligence Manager, the main task is to evaluate disruptive forces outside Stena Bulk and their potential effects on Stena Bulk's day to day business. These forces can be within areas like Technology, Digitization, Sustainability and Energy and a lot more.

Challenges:

The shipping industry is like a Taxi market. Next voyage is approved as soon as the ship reaches a point. All business information is coming from stakeholders in the value chain. The cargo value is huge and based on trust between the shipping company like Stena Bulk and the cargo delivery company. The process involves all traditional paper-based contracts. The main focus of the company is on the digitization of paper-based contracts using smart contracts. There is a need for a system that helps the company track the contract's process and also limit the risk regarding contract handling.

Learnings:

Initial technology evaluation has shown that blockchain technology has key ingredients to solve risk and provide more secure transactions and faster settlement. These ingredients are the protocol of trust on the internet, traceability, auditability, digitization, and ability to delegate the authority if necessary.

Some of the learnings and insights for any business executive before implementing blockchain use cases are as follows –

1) Have a clear business case. Are the value proposition of blockchain adoption meeting the business needs?
2) There is a strong need to identify: What would change post implementation of the solution? How could industry be structured? Who will be the winner and loser?
3) Implementation takes time. The design of solution is important. It has to be super easy integrations with existing ERP and other systems. Otherwise, it will be stuck on integration and cost issues.
4) Usability of the solution design must also be high for wider adoption.

e) Key observations from my discussion with Project Manager for 'Blockchain solutions for SME financing and supply chains' projects at MIT Media lab's Digital currency initiative –

Context:

Interviewee's research is focused on using blockchain technology for financial inclusion. His team at MIT Media Lab is working on blockchain asset registries 'b_verify', and have developed a prototype for inventory-based lending.

Challenges:

The biggest challenge in supply chain 2.0 concerns the sustainable integration of small farmers, and small businesses and suppliers in the value chain. Small farmers usually reside in developing nations, e.g., in South East Asia, with poor infrastructure. They need frequent loans, which are expensive. Small farmers don't know how to build credit rating and signal trust to financers or retailers to get loans. Moreover, as they are uneducated, the usability of technology becomes a problem.

Small, medium enterprises (SMEs) face their fair share of challenges in the supply chain. They need to make frequent payments. Thus capital circulation is important to them. Payments settlement takes significant time due to time for verification. In addition, SMEs don't have tools to signal for quality and viability to bigger retailers to get more business and loans. It makes it difficult for SMEs to enter a new market. Limitation of adding new players to market increases the risk of business dependency on a handful of players.

Solution:

Blockchain is fundamentally different and a new way of organizing people. The decentralized trust protocol would shift the market dynamics. It may not be the solution to existing problem but important in implementing the future we want to build. Blockchain can help build a marketplace that directly connects the creator to the consumer, maximizing the returns for the value creator. There is not one single solution but a group of solutions which could be helpful in making supply chain industry more transparent, inclusive and efficient. Solutions for financial inclusion, digital identity, instantaneous payments, immutability and trust, ability to track loans, etc. together can bring the desired impact on the society as a whole.

f) Key observations from my discussion with Founder & CEO of Context Labs –

Context:

Context Labs is a media research company focused on exploring and developing new technologies intended to enhance and converge traditional media delivery systems for audio, video, and music with the web. The interviewee is contributing to the Open Music Initiative (http://open-music.org/) for creating an open-source protocol for the uniform identification of music rights holders and creators.

Challenges:

More and more logistics objects are equipped with the Internet of Things (IoT) sensors that generate data along the supply chain. As of now this data resides in silos and is difficult to access. Two important challenges arise.

Firstly, Amazon, Apple, Google, and Facebook are the super aggregators, who have control over all user data. They control a significant percentage of the seller's revenue in their marketplace. If one company controls everything, then there is increased the threat of monopoly as well as single point of failure.

Secondly, this data can be easily tampered with. Verifying the authenticity of the data at source is important. Fake data ingested into blockchain would defeat the purpose decentralized trust network. There is a need for a general verification protocol to establish and prove information captured by the Internet of Things devices, and develop an ecosystem of Open API for everyone to use and verify for worldwide transparency.

Solution:

Identity, Trust, and **Data** are fundamental to the successful deployment of any blockchain technology solution. A more peer-to-peer - "creator to consumer" model of the marketplace can be enabled with new blockchain technologies. It can have a transformative impact on super aggregators' business model as it eliminates the trusted intermediaries. Moreover, before the data generated through the Internet of Things (IoT) devices is ingested into the blockchain ledger as a permanent record, it can be verified through the general verification protocol. It is important to know the identity of the validators of the blockchain and to ensure that data only from an authentic device/source is being validated. Blockchain can store this verified data in immutable and accessible fashion

7 Framework for architecting transparent food supply chain

In this section, a framework for holistically improving the trust, traceability, and efficiency of global supply chains by integrating blockchain and smart contracts with food origination, processing, distribution and selling processes in the agriculture food supply chain is proposed. The framework design is based on the blockchain technology analysis, food safety system analysis, stakeholder value network mapping, and the identification of customer's purchase drivers and challenges in managing food supply chain done in previous sections. In addition, learnings from the interviews conducted have been incorporated to design the framework.

There are different types of actors in the supply chain who can be the nodes in the blockchain network with the ability to make transactions and record information. First, the user needs of seven different user types – Farmers, SMEs / Suppliers, Food processors, Regulators, Distributors / Transporters, Retailers and End consumers are listed. Second, high-level requirements that apply to the entire system design are provided. Further, based on these needs and requirements a solution is suggested. The solution uses the decentralized, trustless, immutable, selective privacy and self-execution through smart contracts properties of blockchain technology. Finally, some of the possible business models and strategic considerations for stakeholders participating in the network are mentioned in the discussion.

7.1 User needs and requirements

Various system design requirements of the users for effectively managing the agriculture food value chain and the primary needs of the customers have been summarized with the help of the process chart framework below (see Figure 20). As seen in this framework, I have tried to bucket the primary needs along the most discussed applications of blockchain technology, which are as follows – 1) Identity management; 2) Process automation, auditability and trust management; 3) Financial transactions management. Then created a matrix of primary needs and mapped them to the stakeholders in the food value chain. There is an overlap in some of the user needs across the value chain. In addition, the framework also gives an overview of different users and series of their interactions in the food supply chain.

Farmers	SMEs / Suppliers	Food Processors	Regulators	Distributors / Transporters	Retailers	End Consumers
Identity management						
Reputation management - Build credit rating for loans	Ability to enter new market - Signal for quality and viability	Digital identity for privacy and authenticity	Digital identity for authenticity and ease of management	Product batch serialization and Reputation management	Improve brand image and customer loyalty	Digital identity for privacy and authenticity
Process automation, auditability and trust management						
Maximize value for crops Awareness of Technology Know how to capture & store weather, and soil conditions	Transparency in prices Get more business / orders	Analytics / ML for Demand forecasting Real-time inventory tracking Reduce food recall loss Lower process costs	Ensure Food safety compliance Make process participants transparent Faster investigation Digitize certificates	Inventory optimization Tracking and storing of temperature, pressure and humidity conditions Paperless document processing, flexibility	Analytics / ML for Demand forecasting Meet the customer needs Reduce time taken to trace source of contamination	Health & Food safety Know your food - Trace product ingredients, origination and history of handling
Financial transactions management						
Faster financial flow – Need instantaneous payments	Make frequent payments - Need capital circulation	Partner payments		Supply chain payments	Partner payments	Smart payments – online transactions

Figure 20: Framework to map primary user needs in food supply chain

Based on user needs from the current system, and nature of the business needs for privacy, data security, risk management, and competitive advantage, I have derived the design requirements for a transparent food supply chain solution. Few high-level requirements (R) are as follows –

R1: Stakeholders must have a unified view of information at every step in the supply chain – from raw materials to shipment status.

R2: Any sensitive information shared must be cryptographically secured, immutable and dynamically permissioned. It must be impossible for unauthorized personnel to access the information without the consent of the stakeholders in question.

R3: Supply chain stakeholders must be aware ahead of time and have the ability to pivot quickly in case of natural disasters or supply chain interruptions. For e.g., have immutable traceability in the system in which it is possible to see if the supplier fulfilled the order correctly, and the processor can take actions to either complete order through a different supplier or adjust pricing.

R4: Provide process digitization and flexibility by allowing terms of contracts to be exchangeable without needing to re-create the entire manual process.

R5: To reduce business risks audit trail of transactions must be stored and shared. It would open up supply chains to new partners, including small enterprises and startups.

R6: Develop a solution that can integrate easily with existing IT software and ERP system for product identification, quality and safety management, environmental monitoring, geospatial data capturing and data exchange

R7: Develop dashboards and mobile apps for higher usability of the solution design across the value chain

7.2 High-level system architecture of the supply chain transparency solution

There have been some technological advances in last few years in supply chain management systems. ERP (Enterprise Resource Planning) systems have allowed companies to manage warehousing logistics processes, purchase order management, financing, billing, etc. Moreover, global trade led to the emergence of supply chain operating networks (SCONs). SCONs are business networks that connect companies and map their relationship to one another (see Figure 21). Few examples of commercially available SCONs include Ariba, Descartes, GT Nexus, Elemica, E2Open, LeanLogistics, and One Network. SCONs can be integrated with the organizations' ERP and enable electronic data interchange of purchase orders, bill of lading, etc. among the value stakeholders. Several Transportation Management Systems (TMS) also evolved to meet the need for shipment level tracking.

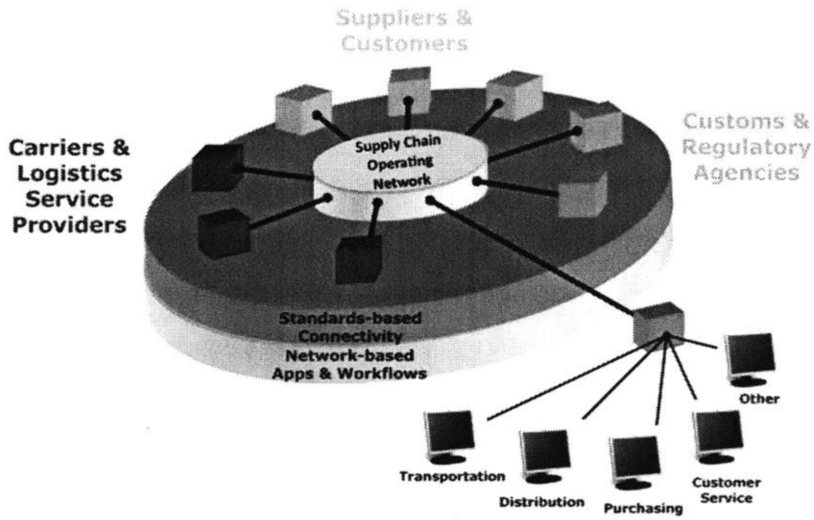

Figure 21: Current supply chain operating networks (SCONs) (Source: [82]*)*

Most of the user needs and requirements mentioned in the previous section, have been traditionally addressed in some shape and form through ERP, SCONs, TMS and other IT systems implementation, yet the challenge of traceability, transparency and efficiency in supply chains remain. Existing tracking solutions are ineffective primarily due to following reasons – continuity of information across multiple partners is not ensured, the information captured is not validated, and the information is disclosed to other stakeholders only on need basis. Large enterprises have enough resources to overcome these challenges. However, small and medium enterprises (SMEs) have cost difficulties in integrating with ERP and SCONs [83].

The following proposed platform solution is aimed to ensure the smooth realization of business operations for all levels of businesses and enterprises in food value chain. It provides transparent agricultural supply chain solution using blockchain technology. The platform aims to document every time any value item changes hands, creating a permanent record of the product from farm to fork. Figure 22 shows the high-level system architecture of the proposed platform.

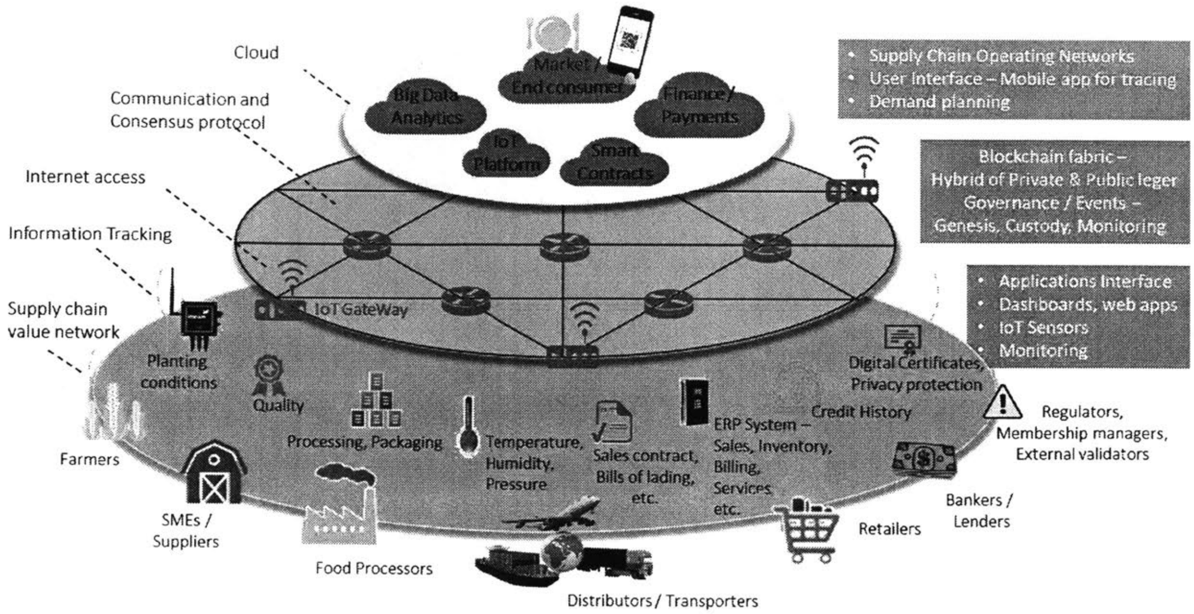

Figure 22: Supply chain architecture based on blockchain technology

The proposed architecture consists of hybrid blockchain ledger with the peer-to-peer distributed network. The private ledger is accessible only to stakeholders involved in any particular transaction and contains that private transaction's information. On the other hand, the public ledger is open to everyone and contains tracking information for all shipments in addition to the hash value of private transactions.

This governance model is helpful in mitigating the fear of stakeholders of sharing their sensitive data. The private ledger helps protect the sensitive data through selective permissions. The hybrid model retains the distributed property of blockchain, and each node keeps the copy of the ledger. Communication and consensus mechanisms ensure that all participating nodes can jointly ensure safety and authenticity of data stored on the blockchain, and can collectively maintain the openness and transparency of the data in the blockchain. The consensus is used to overcome 'trust' issues and the need for in-progress verification. Blockchain holds complete provenance details of every raw material and final product.

Each node in the network are the stakeholders in the supply chain value network. The hybrid model allows opening the network for all internal and external to value chain partners including third-party data monitoring and authentication service providers. Each participating node in any transaction would have administrative membership on the network. When any administrative node would like to add a transaction to the chain, the majority of participants in the network will have to validate it. In addition, administrative nodes would be able to integrate their internal ERP, TMS, SCONs, etc. systems with the blockchain network in a secured fashion. Blockchain is independent of adjacent and legacy systems, making the integration and interoperability easier. In this design, the blockchain network acts as a universal supply chain operating system that supports all types of information exchanges across organizations.

By solution design, additional value stakeholders in the supply chain network are needed. Currently, most of the product conditions are tracked through the Internet of Things (IoT) sensors as it helps automate the process and reduce errors. However, the tracking information is valuable only if it is authentic. Therefore, third-party monitoring services are required for validating the authenticity of the source as well as the sensor data captured before it is accepted as a permanent record on the blockchain. Accessibility to the massive amount of authentic data in real time may give rise to new stakeholders, who would apply machine learning algorithms for demand planning, fraud detection, automation, etc. In addition, membership managers are one of the new stakeholders in the value network. They are responsible for managing the participating nodes' identity and transaction certificates, as well as other aspects of permissioned access. This design requirement is important to ensure security and privacy of the stakeholders.

Usability of the blockchain solution is dependent on the user interface design of the application's interface such as dashboards, web apps, mobile apps, etc. The application service interface is important for the realization of node account management, public ledger service, and storage system management. Every lifecycle stage of a product is connected to form a complete and rigorous supply chain closure. The corresponding nodes in each phase place their transaction data and related product data on blockchain through a unified application interface. In addition, application service interface enables security verification, data linking, and querying data. Retailers who are directly connected to the end consumers are responsible for designing a mobile app for allowing consumers to track the information on various stages of the product – planting, processing, packaging, shipping, warehousing, distribution, and selling.

The distributed ledger keeps a permanent and immutable record of operational data such as Purchase Order > Transaction Approval > Shipments > Invoices > Remittances for any transaction. In addition the logistics and payment information is also stored. This information gives the trading partner immediate and low-cost trust in the identity and reputation of the counterparty in any financial or trading relationship. It also expands the universe of suppliers, especially small medium enterprises for everything from raw materials to shipping, improving efficiency and agility in supply chains. The solution also provides a central record for lenders, making it easier for farmers and SMEs to get loans based on inventory or past orders fulfillment.

Smart contracts embedded on top of blockchain would allow network participants to build terms, conditions and other logic into digital contracts and other transactions. It enables business partners to monitor prices, delivery times, conditions, etc., and automatically negotiate transactions in real time. It makes the processes paperless, automated and efficient and improves capital circulation in the supply chain.

7.3 Business models for blockchain enabled transparent food supply chains

Blockchain enabled supply chains will not only increase operational efficiency but also help in creating entirely new business models. Blockchain and smart contracts enabled convergence would not only allow more efficient deployment of emerging technologies but would also reshape fundamentals of global trade from sourcing and manufacturing to logistics and distribution. Two such scenarios are discussed as follows -

I. Creation of autonomous and personalized peer-to-peer marketplaces

Along with blockchain technology, Internet of Things is one of the most promising themes today. Internet of Thing is a combination of several technologies and devices that can associate with almost every area of customer's behavior. It is even valuable for business operations. The main purpose of IoT is to connect the physical and digital world. Many of the new business models are expected to pivot towards the combination of sensors in the IoT devices, blockchain technology, and machine learning algorithms.

Leveraging the capabilities of smart, connected Internet of Things (IoT) devices along with machine learning can help create peer-to-peer marketplaces. Blockchain platform would act as a catalyst in autonomously delivering any value over the Internet. Blockchains and smart contracts can enable connected devices to be intelligent, independent agents that can not only identify themselves to other machines securely but also carry out micro-transactions based on a set of business rules (smart contracts) that cannot be tampered.

By allowing peer-to-peer transactions without an aggregator, this model directly connects the manufacturer with the end customers. Thus significantly improving the profits of the value creator. Smart devices would collect a lot user behavioral data. Data analytics and machine learning algorithms can be applied to this data to predict the customer behavior. Business decisions can be encoded as logic in the smart contracts. The smart contracts can self-execute based on a prescribed event. It could lead to improved and personalized customer service, better customer engagement, and new customers. In addition, self-executing smart contract and smart devices together would provide autonomy of operations. It would enable the machine to machine interactions (M2M), allowing self-coordination of operation with other products and systems.

II. Shift from industrial-scale mass production to smaller scale, personal production

Blockchain and smart contracts are designed to disrupt the current centralized platform model and remove the intermediaries from the value chain. The blockchain enabled business model would reshape the existing supply chain and logistics mode. There will be winners and losers. It is expected that distribution and retail would become less critical as customers would desire personalized services.

Projects that combine blockchain's shared decentralized Infrastructure with additive manufacturing (3-D printing) are experimenting to open new market opportunities for manufacturers. It is expected that manufacturing would move from industrial-scale mass production to smaller scale, personal production. For e.g., 'The Genesis of Things Project' is secured industrial manufacturing. Industry experts along with technology enthusiasts are building a distributed global factory that identifies an optimal 3-D printer, securely transfers files, establishes a smart contract with information on payment and terms of delivery, and finally delivers products when and where needed, while protecting all stakeholders' intellectual property [84].

7.4 Strategic considerations for adoption of blockchain enabled supply chain

Supply chain transparency using blockchain technology is still rather unexplored. Though there are a few companies such as Walmart, which have launched pilot projects using blockchain technology to solve the problem of food safety. However, detailed information on technical information and implementation plan for these projects are still not readily available. As a product manager, it is important to brainstorm various use-cases and develop a relevant business case for your organization. A pilot project for the proposed blockchain architecture would be helpful in demonstrating how the technology works. However, to better understand the implications of blockchain enabled supply chain architecture on current business model and operations, product managers would need to consider following inputs and evaluation criteria –

a) Target the right business use case

To achieve a return on investment on blockchain technology requires careful evaluation of the suitability of technology for the organization's supply chain needs. Certain criteria need to be met for a business process to benefit from the distributed ledger. First, it is important for product managers to understand their supply chain traceability and transparency needs. The raw materials and final product related information flow is an important problem area of food supply chain. It is important to create use case diagrams to understand the physical material characteristics, production profile transformations, and the key business value drivers. Second, the business process identified should affect multiple supply chain layers, and comprise of both internal and external stakeholders to the organization. Lastly, to tap the full benefits of blockchain technology the use case must need strict audit compliance as well as should not demand a central authority to verify daily transactions.

b) Test the concept, before investing

Before making its way into any enterprise or organization, the blockchain concept of operations for the identified use case must be tested. It will help in understanding the blockchain technology environment and also assess the current technical capabilities and gaps. The blockchain design is such that the final implementation would be most worthwhile when all existing stakeholders including the government institutions participate in the blockchain network. Therefore, even a proof of concept required considerable stakeholder collaboration and engagement. It is highly unlikely that organic proof of concepts driven innovation groups inside the organization would be able to present impactful results. The organization can either participate in supply chain industry consortia driven by like-minded organizations or can partner with promising blockchain startups and entrepreneurial minds who are building blockchain applications to create new business models.

c) Implementing the Proof of Concept

Starting small is important. Product managers must specify the actions needed for implementation, assess the resources required, create a process map, and develop an implementation guide. Further, determine the key performance indicators (KPIs) that can be used to evaluate success. The KPIs will allow the organization to not only assess performance but also communicate value to senior management. It would be beneficial also to understand the potential change in organization culture that would be needed to implement the solution in production. Proof of concept is meant to try the solution concept and fail until it becomes a good and sustainable solution.

d) Current limitations and potential risks

Blockchain is still a new technology with uncertainty around best practices. Thus its limitations and improvements are still being discovered and developed. Not only technical challenges but the difficulty of integration with an installed base of rule-based systems and legacy IT systems must also be considered. Even though cryptographically signed private keys exist in blockchain system, there is still the threat of cybersecurity breach that needs to be addressed before the technology can be trusted.

Moreover, some areas of blockchain technology implementation are highly dependent upon support from regulatory authorities. In the near future, smart contracts are not likely to be enforceable in any court and few parties will be able to rely on smart contracts alone to structure all of the terms of a commercial transaction [85]. It nullifies the original value proposition of building automated and trustless systems using blockchain technology. The most significant benefits of blockchain adoption would come when numerous organizations and commercial entities begin to use blockchain and smart contracts to automate their multi-party business interactions.

8 Summary and Recommendation

Blockchain is a system and architectural design tool for recording transactions while providing an immutable and permanent audit trail of all transactions. Smart contracts are programmable logic coded on blockchain. They contain pre-agreed terms and conditions for any value transfer. Blockchain and smart contracts together can provide a high degree of security, transparency, anonymity, and autonomy for value transactions over the internet. Bitcoin currency is the first application of blockchain that has generated worldwide interest. A wide range of other potential enterprise applications has been identified in financial services, healthcare, manufacturing, and retail industries. The innovative interactions between blockchains, artificial intelligence, the Internet of Things, autonomous robotics, 3D printing, and virtual and augmented reality can significantly disrupt these industries and create whole new markets and economic modes.

However, the blockchain technology led opportunities currently have their fair share of challenges. Some of the biggest challenges in the widespread adoption of blockchain technology are an uncertain return on investment from the new technology, inadequate infrastructure, shortage of skills and talent, lack of governance model, lack of vision and leadership from management, and lack of proven business models. Other barriers and risks to adoption include current technological limitations of blockchain and smart contracts, organizational complexity and misalignment caused by blockchain adoption, system integration issues, interoperability issues, analytical hurdles, and increased cybersecurity risks. These challenges are situated not just within the organizations but across the industry value chain of suppliers, manufacturers, distributors, and regulators.

Supply chain and logistics industry are facing major challenges today. With increasing problem of food frauds and challenges in ensuring food safety, the demand for transparency and traceability has increased. Each organization has its system for handling transactions, leading to information discontinuity, delayed financial flow and higher risk for food fraud. Food ecosystem analysis showed that supply chain organizations are complex with interrelationships and interdependencies across the industry. It is therefore essential to understand the interactions among various components, stakeholders, and environment. Systems thinking approach would enable the industry participants to view and understand interactions between people and technology, holistically as socio-technical systems. Blockchain and smart contracts technological evolution in supply chain industry would influence its structure, critical success factors and the corresponding capabilities required to succeed in that industry. Therefore, blockchain technology proof of concepts would drive supply chain organizations to make important strategic decisions based on the adequacy of their capabilities that support the end value creation. Further, organizations will need to adapt their business models and organizational structures to effectively capture and deliver value created from blockchain technology adoption in supply chain industry. It is important for product managers to develop a long-term roadmap to identify advancements in blockchain security, consensus protocols, smart contract codes, etc., keep track of emerging standards, and also evaluate competing but less advanced offerings for the identified use cases.

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