Using a Group Decision Method to Judge the Value of Blockchain for an Enterprise in Supply Chain

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Abstract

Blockchain technology recently has become popular. This new way of transaction may bring many benefits for a supply chain. Because of its own attributes, a Blockchain network can create a peer to peer transaction environment which is decentralized, tamper proof, safe and reliable, with no need of a centralized trusted third party. What's more, each of the nodes in the network will have the same ledger providing a permanent record for each transaction in the whole net, which makes it nearly impossible to tamper the record. With this transparency of information, it is much easier to trace back the product information.

There are many companies that are studying the application of Blockchain on manufacturing, some have already had some tentative applications. However, it's not a universal technology and it is not suitable for every company in every situation. There are some barriers that need further study. For instance, the benefits mentioned above only happen when all the parties of the supply chain are in the same Blockchain network. If some of the nodes are out of the Blockchain network, or there are two different independent Blockchain networks in the supply chain, those advantages will be greatly discounted. Secondly with limited application cases, currently it's hard to know the actual effect. What's more, the benefit of Blockchain is "invisible". It won't improve the throughput directly like a new processing robot or picking system. It's hard to model and simulate the effect, which makes it hard to quantitative the benefit. To some extent

the evaluation will depend on experience of the evaluators. Many companies are still looking at and searching for a way to decide on whether Blockchain will benefit them and whether they should apply it to their system.

In addition to the technology itself, another difficulty associated with evaluating and making a Blockchain decision is that the influence of the Blockchain may impact different departments in the company. The experts/managers in one department may not familiar with other departments' needs. It is important to gather their opinions to evaluate the technology correctly.

It is hard to estimate whether a company should invest in Blockchain technology for supply chain. This thesis discusses a group-decision method to help make a decision like this. Applying AHP or ANP method, experts/managers in different department can gather their opinion of the Blockchain according to their knowledge and experience and get a reasonable quantitative evaluation of the effective use of the Blockchain technology to their company and make the decision whether it is more beneficial to apply it. The advantage of AHP/ANP method is that it divides the objective into subsets or hierarchies, which allows experts/managers focus on only one strategy level or department. So that they can make a better judgement in the areas they are familiar with. The contribution of this research is the development of a Blockchain specific set of decision attributes for supply chains that can be used as the basis for deciding on whether to implement Blockchain or not.

Keywords: Blockchain. Group decision method. Supply chain.

Chapter 1 Introduction

The purpose of this chapter is to describe the background, motivation, and objectives of this research. Firstly, the chapter provides the research background of Blockchain technology. Then briefly introduces the group decision method and research motivation. The research objectives are also briefly described. Finally, the thesis organization is provided to provide a clear guideline for readers.

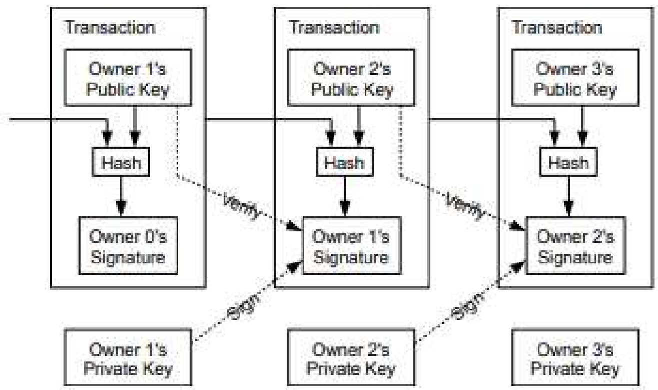
1.1 Research Background

Blockchain technology recently has become popular. Blockchain can provide security, anonymity, and data integrity without a trusted third-party organization controlling transactions [Yli-Huumo, et al., 2016]. Such attributes of Blockchain aroused the research interest. Blockchain is still new technology that is still developing, so there is not many real-world applications yet [Xu, 2017], especially in supply chain and manufacturing domain.

It's been a decade since one called Satoshi Nakamoto posted a white paper introducing Blockchain technology, and the application, Bitcoin, a digital currency implemented by Blockchain technology [Aste, et al., 2017]. As a decentralized transaction and data management technology [Yli-Huumo, et al., 2016], Blockchain is essentially a decentralized database using a chain of data blocks generated by cryptography. In each block it contains a batch of information of transactions used to verify the validity of the transaction information, as well as the information to generate the next block. The records of all the transactions are synchronized and shared by all the network participants [Aste, et al., 2017], called distributed ledger, which makes the records immutable and untampered. All the ledgers kept by all the participants are peer and the same. Falsifying a single participant in the network is futile since once the user connect to the network, the ledger will be checked, verified and updated. What's more, with the change of the hash value of that tampered block, all the transactions after this block in the network need to be tampered to match the hash value. This avoided the possibility of false accounting. Since the number of the ledgers is great enough to make sure the security of the ledger data, unless all the nodes in the network are destroyed.

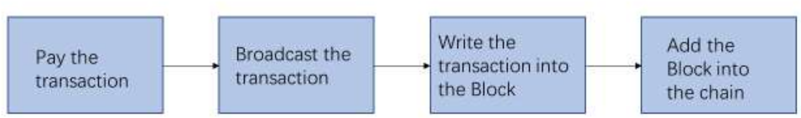
Asymmetric encryption modulo mathematics is the base of the cryptography behind the protocol. The asymmetric means that a "key" for encrypting a message or a transaction is different from the "key" to decrypt it [Apte and Petrovsky, 2016]. A participant in the network will have two "keys". One is called the public key, which can be used as an identity. No real-world identity is needed for transaction: this is a form of pseudonymity and anonymity. [Marco Conoscenti,2016] Another "key" is called the private key, used for signing the transactions. By using elliptic curve cryptography (ECC), The private key can generate the public key. The process is nonreversible, which means one cannot get the private key by using the public key. Then through hash function, the public key generates the address.

Figure 1: Chain of digital signatures [Nakamoto, 2008]



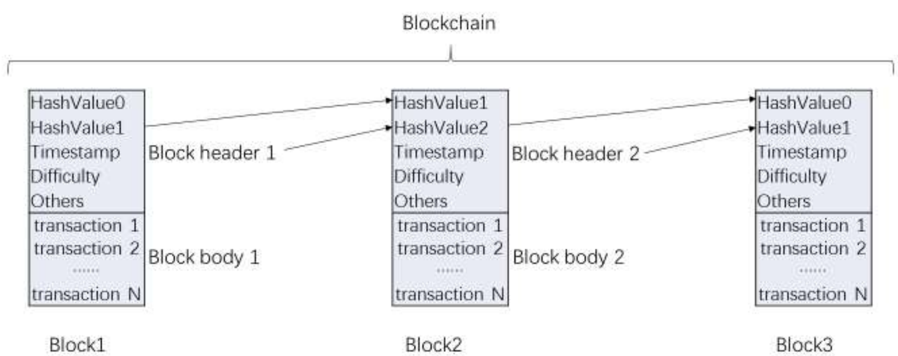
To accomplish a transaction from Alice to Bob, (1). Firstly, Alice will send the hash value, public key and digital signature to Bob. (2) Then Bob will verify the hash value, compare the public key with the address, compare the public key with the digital signature. If all the information match properly Bob will verify the transaction. (3) Then Bob will broadcast the transaction in the network. Once the broadcast is received by the "miners" and is written into the blocks, it means the block is added into the chain. At this point, the transaction is completed. To learn more about the principle and process, consider the book *Elliptic Curve Cryptography* [Hankerson, 2011].

Figure 2: Transaction Process



The parts that make up a Block are called block header and block body. The block header consists its timestamp, its hash value, the hash value of the previous block. The block body consists the information of the transactions during the time that the block is created. To create a new block, “miners” will calculate according to the current block header. Once a miner finds a new block, all the transactions during the time will be written into the block body and form a new block. To “mine” the blocks, computing power is needed from the “miners”. But the miners who found a block will be rewarded by the system so that they will gain rather than lose. For instance, in Bitcoin system “miners” will gain bitcoins directly as reward by finding a block.

Figure 3: Hashvalue and Chain of Blocks



As long as the majority of the computing power, which means more than half of the total, is under control of the honest miners, it can ensure that the system is secure [Nakamoto, 2008]. If a hacker has more than half of the computing power, he can control the whole Blockchain. Such situation is called the 51% attack, even if it’s not necessarily 51%. So, the large calculation that the mining process requires guarantees the security of the transaction. If the mining difficulty is a constant, theoretically, the greater the computing power is, the faster the miners will be to find a new block. To make the transaction rate stable, the difficulty of mining will increase when the overall computing ability improves. By applying such dynamic difficulty, no matter how many miners, and how much computing power in the network, the time to find a new block is roughly stable. In Bitcoin network, for instance, it roughly takes 10 minutes to generate a new block.

The new way of transaction may bring many benefits for supply chain. Because of its own attributes, a Blockchain network can create a peer to peer decentralized transaction environment with no need of a third party. What's more each of the nodes in the network will have the same ledger providing a permanent record for each transaction in the whole net, which makes it impossible to tamper the record. And with the transparency information, it is much easier to trace back the product information [Yli-Huumo, et al., 2016].

1.2 Research Motivation and Objectives

There are many companies are studying the application of Blockchain on manufacturing, some have already had some tentative applications. However, it's not a universal technology so far. It's not suitable for every company in every situation. There are some barriers that need further study. For instance, the benefits mentioned above only happen when all the parties of the supply chain are in the same Blockchain network. If some of the nodes are out of the Blockchain network, or there are two different independent Blockchain network in the supply chain, those advantages will be greatly discounted. Secondly with limited application cases, currently it's hard to know the actual effect. What's more the benefit of Blockchain is "invisible". It won't improve the throughput directly like a new processing robot or picking system. It's hard to model and simulate the effect, which makes it hard to quantitative the benefit. To some extent the evaluation will depend on the experience. So many companies are still looking about and searching a way to decide whether Blockchain will benefit and whether they should apply it to their system [Xu, 2017].

In addition to the technology itself, another difficulty to evaluate and make a decision is that the influence of the Blockchain may involve different departments in the company. The experts/managers in one department may not familiar with other departments. It is important to gather their opinions to evaluate the technology correctly.

In this thesis a group-decision method is adopted to help make these decisions. Blockchain has its benefits and barriers. It may create future competitive opportunities against other supply chains without Blockchain. But if the benefit or the improvement cannot reach the expectation it may cause a waste of the capital cost. What's more, as mentioned above, Blockchain is not a technology that is universal and suitable for all the systems and companies. How to evaluate, or forecast the performance of Blockchain, as a new technology, in the current system, there are a few difficulties. In this thesis the key research questions are:

1) What is the proper way to support the decision regarding whether Blockchain is suitable for a supply chain system?

2) How to interpret the views and opinions from different departments in a Blockchain decision making process?

With the development of simulation technology and computational modeling, now we have more accurate methods to obtain more objective prediction. However, there are many cases that required human judgment to measure intangibles. It happens that Blockchain evaluation is difficult to model. Analytic Hierarchical Process (AHP) and the Analytic Network Process (ANP) are methods applied in view of such situations [Saaty, 1999].

Applying AHP or ANP method, experts/managers in different department can gather their opinion of the Blockchain according to their knowledge and experience and get a reasonable quantitative evaluation of the effective of the Blockchain technology to their company and make the decision whether it is more beneficial to apply it. The advantage of AHP/ANP method is that it divides the objective into subsets or hierarchies, which allows experts/managers focus on only one strategy level or department. So that they can make a better judgement in the areas they are familiar with [Saaty, 1999].

In chapter 2 there will be a literature review of blockchain and group decision methods. In chapter 3 the model will be given to evaluate Blockchain technology. A case will be showed in chapter 4 and there will be conclusions and future research in chapter 5.

Chapter 2 Literature Review

The purpose of this chapter is to review papers about Blockchain and group decision making methods. The chapter starts by introducing Blockchain technology, including the history, features and applications of it. Then it explained why it is hard to evaluate and why subjective judgement is needed in evaluation of the benefit of Blockchain. Finally, it introduces some different group decision methods.

2.1 Brief History of Blockchain and Cryptocurrency

Many people heard of Blockchain from digital currency. The idea of anonymous digital trading system existed long time ago. In 1980s, a computer scientist and cryptography expert, Chaum David, introduced the idea of digital cash and blind signature technology [Chaum, 1983]. He founded DigiCash Inc in 1989, providing encrypted electronic payment system and allowing anonymous transactions of users. The shortage is the centralization of the system. It declared bankruptcy in 1998. In 1997 Adam Back introduced the idea of Hashcash [Back, 2002], a proof-of-work system. In the beginning, it is used to limit email spam and denial-of-service attacks. Now it is one of the core technologies in Bitcoin. In 1998, Wei Dai introduced B-money. Some people think it is the predecessor of Bitcoin.

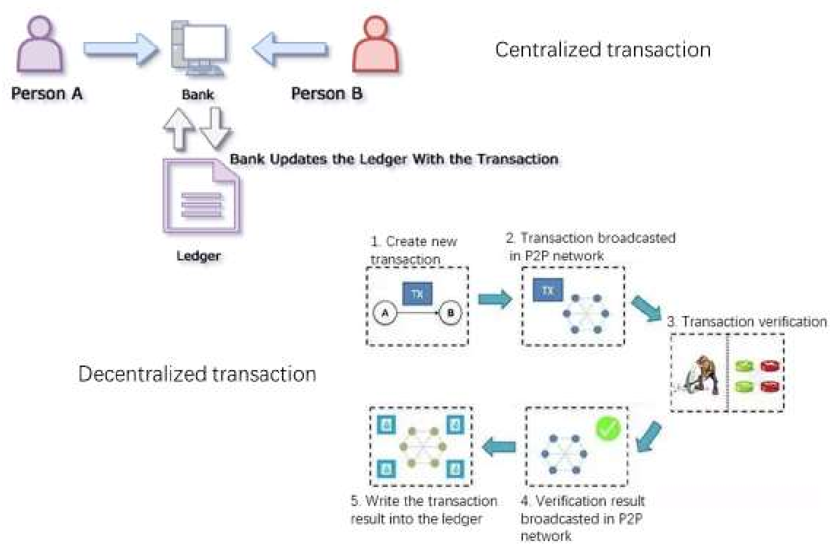
In 1991, two researchers, Haber and Stornetta, first proposed the core concept of Blockchain. They applied for a patent on the process in 1992. In October 2008, a whitepaper called “Bitcoin: A Peer-to-Peer Electronic Cash System” was published on an internet mailing list by “Satoshi Nakamoto”. There is a lot of speculation about his identity, so far there is no conclusion. We don’t even know if Nakamoto is an individual or an organization. By January 2009, version 0.1 of the Bitcoin software was released on Sourceforge [Benton and Radziwill, 2017]. This is the first time that the “Blockchain” concept has been proposed, and also the first time Blockchain has been applied. We can never ignore Bitcoin when discussing Blockchain. Until now, Bitcoin is still the most successful application case of Blockchain. With a market value of $70 billion and more than $9 billion of volume of transactions per hour (US dollars) [Bitcoin Price, 2019], the success of Bitcoin proved the effectiveness of Blockchain technology and its advantages to build a peer to peer cryptocurrency system.

2.2 Features of Blockchain technology

In this part I will compare the traditional centralized transaction system with the Blockchain system to show the advantage of Blockchain.

In a traditional centralized transaction system, a “trusted third party” is needed and the transactions are under the control and supervision of the third party. In the financial domain this middleman is usually a bank. There are a few potential shortcomings comparing with a Blockchain transaction system, and through the comparation between the traditional transaction and Bitcoin transaction, we can see the advantage and potential of Blockchain system:

Figure 4: Centralized Transaction and Decentralized Transaction



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https://ajithp.com/tag/centralized-vs-distributed-agledgers/

In such centralized system, both trading parties must register in the third party. In other words, the third party will know all the details about the transaction: the identities of both trading parties, the transaction amount and content, etc. Thus, it is impossible to complete a private transaction that only the two traders know [Crosby, 2016].

In a Blockchain system there's no third party involved. One transaction is supervised by the algorithm and the whole system. What's more, thanks to the elliptic curve cryptography (ECC), the information of the transaction will not be released to anyone else. A hash value will be generated and published, but under the existing conditions (computing power, computing duration), it is impossible to get the transaction information reversely. This ensures the anonymity of the transaction.

1. In a traditional system, since the fund will flow in and out of the third party, a cost may occur due to these redundant flows. Sometimes the bank will bear the cost, while sometimes the bank may charge.

While in a peer to peer system, once the transaction information is included in a Block, the transaction is authenticated and finished. There are no extra flows of the funds.

2. In a traditional system, when a transaction from A to B is finished, it is hard for B to find out where the fund comes from before A. It is hard to find any information about the fund before A, and no way to know its legality.

In a Blockchain system it is easy to trace back according to the hash value. In Bitcoin, one can trace back through the chain of blocks using the hash value and find out where it comes from. This mechanism ensures that every money has a legitimate source. (Here "legal" means it is proper in algorithm. It doesn't mean it is proper in law.)

3. Traditionally a transaction record can be tampered, technically, by the third party. That's why it is called trusted third party. Both parties of the transaction agree to process

the transaction through the third party because they trust the third party. However sometimes trust is not enough. Even if the third party is totally honest and will not rewrite the ledger, a system error or hacking event will cause the failure of the transaction or the error in the ledger. A failure in a node will cause a failure in the system.

Blockchain will ensure the correctness of the ledger compulsively. The blocks are linked by the hash values and the distributed ledger will make sure the correctness of the members in the network. To tamper a single node, one must tamper the whole system network.

These features above exist not only in cryptocurrency system but in all kinds of Blockchain systems.

2.3 Core Related Technologies Introduction

2.3.1 Distributed ledger

The blockchain system is a form of distributed ledger. A distributed ledger (DLT, also known as a shared ledger) is a consensus that replicates, shares, and synchronizes digital data geographically across multiple sites, countries, or organizations. The distributed ledger database is distributed across multiple nodes (devices) on the peer-to-peer network, each node copying and saving the same copy of the ledger and updating itself independently. There is no central administrator or centralized data storage. The data is stored in different servers and keep the servers communicate to ensure the accuracy and timeliness of the records of the transactions.

Distributed ledger is not equal to Blockchain technology. In a sense, DTL can be regarded as a “first step” towards Blockchain. The function that DTL realized is to store the data in different servers and the chain is not necessary [Abeyratne and Monfared, 2016].

All the nodes in the system have the same ledger. Before being able to transfer to other nodes, one node must update its ledger to keep pace with other nodes on the network. This ensures the security of the network since the tampering with a few nodes is meaningless. This also ensures the decentralization of the network.

2.3.2 Proof of work system and consensus mechanism

Consensus mechanism means a method that allows the nodes in the system reach a consensus complete the transactions. A Proof-of-Work (PoW) system (or protocol, or function) can be used as one kind of consensus mechanism. It is used by Bitcoin network. The concept was invented by Cynthia Dwork and Moni Naor as presented in a 1992 conference [Cynthia and Moni, 1992].

The work must be feasibly hard enough to prove the work. On the other hand, the service provider should have an easy way to check the work. This is a key feature of these schemes, the asymmetry. In Bitcoin, the PoW system, the dynamic difficulty ensures that the generation time of each block is approximately the same. Relying on the strong computing power provided by coin "miners", it is hard to attack the system by computing power, which ensures the security of the system.

However, for some smaller-scale Blockchain users, sometimes it is not an economy efficient choice, for such computing power requires much more electric power, space and equipment, comparing to the regular servers. So, people are searching different consensus mechanisms, like PoS (Proof of stack), DPoS (Delegated Proof of Stake), PBFT (Practical Byzantine Fault Tolerance), etc.

2.3.3 Hash function and elliptic curve cryptography

Hash function is an encryption algorithm. It can map arbitrary length messages to a shorter and fixed length value. In the Bitcoin system, it can map the Block, with block head and transaction information, to a 64-bit hash value. It is difficult to find a such value. The process to find such value is called "mining".

A cryptographic hash function has such a characteristic that it allows one to easily verify whether some input data map onto a given hash value, but if the input data is unknown it is deliberately difficult to reconstruct the original data by knowing the stored hash value. This characteristic ensures the confidentiality of the transaction information.

Elliptic-curve cryptography (ECC) is an approach to public-key cryptography based on the algebraic structure of elliptic curves over finite fields. ECC requires smaller keys compared to non-EC cryptography (based on plain Galois fields) to provide equivalent security. The disadvantage is that the implementation of encryption and decryption operations under the same length key takes longer than other mechanisms, but since the shorter key can be used to achieve the same level of security, the speed of the peer security is relatively faster. The use of elliptic curves in cryptography was independently proposed by Neal Koblitz and Victor Miller in 1985.

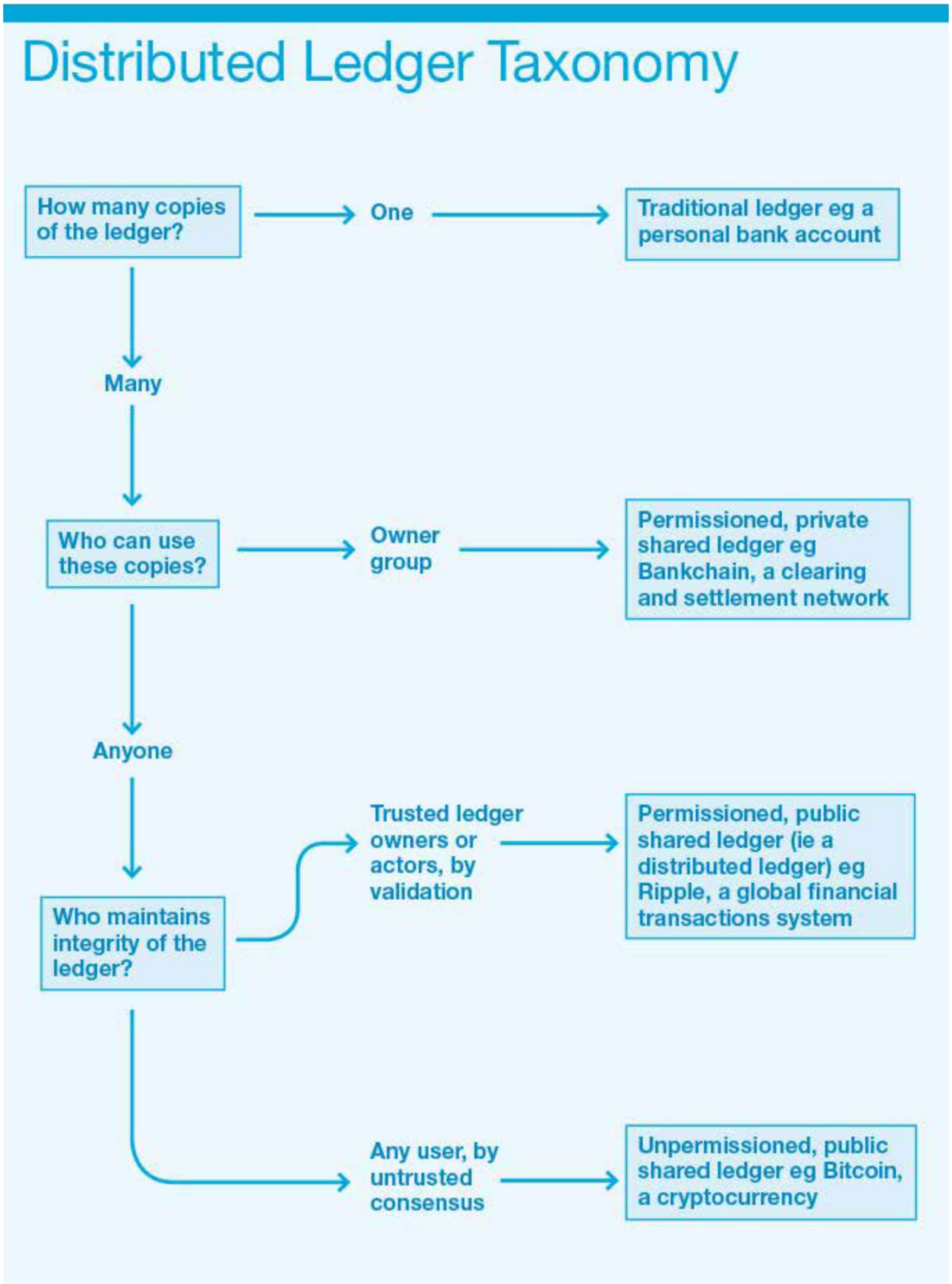
2.4 Classification of Blockchain

2.4.1 According to openness and network range

According to the openness and network range, we can divide Blockchain into the following categories: public chain, private chain and alliance chain.

The public chain is the earliest and most widely used Blockchain at present. All the nodes in the chain will participate in reading and writing of the ledger and the maintenance. The network is totally decentralized, and all the users are peer. This is the most common Blockchain at present. Both Bitcoin and Ethereum are public chains. Sometimes when discussing the characteristics of the Blockchain, the default is the characteristics of the public chains, like the anonymity and decentralization. The public chains rely on the encryption technology to ensure the secure of the network [UK Government Chief Scientific Adviser, 2016].

Figure 5: Distributed Ledger Taxonomy



Modified from: https://www.gov.uk/government/publications/distributed-ledger-technology-blackett-review

A private chain has a limited openness and decentralization. Usually it is a system used within an organization. Users in the system usually should provide identity authentication, which means there is usually no anonymity. From the perspective of network range, if the Bitcoin system is built in a LAN and doesn't link to the external internet, and all the users need to register, then we can regard it as a private chain. The access and usage of the data requires authority.

An alliance chain means that the system is half-open. It is in somewhere between the public chain and the private chain. Usually the number of the accounting nodes is certain. These nodes will maintain the ledger together and share the ledger. Other nodes can trade within the network, but they don't have the right of accounting.

2.4.2 Side chain technology: primary chain and side chain

A primary chain means a formal independent Blockchain network. Correspondingly, a side chain means such Blockchain "anchors" a primary chain. Entries from the primary Blockchain can be linked to and from the side chain. The side chain technology is used to solve the information island problem. One Blockchain can be both a primary chain as well as a side chain at the same time. One Blockchain can "anchor" another Blockchain, and it becomes a side chain. At the same time this Blockchain can be "anchored" by other Blockchains, and it can be a primary chain. Both primary chain and side chain are independent systems. They can exchange some data according to the protocol.

Applying the side chain technology, it is possible to build an interconnection chain system. It is possible for multiple chains to work together and communicate.

2.4.3 Hard forking technology: original chain and hard fork chain

In simple terms the hard-forking technology allow some of the Blockchain users create a branch chain from the original chain. After the forking, these two chains become two different independent chains. They share the same ledger history before the forking, but they don't have any relationship after the forking.

Sometimes it is hard to upgrade the original Blockchain. Maybe the cost to upgrade is too high or maybe most of the nodes don't agree with the upgrade. One example of the hard-forking is the Bitcoin Cash (BCH). In the Bitcoin system, with the growth of the trading volume, many people believe that the current block size (1 mb) is not enough for such a trading volume and this problem caused a high transaction fee. The discussion about the size of the blocks finally caused a hard-forking and created BCH, a similar cryptocurrency as Bitcoin but with larger size of Blocks.

2.5 Current Applications of Blockchain

2.5.1 Cryptocurrency and financial service

As mentioned above, currently the most successful and the most mature application domain is the cryptocurrency, like Bitcoin and Ethereum, and many others, Litecoin, Peercoin, etc.

While in financial domain, because of the permanent, comprehensive and public records, as well as the transaction without the need of trust, Blockchain can also give full play of its advantages. In the field of payment and liquidation, the traditional banking system requires more complex processes, especially the cross-border transfer: deposit bank, the other party bank, liquidating organization, offshore bank, etc. Usually these banks or organizations will have their own ledger, which will make more complex to verify the record. Using the Blockchain will make the cross-border payment more convenient without these processes. OKCoin launched OKLink using Blockchain to reduce the cost of the cross border small transfers.

Blockchain can also be applied in securities exchange to improve the efficiency and transparency. With automatic account synchronization and audit function, it will greatly reduce the ledger reconciliation cost of the participants. It also increases the efficiency and transparency in securities trading. Nasdaq has partnered with Chain for a pilot program to test the use of Blockchain in Nasdaq Private Market. [Laura Shin, 2015]

Another application is the insurance domain. Blockchain can ensure the authenticity and effectiveness of the information. It can help insurance companies trace the information of production, processing, sales, purchase, consumer complaint and other links easily through Blockchain, so as to effectively judge the incidence of quality defects of related products and formulate insurance proper insurance products. Blockchain also can do well in the insurance claims link and insurance anti-fraud field thanks to the smart ledger.

2.5.2 Supply chain and logistics chain

In many logistics chain systems, anti-fake is an imperative demand. One common traditional way for anti-fake is using RFID (Radio Frequency Identification) chips and NFC (Near Field Communication) technology. Once customer received the product, he can use a device with NFC function (a cell phone, for instance) to scan the RFID on the product. The shortage is that such anti-counterfeiting techniques are totally centralized. The one with authority may modify it at will. This is also a common problem of centralized systems. Decentralized peer nodes in Blockchain system will solve these problems and greatly increase the fraud cost.

Another field suitable for Blockchain is the supply chain finance. There is something already mentioned above. In supply chain finance some problems can be more prominent. Because there is no effective trust mechanism between banks and small and medium-sized enterprises, traditionally it is kind of hard for small and medium-sized enterprises to lend and finance, because these enterprises are always small in scale, unstable in development, low in credit and high in risk. The “core enterprise” in the supply chain always has strong financing ability. But is difficult to drive small-medium-enterprises in the supply chain because the banks will only consider the small-medium-enterprises themselves and will not consider the “core enterprise”. While using a Blockchain, the data of the “core enterprise”, the contract and the bill can be uploaded on the chain to make sure the reliability of the data. When facing the financing requests from small-medium-enterprises, banks and other financial institutions can not only evaluate the enterprise itself, but also consider the purchase intention from the “core enterprise”. With the credit strength and reliable trading chain, the “core enterprise” can endorse financing for small-medium-enterprises, so that to mitigate the difficulty of financing for small-medium-enterprises.

2.5.3 Others

Thanks to the characteristics of Blockchain, there are many other applications.

Intellectual property protection. No matter it’s picture, music, article, video or software, uploading it to the Blockchain can preserve the evidence and cannot be tampered. Some similar applications include the luxury anti-counterfeiting, jewelry anti-counterfeiting, document verification. Such application requires reliable RFID technology.

Credit record. Blockchain can provide transparent and untampered record online without third party. Personal biometric data can be used as ID, like fingerprint or eye iris. Different banks or organizations can use and share the credit record on the same Blockchain.

2.6 Limitations and drawbacks of Blockchain

Still Blockchain is a risky new technology for enterprise users. Many enterprises are still in the experimental application stage. Right now, there are still some challenges and limitations for Blockchain [Yli-Huumo, et al,. 2016].

2.6.1 Throughput

The potential throughput of Bitcoin network is currently maximized to 7 transactions per second. (Due to the size of each block). Other transaction processing networks are VISA (2000 tps) and Twitter (5000 tps).[7] When the frequency of transactions in Blockchain increases to similar levels, the throughput needs to be improved.

2.6.2 Latency

Though the Blockchain avoided the third-party latency, currently it takes roughly 10 minutes to create a block to complete the transaction, so that it can avoid the double-spend attack. To achieve efficiency in security, more time has to be spent on a block, because it has to outweigh the cost of double spending attacks.

2.6.3 Size and bandwidth

Currently, the blockchain size in the Bitcoin network exceeds 50,000 megabytes. When throughput increases to the level of VISA, the Blockchain may grow by 214PB per year. We can imagine that in the long run the net size will become too big to use.

However, we cannot decrease the size of the blocks since the smaller the block, the fewer transactions it can handle in each block. The Bitcoin community sets up that the size of one block is 1MB, and a block is created every ten minutes. Therefore, there is a limitation in the number of transactions that can be handled (500 transaction in one block on average). The debate over block capacity also led to a hard fork. If the Blockchain needs to control more transactions, the size and bandwidth issues have to be solved.

2.6.4 Security (51% attack)

If a miner follows the Bitcoin protocol as prescribed, we call him an honest miner. As mentioned, the Bitcoin protocol requires more than half of the miners to be honest [Ittay Eyal, 2013]. If an entity can have more than 50% of the computing power of the Blockchain system, such single entity would have full control of the majority of the network's mining hash-rate and would be able to manipulate Blockchain. The risk would be high when the Blockchain network is small and mining power is low. To overcome this issue, more research on security is necessary.

2.6.5 Wasted resources

To some extent, proof of work mechanism wastes a lot of resources on mining process. Take Bitcoin for example, currently mining Bitcoin costs huge amounts of electric energy (about $15million/day). With Proof-of-Work, the probability of mining a block depends on the work done by the miner. In order to compete against other miners and get the rewards, miners run mining machines on a large scale and consume huge amount of electricity. However, as introduced before, the computing power will not speed up the system. The generation frequency of the blocks is limited by the dynamic difficulty mechanism, and the capacity of a block is constant. So much computing power ensures the data security and system stability. The issue with wasted resources needs to be solved to have more efficient mining in Blockchain.

There are some alternatives in industry fields, such as proof-of-stake. Read this paper to get more information, Blockchain Without Waste: Proof – of – stack. [Saleh, 2019]

2.6.6 Privacy

In a blockchain network without a trusted distributed consensus network, all transactions are transparent and disclosed to the public. Therefore, the privacy in the blockchain is maintained by interrupting the information flow. The public can see all transactions, but there is no information to associate transactions with identities. The anonymity of blockchain has two sides. On the one hand, no one knows who the two sides of the transaction are. On the other hand, everyone knows that the transaction happened at a certain time.

2.6.7 Versioning, hard forks, multiple chains

Some potential technical risks. Blockchain technology itself still has some problems to be studied. Some companies and applications have offered some solutions. The result and effect are still yet to be insured and verified. Some of these challenges may have better application value after careful study and practice.

2.7 Evaluation of Blockchain

Many companies are trying to apply Block chain, a new decentralized transaction and data management technology, to the supply chain management because of the good characteristics of the Block chain: decentralized network, safe data, anonymous transaction. However, as a new technology, people would like to know whether it would be profitable in some real cases. Here we want to discuss how can we determine whether it is feasible or profitable to apply the Block chain technology in a company and what factors should we consider. We hope to find to develop a scheme for companies to evaluate whether they should apply the Block chain or not.

There are some difficulties that make it hard to evaluate the profit and benefit of applying Block chain:

1. A new stage technology

As mentioned, the Blockchain technique itself is still in its early stage in manufacturing. After that most of the application of Blockchain is in financial domain. So, if an industrial manufacturing company has interests in the new technology, there's no evidence showing it's beneficial. Right now, there are many companies that have already started applying Blockchain in their supply chain. However, the performances are regarded as commercial confidentiality and still we don't have useful data about the performance of the Blockchain application. We know theoretically the benefit of Blockchain, but we don't know specifically how well it works and we don't have the data.

2. Difficult to quantify

Unlike some "touchable" technology like new robot or new flow line, Blockchain is invisible.

For instance, one company want to apply some kind of new robot to help handle and the warehouse and help pick up items. We know the parameter of the robot: speed, load capacity, electricity cost, etc. And we have the algorithm that manage the robots' behavior. To make these parameters more visualized, it's better to transfer these data into one single result like profit increased or labor saved. We can simulate the performance of the new system with these warehouse robots using the data above on the computer, and we can know how many more items can be picked. Then we can compare the simulation result with the current system performance and find out the difference. The improvement of the picking speed can be transferred into the throughput capacity. The improvement of the picking accuracy can be transferred as the reduced cost of the wrong picking. We can easily make the decision whether to adopt the technology by comparing these results.

However, for the Blockchain, we cannot do such a similar process. The benefit of adopting Blockchain is indirect. For instance, the Blockchain can improve the traceability. In Walmart it typically took approximately 7 days to trace the source of products. With the Blockchain, it's been reduced to 2.2 seconds. However, it is hard to translate these numbers into more visualized parameters like time or money being saved. This will improve decision making about inventory management and repairs. But there is a problem. Although we know it can make it easier to make a proper and better decision with a fast, traceable system, it is hard to figure out what extent can the traceable system affect the decision making. And then it's also hard to estimate the profit that a better decision making, or inventory management can make. So, we can see that there are benefits of the Blockchain that are indirect. In another word, for some of the technology, the improvement is direct, and we can calculate the theoretical benefit measured in terms of money saved, or time saved. And then we can compare it to the current number to help deciding whether the company should adopt it. But for

Blockchain it is hard to transfer the benefit into "the money saved" or "the labor time saved", which makes it hard to compare with the current system.

3. Lack of performing data

This point is caused because of the previous two points. Because there is not much public data about the Blockchain performance, we cannot take other companies' performance as reference. Also, because Blockchain is an "invisible" technique, it is hard to simulate or calculate the performance and benefit of it. If we want the performing data, the only way is to apply and run it.

Many decision-making methods require the performance parameters to make the comparison. What we need is to find one method that makes a good decision using limited data.

From above we can see that right now the Blockchain technique still has its limitation. If applying Blockchain is gainful, then company may hope to apply it as early as possible to gain the initiative to improve the competitive. However, because there can be capital cost, training cost or other costs, it can be risky if the Blockchain cannot bring the expected improvement. Thus, a fast and concise method or algorithm is needed for companies to help evaluate the Blockchain technology. That’s why an enterprise need a scientific method to make a decision whether to apply Blockchain in their own business.

2.8 History of Group Decision Making Methods

- Expert evaluation method (expert grading method)

This method is widely used in the situations that heuristic evaluation cannot be applied. Experts from the different domains of the company will evaluate the benefit of Blockchain according to their understanding of the current system and the principle of the Blockchain. What they need to do is to understand the effect of the Blockchain and how it will influence the system. There can be a few different domains that the Blockchain may influence the system. For instance, the supply chain, quality control, logistics, information system, etc. The weight for each object comes from discussion. Each expert will give a score for each object. And then we can collect these opinions and find out the predicted "score" of Blockchain.

Formula: $$T = \sum_{i=1}^{m} \sum_{j=1}^{n} w_j x_{ij}$$

T: total score.

m: assume there are m experts.

n: assume there are n factors.

wj: the weight for factor j.

xij: the score that the expert i gave for the factor j.

The formula is simple enough, but we need to find out the factors, or the performance measurements that we can use to evaluate the influence of the Blockchain. Or in another word, we need to find out the factors that will be influenced by the application of Blockchain.

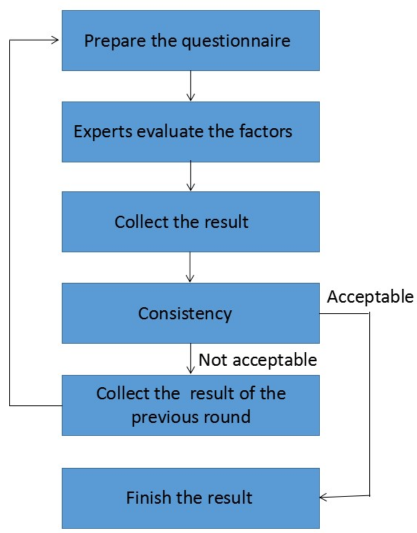
We can score the factors in the lowest level. For instance, from 1 to 10, grading less than 5 means negative influence and grading more than 5 means positive influence.

The advantage of expert grading method is that this is the most straightforward and concise method. However, a high degree of risk and error can be expected, because of the uncertainty. An accidental error or one misunderstanding grading will affect the result significantly and there's no guarantee for the consistency. To evaluate a new technology like Blockchain, which will change the whole system, the expert grading method is not enough.

- Delphi method

Similar to the expert evaluation method, Delphi method also need the experts to give a weighted score for different factors. The difference is that the experts will grade the factors anonymously. They not only give the score, but also need to explain how they get the score from the given data and resource. If the consistency of the result is not acceptable, then another round of the questionnaire will be handed out. The scores and explanations from the previous round will also be handed out as reference. After the iteration it is more likely to get a consistent result.

Figure 6 Delphi Process



The advantage is that by using the iteration the Delphi improved the consistency of the result. The problem is that the accuracy is still not enough. Another thing is the assumption that all the factors are independent, while in reality some factors will influence others. It cannot give a good solution when factors are not independent. The iteration is a good way to get a unified result when there are more than 1 expert. But a more accuracy method is needed [Skulmoski, et al., 2007].

- AHP (Analytical Hierarchy Process) and ANP (Analytic Network Process) method

AHP is a group decision-making method proposed by Dr. Thomas L. Saaty in 1970s. It structures a decision problem into a hierarchy with a goal, decision criteria and alternatives. The ANP method is a more general form of the AHP method [Saaty, 2006].

The AHP helps decision makers find one that best suits their goal and their understanding of the problem, Rather than prescribing a correct decision. The advantage of an AHP/ANP model is that it can “handle data limitations and intangibles based on individual or collective judgment of the situation”. As discussed above, to evaluate Blockchain, a pilot technology, we are right now lack of usage data. And in different application scenarios, its functions and importance will vary. We lack quantitative tools and the advantages of Blockchain are scattered in many aspects. With AHP/ANP model we can create a scientific evaluating system based on the actual situation and the opinions from experts from different fields of the company.

Specific circumstances will be explained in the following chapters.

Chapter 3: Model and Application

The purpose of this chapter is to explain how to use AHP and ANP methods evaluating Blockchain. After each method an assumed application case is provided and a brief conclusion of each evaluation.

3.1 Use AHP (Analytical Hierarchy Process) method to Evaluate Blockchain

Routine steps of AHP method evaluating Blockchain [Saaty, 2006]

As mentioned before, AHP/ANP methods depend on experts' subjective evaluation. To evaluate Blockchain, before the process the experts to make evaluations should firstly have enough understanding of Blockchain and know the characteristics of Blockchain and expected impact to a manufacturer in a supply chain, as well as the current status of relevant aspects of the company and what the company want from Blockchain.

Step1. Set an objective. The extent and importance of the advantages of Blockchain would be different for different companies. Companies' objective may vary. Some companies may hope to solve the problems in current system, some may just want to avoid possible technological backwardness in the future. Different objectives can cause different decision results. Also, as a reference the objective can make it easier for experts to grade properly. A common overall objective is to improve the profit or increase the competitive. It will be better if the company has some clear sub objectives.

2. Then structure the hierarchy. Structure the hierarchy from the top levels to the level at which it's easy enough to make a choice.

Table 1: Intensity of Definition Importance

Intensity of Definition Importance		Explanation
1	Equal Importance	Two activities contribute equally to the objective.
2	Weak	
3	Moderate plus	Experience and judgement slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favor one activity over another
6	Strong plus	
7	Very strong demonstrated importance	Experience and judgement very strongly favor one activity over another. Its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

3. Construct a pairwise comparison matrix of the relevant contribution or impact of each element on each governing criterion in the net higher level. Pairs of elements are compared with respect to a criterion in the superior level.

Table 2 Sample Matrix for Pairwise Comparison

C	A1	A2	...	Aj	...	An
A1	1					
A2		1				
...			...			
Ai				aij		
...					...	
An						1

Assume the pair-wise comparison matrix A= a_{ij} , where a_{ij} stands for the relative importance of criteria Ai over Aj. For all i and j, it is necessary that a_{ii} =1 and $a_{ij} = 1/a_{ji}$. n is the number of factors in the matrix.

4. Obtain all judgments required to develop the set of matrices in step3.

5. Collecting the pairwise comparison data. Obtain the priorities and test the consistency.

6. Perform steps 3, 4 and 5 for all levels and clusters in the hierarchy.

7. Use the hierarchy to weight the priority vector with standard weights and sum all weighted priority entries, which correspond to those in the net lower level, and so on.

Assume the pair-wise comparison matrix A= a_{ij} , where a_{ij} stands for the relative importance of criteria Ai over Aj.

Then we normalize the matrix: C= c_{ij} , $c_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$

Determine $\lambda_{\max}$: $\lambda_{\max} = \frac{\sum_{i=1}^{n} \left(\frac{\sum_{j=1}^{n} c_{ij}}{c_{ii}} \right)}{n}$

AW= λ W

8. Evaluate consistency for the entire hierarchy.

The consistency index (CI) and consistency ratio (CR) are used to estimate the consistency of the pair-wise comparisons.

CI = $\frac{\lambda_{\max} - n}{n-1}$. CR = $\frac{CI}{RI}$

RI is the average index for randomly generated weights. If numerical judgments were taken at random from the scale 1/9, 1/8, ..., 1/2, 1, 2, 3, ..., 9, then using a reciprocal matrix we would have the following average consistencies for different-order random matrices.

Table 3: Random Index (RI)

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3.2 AHP Application Example

Assume there is a food processing plant Company A. The upstream suppliers are some other food processing plants, warehouses and some farms. The downstream consumers are distribution center, retailers and wholesalers. Right now, their transactions are still based on a traditional system: companies in the supply chain will check accounts only with their direct upstream and downstream nodes. These companies have their own independent accounting records. This draws back the logistics management of the supply chain as a whole. To resolve the problem, now some of the nodes in the supply chain has already applied Blockchain technology, yet still many others are looking about. The manager of this distribution wants to make a decision whether to apply the Blockchain technology and join in the Blockchain network.

We assume that the Company A is a hierarchic system. There are several independent and parallel departments in the enterprise. Since the AHP method is suitable for a hierarchic structure system, we determine to use AHP method to make the decision.

Step 1.

Firstly, the experts, manager and engineers, who are going to make the evaluation and decision, should have a comprehensive understanding of both schemes. Usually decision makers are already been aware of the schemes being used. So, experts need to know the characteristics of Blockchain in detail and have a general analysis of the impact on the company in mind. It is recommended to have a detailed communication with the Blockchain service provider.

Secondly experts are supposed to determine the objective of this decision making. Blockchain is a "general" technology. As mentioned in the previous chapter, Blockchain has different types and characters. Different companies may have different reasons to apply Blockchain. Maybe they want to solve some problems that cannot be solved by existing systems, or they are looking at some of the improvements that Blockchain can bring.

We assume that after the discussion, the experts of the Company A decide that the objective is to improve the benefit of the company. The benefit is reflected in many ways: better quality control, lower cost, lower risk or higher consumer satisfaction.

The Company A will apply Blockchain technology if the estimated result shows that they can take good profit with reasonable cost.

Step 2.

In this step, experts need to predict the factors that will be influenced by the new Blockchain system, and what will change in the company, including positive changes and negative ones. According to the characteristics of Blockchain, different departments will be affected to some extent. List these affects and build a hierarchic structure.

Assume that here is the hierarchy structure of the elements:

Table 4: Assumed hierarchy structure.

Overall Profit	Quality Control	Return cost
		Food safety
		Inspection
	Logistics	Transaction
		Transparency
	Consumer Satisfaction	Product Info
		Supply Stability
		Product Quality

	Information management	Marketing Prediction
		Information Gathering
		Information security
	Human resource	Training
		Labor cost
	Capital cost	
	Outbound environment	

Step 3,4

Collect the pairwise comparison from the experts. Making the pairwise comparison layer by layer. For instance, we assume that the score of “Quality Control” over “Logistics” is 2. It means that the experts think that, considering the overall profit, “Quality Control” is slightly more important than “Logistics”. Such result is not from only one expert, but the assessment from all the experts.

Experts will do all the pairwise comparison for every layers and elements. Assume that here is the result. The conclusion of the other elements and layers will be shown in the following steps. The reason why I have such assumption and my personal comparison between a Blockchain and a traditional system will be explained in the following steps.

Table 5: Assumed Experts' opinions of the first layer

Overall Profit	QC	Lo	CS	IM	HR	CC	OE
Quality Control	1	2	1/2	7	5	1	1/2
Logistics	1/2	1	1/5	2	2	8	1/2
Consumer Satisfaction	2	5	1	9	9	1	1/2
Information management	1/7	1/2	1/9	1	1	1/3	1/9
Human resource	1/5	1/2	1/9	1	1	1/3	1/8
Capital cost	1	1/8	1	3	3	1	1/2
Outbound environment	2	2	2	9	8	2	1

Assume that the expert's opinions are all collected. When opinions are inconsistent, we can use the Delphi method mentioned above to improve the consistency.

Step 5

Collecting the pairwise comparison data. Obtain the priorities and test the consistency.

For instance, the first layer of the structure:

Normalized matrix, row sums and overall priorities.

Table 6: Normalized matrix of the first layer

Overall Profit	QC	Lo	CS	IM	HR	CC	OE	Row Sums	Priority vector
Quality Control	0.146	0.180	0.113	0.219	0.172	0.068	0.155	1.053	0.150
Logistics	0.073	0.090	0.045	0.063	0.069	0.545	0.155	1.040	0.149
Consumer Satisfaction	0.292	0.449	0.226	0.281	0.310	0.136	0.155	1.850	0.264
Information management	0.021	0.045	0.025	0.031	0.034	0.023	0.034	0.214	0.031
Human resource	0.029	0.045	0.025	0.031	0.034	0.023	0.039	0.226	0.032
Capital cost	0.146	0.011	0.113	0.094	0.103	0.068	0.155	0.690	0.099
Outbound environment	0.292	0.180	0.452	0.281	0.276	0.136	0.309	1.927	0.275

Determine $\lambda_{\max}$:

$$\begin{bmatrix} 1.053 \\ 1.040 \\ 1.850 \\ 0.214 \\ 0.226 \\ 0.690 \\ 1.927 \end{bmatrix} \div \begin{bmatrix} 0.146 \\ 0.090 \\ 0.226 \\ 0.031 \\ 0.034 \\ 0.068 \\ 0.309 \end{bmatrix} = \begin{bmatrix} 7.204 \\ 11.566 \\ 8.182 \\ 6.840 \\ 6.565 \\ 10.125 \\ 6.235 \end{bmatrix}$$

$$\lambda_{\max} = \frac{\sum_{i=1}^{n} \left(\frac{\sum_{j=1}^{n} c_{ij}}{c_{ii}} \right)}{n} = 8.1025$$

CI = $\frac{\lambda_{\max} - n}{n-1}$ =0.1837

CR = 0.665/1.32 = 0.1392

We get the consistency value and the priority vector. Do the same for all the criteria and get the vectors of priorities. For the sake of the simplicity, the calculation of other criteria is omitted here. The assumed values and their calculation results will be shown in step7.

Step 6

Perform step 3, 4, and 5 for all levels and clusters in the hierarchy.

If we decide this consistency value of one priority vector acceptable, then go to step7. If not, go back to step 3 to collect the pairwise comparison again. It is important to explain to the experts what a consistency value means and why the result is not accepted.

Step 7.2.1 Quality Control

For the next hierarchy, the computing process is the same. Assume here is the assumed pairwise comparison from step3 and the computing result of priority and consistency from step5:

Table 7 Assumed Experts' opinions of the Quality Control

Quality Control	RC	FS	In	Priority
Return cost	1	1/2	2	0.297
Food safety	2	1	3	0.539
Inspection	1/2	1/3	1	0.164

λ_{max} =3.01 CI = 0.0056

There are many cases that some food product from the same source will need a recall due to the virus alert, parasite alert or excessive harmful substances. The blockchain technology can create a complete and smooth information chain and each participant is unable to deny any part of the transaction. For hand-to-hand paperwork network, it will be extremely slow to trace back to the resource and recognize which product comes from the affected area. With Blockchain the trace back process can be reduced to as short as a few seconds. Also, with Blockchain it is easy to query to the detailed information about the product like when and how it is transferred to where. This will help to monitor the food safety and reduce the inspection cost.

(When there are only 2 rows, λ_{max} =2 and CI=0.)

Table 8 Assumed Experts' opinions of the Return Cost

Return cost	BC	TA	Priority
Blockchain	1	4	0.80
Traditional	1/4	1	0.20

Table 9 Assumed Experts' opinions of the Food Safety

Food safety	BC	TA	Priority

Blockchain	1	3	0.75
Traditional	1/3	1	0.25

Table 10 Assumed Experts' opinions of the Inspection

Inspection	BC	TA	Priority
Blockchain	1	2	0.67
Traditional	1/2	1	0.33

intensity: Blockchain: 0.752. Paperwork: 0.248

Step 7.2.2 Logistics

Table 11 Assumed Experts' opinions of the Logistics

Logistics	Transaction	Transparency	Priority
Transaction	1	5	0.83
Transparency	1/5	1	0.17

Table 12 Assumed Experts' opinions of the Transparency

Transparency	BC	PW	Priority

Blockchain	1	6	0.86
Tradition	1/6	1	0.14

For the logistics part, the criteria "transaction" means the time spent to complete a single transaction. This may influence the lead time of an order. Since the consumer of this company contains some retailers that may have some high frequency small orders, the improvement of transaction speed may have obvious positive influence on the throughput. The "transparency" means whether it is easy for managers to review and examine the transaction content. Or the manager may also review the upstream transactions (transactions between suppliers and the suppliers' suppliers) if it is allowed in the agreement. This is an important way for the company to know the raw material.

Table 13 Assumed Experts' opinions of the Transaction

Transaction	BC	PW	Priority
Blockchain	1	9	0.9
Tradition	1/9	1	0.1

intensity: Blockchain: 0.983. Tradition: 0.017.

Step 7.2.3 Consumer Satisfaction

Table 14 Assumed Experts' opinions of the Consumer Satisfaction

Consumer Satisfaction	PI	ST	PQ	Priority
Product Info	1	1/7	1/8	0.060
Supply Stability	7	1	1/6	0.236
Product Quality	8	6	1	0.705

λ_{max} =3.549 CI = 0.274

In this group the "Product Info" reflects the information that the consumer can achieve while purchasing the products. With Blockchain it is easy for customer to track the information through the whole supply chain to the resource and get all the storing, transportation, processing information that they need easily. And the "Rapid response" means that in case of any supply changes resulting from climate change and market demand changes, the company can response rapidly to the changes and provide a stable supply of the goods. For the "Product Quality" factor, neither Blockchain nor paperwork will influence the it. So, the priority will be equally 0.5.

Table 15 Assumed Experts' opinions of Product Information, Supply Stability and Product Quality

Product Info	BC	TA	Priority	Supply Stability	BC	TA	Priority	Product Quality	BC	TA	Priority
Blockchain	1	9	0.90	Blockchain	1	8	0.89	Blockchain	1	1	0.5
Tradition	1/9	1	0.10	Tradition	1/8	1	0.11	Tradition	1	1	0.5

Intensity: Blockchain: 0.617. Tradition: 0.383.

Step 7.2.4 Information Management

Due to the increasingly complexity of the supply chain and the danger of the supply chain uncertainty, it is important for the firms in the supply chain to have the ability to process the information [Su and Zhang, 2011][Fan, et al., 2016]. Information is one of the most valuable resources for manufacturers to build a competitive supply chain [Nakasumi, 2017].

There are a few different kinds of problems of current information system in supply chain that Blockchain technology may solve or relieve:

(a) Demand forecast information asymmetry (Bullwhip effect). The bullwhip effect will cause over-producing, high inventory and products expiration [Nakasumi, 2017]. To avoid bullwhip effect as well as some other supply chain risks, information sharing is very important [Su and Zhang, 2011] [Fan, et al., 2016][Nakasumi, 2017][Yang, 2016]. Blockchain technology will provide convenient information sharing method without third party or consideration of code schemes problem [Nakasumi, 2017]. This will help to abate the bullwhip effect.

(b) Fraudulent information and tampered data. Due to the complexity of the supply chain, enterprise prestige and morality cannot be guaranteed. Some node enterprise may tamper the data or release fake information for self-interest. Fortunately, one of the core problems solved by Blockchain technology is to build a consensus foundation for secure information transaction without worrying about data tampered when any nodes cannot be trusted in the whole network [Tian, 2016]. All actions performed by system participants are recorded on the chain, and the continuously expanding chain makes it computationally challenging to change any block without detection [Zhu, et al., 2018].

(c) Information secure. The information management also face to the risk of hacker and virus. It may cause data missed and information system paralysis. Under the condition of the sufficient computing power, each of the node in the network is safe. In a Blockchain network a hacker can manipulate Blockchain only if his computing power is more than 51% of the whole net. It is impossible to hack only 1 node because the ledger and transaction information are saved in all of the nodes in the network. [Yli-Huumo, et al., 2016] Blockchain miners' proof of work structure and distributed ledgers data greatly reduce the possibility of data theft, data corruption and the leakage of the sender's identity [Alcazar, 2017].

(d) Utilization rate of information. Due to the risks above some enterprises don't trust other cooperation partners in the supply chain and they give up utilizing the information they can get [Su and Zhang, 2011]. Within a Blockchain network all of the parties are not necessarily trust each other or even know each other [Nakasumi, 2017]. Companies don't need to worry the trust issues since the authenticity of the data is guaranteed by the network structure.

Table 16 Assumed Experts' opinions of the Information Management

Information Management	MP	IG	IS	Priority
Marketing Prediction	1	3	7	0.681
Information Gathering	1/3	1	2	0.216
Information security	1/7	1/2	1	0.103

λ_{max} =3.004 CI = 0.002

The "marketing prediction" reflects the prediction accuracy. With Blockchain we can not only trace back to the source, but also can get the downstream transaction information easily, if permitted in the contract. So, we can not only know the fluctuation of the direct buyer, but also the further downstream. This will help to make a proper prediction of the demand. For the "information gathering" it means the cost and time to collect enough data that the company needs. In a paperwork system it takes a lot more time to get useful information. The "information security" reflects the risk and the lost for a disclosure of information.

Table 17 Assumed Experts' opinions of the Marketing Prediction

Marketing Prediction	Bc	PW	Priority	Information Gathering	Bc	PW	Priority	Information Security	Bc	PW	Priority
Blockchain	1	4	0.80	Blockchain	1	8	0.89	Blockchain	1	7	0.88
Tradition	1/4	1	0.20	Tradition	1/8	1	0.11	Tradition	1/7	1	0.13

Intensity: Blockchain: 0.828   Paperwork: 0.172

Step 7.2.5 Human Resource

Table 18 Assumed Experts' opinions of the Human Resource

Human Resource	Training	Labor cost	Priority
Training	1	1/8	0.11
Labor Cost	8	1	0.89

To apply a new network system definitely a training cost is required to let the workers get used to the new system. While after the training the new Blockchain transaction system is supposed to be more convenient than the paperwork-based transaction system and so that the labor hour should be reduced.

Table 19 Assumed Experts' opinions of the Training and Labor Cost

Training	BC	TA	Priority	Labor Cost	BC	TA	Priority
Blockchain	1	1/8	0.11	Blockchain	1	2	0.67
Tradition	8	1	0.89	Tradition	1/2	1	0.33

Intensity: Blockchain: 0.608 Traditional: 0.392.

Step 7.2.

Table 20 Assumed Experts' opinions of the Capital Cost

Capital Cost	BC	TA	Priority	Outbound Environment	BC	TA	Priority
Blockchain	1	1/9	0.10	Blockchain	1	1/9	0.10
Tradition	9	1	0.90	Tradition	9	1	0.90

Obviously, the capital cost is required only if the company applies the new technology. The "Outbound Environment" reflects the "trust barriers" in the supply chain. There might be some firms that choose not to trust the new Blockchain network or they have already joined in another Blockchain network. In that case all the benefits of Blockchain will be discounted. All of the benefits that the Blockchain may provide require that both of the vendor and purchaser are in the same Blockchain network.

Step 7.3

Table 21: Total weighted vector of priority for the intensities

	Quality Control	Logistics	Consumer Satisfaction	Information Management	Human Resource	Capital Cost	Outbound Environment
Priority	0.150	0.149	0.264	0.031	0.032	0.099	0.275
Blockchain	0.752	0.983	0.617	0.828	0.608	0.10	0.10
Tradition	0.248	0.017	0.383	0.172	0.392	0.90	0.90

Then calculate the total weighted vector of priority for the intensities.

Table 22 Overall priorities

	Quality Control	Logistics	Consumer Satisfaction	Information Management	Human Resource	Capital Cost	Outbound Environment
Blockchain	0.113	0.146	0.163	0.025	0.020	0.010	0.028
Tradition	0.037	0.003	0.101	0.005	0.013	0.089	0.248

Add the rows to get the overall priorities of these two networks.

Blockchain = 0.505, Tradition = 0.495.

Step 8

The consistency has been calculated in each sub-step above.

Conclusion

From the result we can see that the Blockchain is a little better than the traditional network. We can see the total weighted vector of priority in the last part above, it shows that although in many options Blockchain shows advantages, while in "outbound environment" it greatly draws back the score. It implies that the experts/managers still worry about the number of the parties in the Blockchain network.

3.3 ANP (Analytic Network Process) method

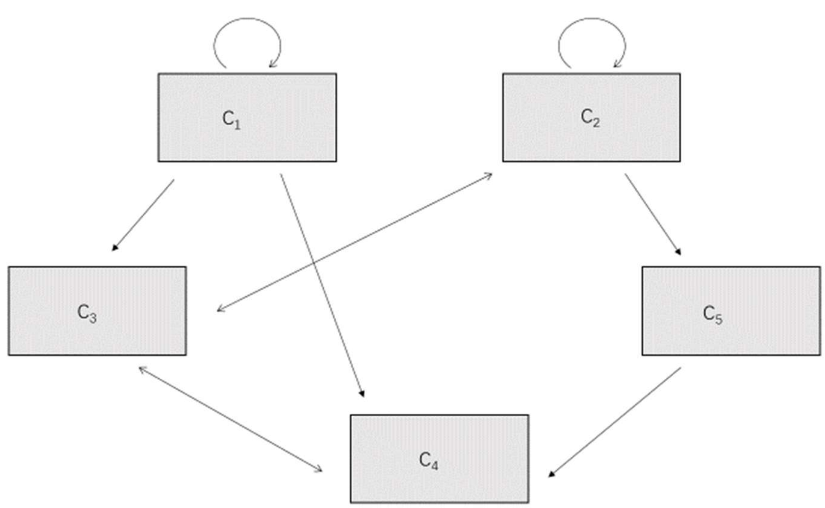
In many systems, the decision problem cannot be structured hierarchically because they involve the interaction and dependence of higher-level elements on lower level elements [Saaty, 2006]. For instance, the information security is important for all kinds of supply chain. However, there are thresholds for the importance of the security levels. No matter a traditional system or a Blockchain system, the risk of information fraud cannot be completely avoided, even if Blockchain can significantly reduce the risk of information fraud. Once both systems can meet the information security needs of the company, the importance of information security will decrease sharply. As Dr. Saaty said, “Feedback enables us to factor the future into the present to determine what we have to do to attain a desired future.” [Saaty, 2006]

The ANP model can help make a better decision when the importance of the alternatives, applying Blockchain or not, determines the importance of the criteria.

Same as the AHP method, to evaluate Blockchain, it is important to know what we want and what we can get from Blockchain. Also, it is important to inspect what cost is needed to apply Blockchain.

Create a structure showing the relationship of these advantages and costs according to the synergy.

Figure 7: An ANP structure sample



Each component C_h may contain different elements.

Table 23 The supermatix of a network

	C1	C2	……	CN
C1	W11	W12	……	W1N
C2	W21	W22	……	W2N
……	……	……	……	……
CN	WN1	WN2	……	WNN

C1 C2 , ……CN : Components in the structure.

Wij : a block of the supermatrix.

$$W_{ij} = \begin{bmatrix} W_{i1}^{j1} & W_{i1}^{j2} & \cdots & W_{i1}^{jn_j} \\ W_{i2}^{j1} & W_{i2}^{j2} & & W_{i2}^{jn_j} \\ \vdots & & \ddots & \vdots \\ W_{in_i}^{j2} & W_{in_i}^{j2} & \cdots & W_{in_i}^{jn_j} \end{bmatrix}$$

W_{ij}: a principal eigenvector of the influence (importance) of the elements in the ith component of the network on an element in the jth component.

Establish pair-wise comparison matrices using the 9-point priority measurement scale. See table 1 before.

4. Determine the pairwise comparisons for the model elements. Calculate the eigenvalues and eigenvectors of the comparison matrix to obtain relative weights.

5. Check the consistency of the matrix.

6. Form the unweighted super matrix. Multiply unweighted super matrix by cluster weights to form weighted super matrix.

3.4 ANP Application Example

Use the same assumption mentioned in the AHP method.

Step 1.

Clear the objective. According to the assumption the objective of the company is to evaluate the potential profit of Blockchain technology considering the cost.

Step 2.

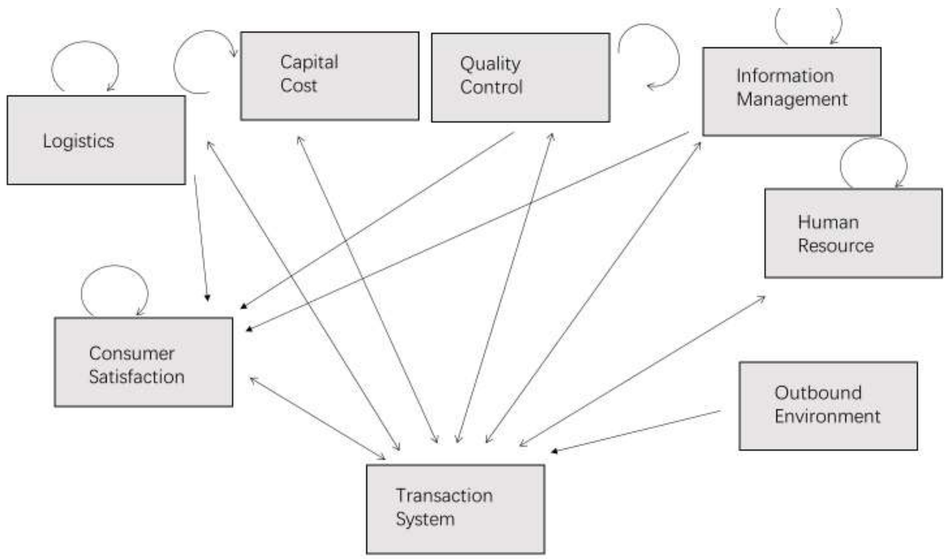
The structure is just an example. In different situation and companies, the structure should be different. We can list the criteria and the elements first.

Table 24 Assumed structure

Overall Profit	Quality Control	Return cost
		Food safety
		Inspection
	Logistics	Transaction
		Transparency
	Consumer Satisfaction	Product Info
		Supply Stability
		Product Quality
	Information management	Marketing Prediction
		Information Gathering
		Information security
	Human resource	Training
		Labor cost
	Capital cost	
	Outbound environment	
	Transaction System	Blockchain
		Traditional Approach

Then the structure of the criteria should be decided.

Figure 8: Assumed structure



The criteria are the same as the AHP model. Many criteria have loops connecting themselves. The reason is that the importance is influenced by the extent of the criteria. For instance, if the current information system is already perfect and Blockchain only reduce a little bit of the information fraud risk, which is considered insignificant, then the importance of “Information Management” criteria will be considered very low. Or for another instance, the cost of Blockchain infrastructure/equipment is so low that the company considers the cost insignificant, then the importance of “Capital Cost” will be considered very low.

We assume that the “Logistics”, “information Management”, and “Quality Control” not only influence the alternatives, “Transaction System”, but also influence “Consumer Satisfaction” because we assume credible delivery, authentic quality and detailed product information will improve the satisfaction of the downstream users.

Step 3.

Determine the main components weights.

Table 25 Assumed Experts’ opinions with respect to Capital Cost

With respect to Capital Cost		
	Capital Cost	Transaction System
Capital Cost	1	1/3
Transaction System	3	1

Normalize the matrix and get the weights:

Table 26 Normalized matrix of the Capital Cost

With respect to Capital Cost			
	Capital Cost	Transaction System	Weights

Capital Cost	0.25	0.25	0.25
Transaction System	0.75	0.75	0.75

Calculate the consistency. The process is the same as the AHP method.

Inconsistency Index = 0.

Same process to other components:

Table 27 Assumed Experts' opinions with respect to Quality Control

With respect to Quality Control				
	Quality Control	Consumer Satisfaction	Transaction System	Weights
Quality Control	1	2	2	0.5
Consumer Satisfaction	1/2	1	1	0.25
Transaction System	1/2	1	1	0.25

Inconsistency Index = 0.

Table 28 Assumed Experts' opinions with respect to Logistics

With respect to Logistics

	Logistics	Consumer Satisfaction	Transaction System	Weights
Logistics	1	1/3	1/2	0.164
Consumer Satisfaction	3	1	2	0.539
Transaction System	2	1/2	1	0.297

Inconsistency Index = 0.003

Table 29 Assumed Experts' opinions with respect to Information Management

With respect to Information Management				
	Information Management	Consumer Satisfaction	Transaction System	Weights
Information Management	1	1	1/2	0.261
Consumer Satisfaction	1	1	1	0.328
Transaction System	2	1	1	0.411

Inconsistency Index = 0.0275

Table 30 Assumed Experts' opinions with respect to Human Resource

With respect to Human Resource			
	Human Resource	Transaction System	Weights
Human Resource	1	1/2	0.33
Transaction System	2	1	0.67

Inconsistency Index = 0

Table 31 Assumed Experts' opinions with respect to Consumer Satisfaction

With respect to Consumer Satisfaction			
	Consumer Satisfaction	Transaction System	Weights
Consumer Satisfaction	1	1/3	0.25
Transaction System	3	1	0.75

Inconsistency Index = 0

Table 32 Assumed Experts' opinions with respect to Transaction System

With respect to Transaction System

	Consumer Satisfaction	Logistic	Capital Cost	Quality Control	Information Management	Human Resource	Weights
Consumer Satisfaction	1	5	1	2	9	9	0.368
Logistic	1/5	1	8	1/2	2	2	0.192
Capital Cost	1	1/8	1	1	3	3	0.154
Quality Control	1/2	2	1	1	7	5	0.204
Information Management	1/9	1/2	1/3	1/7	1	1	0.040
Human Resource	1/9	1/2	1/3	1/5	1	1	0.042

Inconsistency Index = 0.284

Summarize the weights data above:

Table 33 Weights Summary

Control Matrix Node	Capital Cost	Quality Control	Logistics	Information Management	Human Resource	Consumer Satisfaction	Transaction System
Capital Cost	0.250	0.000	0.000	0.000	0.000	0.000	0.154
Quality Control	0.000	0.500	0.000	0.000	0.000	0.000	0.204
Logistics	0.000	0.000	0.164	0.000	0.000	0.000	0.192

Information Management	0.000	0.000	0.000	0.261	0.000	0.000	0.040
Human Resource	0.000	0.000	0.000	0.000	0.330	0.000	0.042
Consumer Satisfaction	0.000	0.250	0.328	0.328	0.000	0.250	0.368
Transaction System	0.750	0.250	0.411	0.411	0.670	0.750	0.000

Step 4.

Determine the pairwise comparisons for the model elements. For brevity, I will use the same assumption as in the AHP part:

Table 34 Assumed Experts' opinions of the Quality Control

Quality Control	RC	FS	In
Return cost	0.286	0.273	0.333
Food safety	0.571	0.545	0.500

Inspection	0.143	0.182	0.167

Table 35 Assumed Experts' opinions of the Return Cost

Return cost	BC	TA	Priority
Blockchain	1	4	0.80
Traditional	1/4	1	0.20

Table 36 Assumed Experts' opinions of the Food Safety

Food safety	BC	TA	Priority
Blockchain	1	3	0.75
Traditional	1/3	1	0.25

Table 37 Assumed Experts' opinions of the Inspection

Inspection	BC	TA	Priority
Blockchain	1	2	0.67

Traditional	1/2 1	0.33

Multiplying the weight from the control matrix, we'll get:

Table 38 Quality Control against Transaction System

		Quality Control			Transaction System	
		Return Cost	Food Safety	Inspection	Blockchain	Traditional
Quality Control	Return Cost	0.143	0.137	0.167	0.204	0.204
	Food Safety	0.286	0.273	0.250	0.204	0.204
	Inspection	0.072	0.091	0.084	0.204	0.204
Transaction System	Blockchain	0.200	0.188	0.168	0.000	0.000
	Traditional	0.050	0.063	0.083	0.000	0.000

For other criteria, the same approach is performed. Then we get the super matrix as table 41.

Table 39 Supermatrix

Control		Capital	Quality			Logistics		Information			Human		Consumer			Outbound	Transaction	
Matrix Node		Cost	Return	Food	Inspection	Transaction	Transparency	Marketing	Information	Product	Training	Labor	Product	Supply	Product	Environment	Blockchain	Traditional
Capital		0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.154	0.154
Quality Control	Return Cost	0.000	0.143	0.137	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.068	0.068
	Food Safety	0.000	0.286	0.273	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.068	0.068
Logistics	Transaction	0.000	0.000	0.000	0.000	0.137	0.137	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.096	0.096
Information Management	Marketing	0.000	0.000	0.000	0.000	0.000	0.000	0.177	0.174	0.183	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.013
	Information	0.000	0.000	0.000	0.000	0.000	0.000	0.059	0.058	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.013
	Product	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.029	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.013
Human	Training	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.020	0.000	0.000	0.000	0.000	0.021	0.021
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Consumer Satisfaction	Product Info	0.000	0.159	0.063	0.100	0.109	0.109	0.209	0.191	0.034	0.000	0.000	0.016	0.005	0.024	0.000	0.123	0.123
	Supply	0.000	0.048	0.063	0.050	0.109	0.109	0.034	0.036	0.209	0.000	0.000	0.109	0.035	0.032	0.000	0.123	0.123
	Product	0.000	0.044	0.125	0.100	0.109	0.109	0.085	0.101	0.085	0.000	0.000	0.125	0.210	0.194	0.000	0.123	0.123
Outbound Environment		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Transaction System	Blockchain	0.075	0.200	0.188	0.168	0.370	0.353	0.329	0.366	0.362	0.074	0.449	0.675	0.668	0.375	0.000	0.000	0.000
	Traditional	0.675	0.050	0.063	0.083	0.041	0.058	0.082	0.045	0.053	0.596	0.221	0.075	0.083	0.375	0.000	0.000	0.000

Table 40 Limit super matrix

Control Matrix Node		Capital Cost	Quality Control			Logistics		Information Management			Human Resource		Consumer Satisfaction			Outbound Environment	Transaction System	
			Return Cost	Food Safety	Inspection	Transaction	Transparency	Marketing Prediction	Information Gathering	Product Quality	Training	Labor Cost	Product Info	Supply Stability	Product Quality		Blockchain	Traditional
Capital Cost		0.063	0.064	0.064	0.064	0.056	0.056	0.064	0.064	0.064	0.043	0.043	0.063	0.063	0.063	0.000	0.062	0.062
Quality Control	Return Cost	0.040	0.040	0.040	0.040	0.035	0.035	0.040	0.040	0.040	0.027	0.027	0.040	0.040	0.040	0.000	0.039	0.039
	Food Safety	0.056	0.057	0.057	0.057	0.049	0.049	0.056	0.056	0.056	0.038	0.038	0.056	0.056	0.056	0.000	0.055	0.055
	Inspection	0.031	0.032	0.032	0.032	0.028	0.028	0.032	0.032	0.032	0.022	0.022	0.031	0.031	0.031	0.000	0.031	0.031
Logistics	Transaction	0.039	0.040	0.040	0.040	0.035	0.035	0.039	0.039	0.040	0.027	0.027	0.039	0.039	0.039	0.000	0.038	0.038
	Transparency	0.031	0.032	0.032	0.032	0.028	0.028	0.032	0.032	0.032	0.022	0.022	0.031	0.031	0.031	0.000	0.031	0.031
Information Management	Marketing Prediction	0.007	0.007	0.007	0.007	0.006	0.006	0.007	0.007	0.007	0.005	0.005	0.007	0.007	0.007	0.000	0.007	0.007
	Information Gathering	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.003	0.003	0.005	0.005	0.005	0.000	0.005	0.005
	Product Quality	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.004	0.004	0.004	0.000	0.004	0.004
Human Resource	Training	0.007	0.007	0.007	0.007	0.006	0.006	0.007	0.007	0.007	0.005	0.005	0.007	0.007	0.007	0.000	0.007	0.007
	Labor Cost	0.007	0.007	0.007	0.007	0.006	0.006	0.007	0.007	0.007	0.005	0.005	0.007	0.007	0.007	0.000	0.006	0.006
Consumer Satisfaction	Product Info	0.065	0.066	0.066	0.066	0.058	0.058	0.066	0.066	0.066	0.045	0.045	0.065	0.065	0.065	0.000	0.064	0.064
	Supply Stability	0.067	0.068	0.068	0.068	0.059	0.059	0.067	0.067	0.068	0.046	0.046	0.067	0.067	0.067	0.000	0.066	0.066
	Product Quality	0.101	0.103	0.103	0.103	0.090	0.090	0.102	0.102	0.102	0.070	0.070	0.101	0.101	0.101	0.000	0.099	0.099
Outbound Environment		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Transaction System	Blockchain	0.192	0.196	0.196	0.195	0.170	0.170	0.193	0.193	0.194	0.132	0.132	0.192	0.192	0.192	0.000	0.189	0.189
	Traditional	0.110	0.113	0.113	0.112	0.098	0.098	0.111	0.111	0.112	0.076	0.076	0.110	0.110	0.110	0.000	0.108	0.108

To capture the transmission of influence along all possible paths of the super matrix, raise the super matrix to powers until it converges, and get the limit super matrix. For specific reasons and proof, Dr. Saaty has explained in his book [Saaty, 2006].

Table 42 shows the final super matrix of the results. The priorities, or weights of the two alternatives of the transaction system, “Blockchain” and “Traditional Approach”, are 0.199 and 0.108 respectively.

Conclusion

The conclusion of the ANP method is that, after synthesizing the opinions of the experts, the company consider it more beneficial to apply Blockchain (0.199) than using the traditional transaction system (0.108). We can see that the result drawn from AHP and ANP methods are different. The difference of the result from ANP process is more obvious than the difference of the result from AHP process. The reason for this phenomenon is that in ANP method, “Logistics”, “Quality Control” and “Information Management” are not only criteria influenced the selection of “Transaction System”, but also influenced the “Customer Satisfaction”. Since “Customer Satisfaction” is a pretty important criterion, this adds the weights of those criteria invisible.

Chapter 4: Conclusions

4.1 Summary

This study started from a literature review of the Blockchain technology and explained why it is needed to have a systematic evaluation method to make the decision whether Blockchain can bring expected benefits to the company.

Here are the summary reasons of using AHP/ANP method to evaluate Blockchain. There are many group decision methods. However, there are some special points in the evaluation of Blockchain. At present, as a pilot technology, the data of the real practice of Blockchain is scarce. Blockchain has not been universally applied and relevant data are still regarded as business secrets. This makes horizontal comparison difficult. Secondly it is almost impossible to build physical or mathematical models to reflect the advantages and disadvantages. This makes it difficult to use the method of simulation experiment. And it is unable to conduct small-scale testability application, because the effect of Blockchain is related to the linkage of the whole network. Also, enterprises have different concerns. Some of important advantages of Blockchain are not worth mentioning for some companies. Considering these characteristics of Blockchain, the evaluation of Blockchain relies heavily on the experts' understanding of the technology and their subjective judgment and experience. Under such circumstances, a scientific evaluation method is needed to decompose the evaluation into comparisons that is easy to judge, and assign the weights of the criteria reasonably. Thus AHP/ANP is a method that can be found to meet the requirements above.

Here is the summary process of evaluating Blockchain using AHP/ANP. Firstly, find out the experts/engineers/decision makers in the relevant departments considering the characteristics of Blockchain firstly. Usually it includes experts of logistics, supply chain management, information system management and diplomatic department. (Purchasing and after-sales). Experts will decide what evaluation structure is more appropriate for the company according to the focus of the company and the actual structure of the company. For a simple hierarchy structure, apply AHP method. For a more complex structure, apply ANP method. List all the possible criteria and build the structure. Do the pairwise comparison and collect the data. Test the consistency of the data. If the consistency is insufficient, re-collect the data. If the consistency accepted, get the weight of the criteria. Finally calculate the result of the matrix and get the score of Blockchain.

4.2 Contributions

Firstly, the study discussed how to view Blockchain from the perspective of a company, and the difficult of making an evaluation based on the literature review. There have been many scholars have discussed the potential application scenarios and benefits of Blockchain in multiple domains and industries. And there have been many leading companies managing to apply Blockchain to their industries. However still there are many companies on the sidelines, because there are not research helping companies to predict the returns of Blockchain. Based on the literature review and the properties of Blockchain, the paper discussed the possible reasons for the hesitation and how to use a right approach to evaluate Blockchain that is hard to evaluate. This shifts the focus from “What can Blockchain do?” to “What Blockchain can bring to my company?” In chapter 3 the study has a more detailed discussion about the characteristics of Blockchain from a company’s perspective. This can help us look at Blockchain technology more comprehensively from another perspective.

Secondly the study discussed how to make scientific decision systematically by applying group decision making method, even in the extreme lack of application examples and experimental data. In most cases, if possible, detailed experiments and data can help decision makers make more correct decisions. So, for many application evaluations of new technologies, researchers focus on building a proper simulation or using the analogical data scientifically. However, for Blockchain, enterprises may not be able to find analogical data, and it's unable to construct an effective mathematical model. It seems that little research has studied the situations that decisions highly rely on experts' subjective opinions. Even if there is no data, it is needed to collect correct opinions comprehensively and allocate the appropriate weights of the criteria, when important decisions need to be made. This study takes Blockchain as an example to discuss the feasibility of using AHP/ANP method as an approach of enterprise to evaluate new technology.

Thirdly, through the assumed examples this study discussed what is the impact and value of Blockchain on an enterprise, as an individual, in a supply chain. Many studies have discussed how Blockchain improves the supply chain as a whole. However, in reality, many enterprises are more concerned about their own local optimum rather than the overall optimum of the supply chain system. At present, there are few studies on how Blockchain improve the interests of individual enterprise. This thesis provides some insights into this.

4.3 Limitations and Future Research

The application case of the study is based on rational assumptions. But the problem is that even if a real company can try the method, it's hard to know in a short time whether the decision is correct or not. After all, the results of decision-making only show that the application of Blockchain is a beneficial or disadvantageous for the company after the opinion of experts in the company. The aim of the method is to help companies make reasonable decisions and evaluations, rather than quantifying how much dollars can Blockchain be converted in to. If there are multiple companies applying the methods and if we can collect their result of applying Blockchain then the method of evaluation can have statistical significance.

This study analyzed using ANP/AHP method to evaluate Blockchain when data is hard to get mand models are hard to build. It is possible to use such method to evaluate other technologies. The practicability of expanding the application of the evaluation method can be studied.

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