Bachelor’s degree Thesis

Bachelor's degree in Industrial Technology Engineering

Using Blockchain and Big Data in the supply chain

REPORT

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ETSEIB

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ABSTRACT

As supply chain grows in complexity, any tools helping with this issue will be considered useful. Whether by helping providing some clarity to the supply chain or by attempting to reduce its complexity.

The main goal of this project would be to analyze and try to project/predict the impact of the implementation of the Blockchain and Big data technologies to the current supply chain. Both technologies will be studied thoroughly to allow the reader to grasp a more concrete notion of how they work, what can they achieve but more specifically in the supply chain field and their respective limits. Then a study will be made around what it’s thought to be the more immediate sectors to be able to benefit from such implementations, these would be the alimentary sector, the pharmaceutical sector and the luxury sector.

Summary

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1. Preface

1.1. Project Genesis

The idea of this project was provided by my tutor Ernest Benedito, among two other projects. Although my knowledge about Blockchain was particularly poor at the time, I had heard of Bitcoin and not much more, I considered a good opportunity to learn about it and a use of it in supply chain was news to me, making it seem quite interesting. After a few months of this decision I can say it's been a great choice, as finding the subject interesting makes the Job easier.

The main challenge I have found doing this project has been finding the right balance regarding the depth of each subject, I didn't want to talk too superficially but at the same time I wanted to avoid too many ramifications. As the three main fields we'll be studying are wide enough to provide several thesis of their own; I've found myself quite often reading or writing about particular aspects that I couldn't find their place in this project due to the fact that I wanted this project to have a logical string connecting different subjects, including all this information would have made this project dense, unrelated and confusing.

1.2. Prerequisites

In order to write this project, having had a technical background has proven useful, specifically Programing language knowledge in order to understand Blockchain technology, Electronics when reading about sensors and data transmission and all the information received about logistics. All three areas covered by the three school's subjects "Informatics", "Electronics" and "Organization and Management" respectively.

2. Introduction

The concept of Supply Chain has been around for over a hundred years. During this time it has been evolving with the arrival of new technologies, in the last thirty years its complexity has exploded as the computing power got unlocked and the arrival of the internet, yet the supply chain remains centered upon the distributed models.

The last fifteen years have been no exception to humankind progress, and new technologies have arisen. As it would be crazy to try to mention them all and ridiculous to attempt to study them in a single paper, we'll be focusing on two main new technologies, Blockchain and Internet of things.

The goal of this project is to understand said technologies, identify why and how they could be useful to use in the supply chain.

A fair warning to the reader is in order, as the title may turn out to be misleading with the mention of Big Data. Big Data or Big Data analysis as such will only be briefly mentioned in this project. As these are quite broad subjects we'll be studying in order to keep a linear narrative, we'll only be approaching the preliminary phase of Big Data by studying Internet of Things, which can be considered the acquisition of data necessary to employ Data science and Big Data as such.

2.1. Project target

Therefore, the objectives of this study are the following ones:

- To analyze in depth how Blockchain works
- To understand what can Blockchain bring to the supply chain
- To learn real adaptations of Blockchain used in different supply chains

The underlying objective throughout this project is to give the reader a broad vision of the importance of the new technologies in a quite traditional field such as supply chain.

3. The Blockchain

Take 4-5 technologies, combine them in a way and you roughly have the Blockchain. We'll be focusing mainly on three of them, sha256, hascash, and the peer to peer network.

Hashcash is a proof-of-work algorithm, which has been used as a denial-of-service counter measure technique in a number of systems. A hashcash stamp constitutes a proof-of-work which takes a parameterizable amount of work to compute for the sender. The recipient (and indeed anyone as it is publicly auditable) can verify received hashcash stamps efficiently. Hashcash was invented by Adam Back in 1997.
Proof of work mechanism in order to establish consensus on global decentralized network. Sha0, an early predecessor of sha256 was first published in 1993 , hashcash has existed since 1997 as we've seen both technologies have existed for decades; what Satoshi Nakamoto did, was combine this with a peer to peer network to create a digital cash system. In order to better understand the Blockchain as a whole, we'll firstly do a brief study these algorithms and then we'll be looking at Blockchain as a whole, how it works, what it needs in order to work properly and what are the main benefits it brings to the table.

3.1. SHA summarized

One of the more important cryptographic hash functions, sha256; consists in an algorithm that no matter what file your put in it, it will return you a 256 bit long string, a useful way to think of this is as a fingerprint of data. What does come out, appears random, however it is deterministic, if you change a single bit from the initial file you inserted, a completely different 256 bit long will come out.

For practical purposes, we'll be taking a closer look to SHA-1 rather than SHA-256, since all we want to do is to get a general idea of the amount of work it takes to do proof of work, and looking at SHA-1 helps us accomplish this goal without getting into a more complex algorithms who does roughly the same.

This is the basic process behind hashing – simply convert a number into binary then perform a set of simple functions that operate through basic standard transistor and bus processes such as AND, XOR, NOT, Rotate &OR. This is part of the reason that ASIC, or application specific chips can be designed that optimise hashing. Here Below we can see what SHA-1 algorithm does step by step [1]:

1 – Create five variables

H0 - 01100111010001010010001100000001
H1 - 11101111110011011010101110001001
H2 - 10011000101110101101110011111110
H3 - 00010000001100100101010001110110
H4 – 11000011110100101110000111110000

2- Then choose a word to hash. In this case we will choose the word "CRYPTO"

3- Convert the word to ASCII – "American Standard Code for Information Interchange". Each letter has a number assigned to it.

CRYPTO – 67-82-89-80-84-79

4- Convert ASCII code to binary –

CRYPTO – 01000011-01010010-01011001-01010000-01010100-01001111

5- Join characters and add 1 to the end.

CRYPTO – 0100001101010010010110010101000001010100010011111

6- Add zeros to make the message equal to 448 mod 512 – (modular arithmetic just like a clock except with 512 hours). So a 48 bit message with the added one will need to have 399 zeros added to the end, and if the message was 64 characters (or 512 bits) long you would need 447 zeros.

0100001101010010010110010101000001010100010011111000000000000000000000000-
00000000000000000000000000000000000000000000000000000000000000000000000000-
00000000000000000000000000000000000000000000000000000000000000000000000000-
00000000000000000000000000000000000000000000000000000000000000000000000000-
00000000000000000000000000000000000000000000000000000000000000000000000000-
00000000000000000000000000000000000000000000000000000000000000000000000000-
0000

7- Add the original message length into the 64 bit field left over after the 448 modular arithmetic. The message is 48 characters long which expressed in binary is 110000. So the below is added to the end of the message in part six.

0000000000000000000000000000000000000000000000000000000000110000

8- Break the message up into sixteen sections of 32 characters/bits.

01000011010100100101100101010000
01010100010011111000000000000000

```
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000000000
00000000000000000000000000110000
```

9- Transform the 16 x 32 character bit words into 80 words using a step loop function. First select four words for the first run through the loop which are strings 1,3,9 &14 from step 8.

The next time through the loop we will use words 2,4,10,15 from stage 8.

The next process is to XoR the words together. Xoring is just a basic computational function that gives the output of q only if the two inputs both have a 1 in that position – if they don't the output is zero.

```
The function is ((14 XOR 9) XOR 3) XOR 1) which is:
00000000000000000000000000000000
XOR
01000011010100100101100101010000
Is
01000011010100100101100101010000
10- perform a left rotate on the numbers – i.e. move the left most digit to the right.
So
01000011010100100101100101010000
Becomes
10000110101001001011001010100000
```

This process is then repeated until there are 80 words, or strings of 32 bits.

10- The next step is to run a set of functions over the words in a specific order operating off the five variables that were set in step 1. The functions combine AND, OR & NOT operators combined with left shifts.

The end result is that you are left with five variables of:

```
H0 – 01000100101010010111000100110011
H1- 01010000111001010011100001011000
H2-11110000010110000100011000111101
H3-01001011111101111111000111100101
H4-01000010110110011100101001001011
```

11- Convert the H variables into hex:

```
H0- 44a97133
H1- 50e53858
H2- f058463d
H3 - 4bf7f1e5
H4 - 42d9ca4b
```

12- Join the variables together to give the hash digest:

```
44a9713350e53858f058463d4bf7f1e542d9ca4b
```

In the case of SHA-256 chips have been specifically designed to optimize the iterations throughout the steps to increase the speed of creating a hash from an input. In the case of mining this means you can calculate more hashes per second by iterating through the nonce and extra nonce parameters and have a higher probability of winning the block reward.

As an illustrative example:

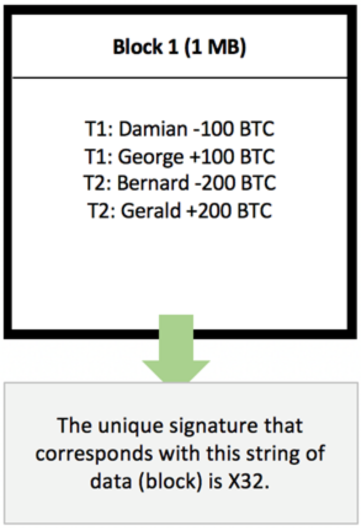

Figure 3.1.1 Hash obtained in a transaction block

3.2. Hashcash

Hashcash is a proof-of-work algorithm, which has been used as a denial-of-service counter measure technique in a number of systems. A hashcash stamp constitutes a proof-of-work which takes a parameterizable amount of work to compute for the sender. The recipient (and indeed anyone as it is publicly auditable) can verify received hashcash stamps efficiently. Hashcash was invented by Adam Back in 1997.

The principle is as follows, every time you want to send a message to the message board, the system will ask you to do some parametricable work, it will take the user no more than a second, but in the case of the spammer who aims at millions of different people it will take him millions of seconds.

This is what we can understand as proof of work.

Verification can be done by a human eye (count leading 0s) even with availability of common preinstalled command line tools such as sha1sum. The algorithm works with a cryptographic hash, such as SHA1, SHA256 or coming SHA3 that exhibits 2nd-preimage resistance.

3.3. Linking both technologies together through a peer to peer network

Blockchain technology was used for the first time by Satoshi Yakamoto. As we're now more comfortable with SHA and Hashcash notions, we're a step closer to understand Blockchain. We'll be focusing on Satoshi Yakamoto's work in order to get a first approach to this mixture of technologies.

The principle of bitcoin being, 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. These two willing parties transact through the use of electronic coins. We define an electronic coin as a chain of digital signatures, each party transfers the coin to the next by digitally signing a hash of the previous transaction and the public key of the next owner and adding these to the end of the coin.

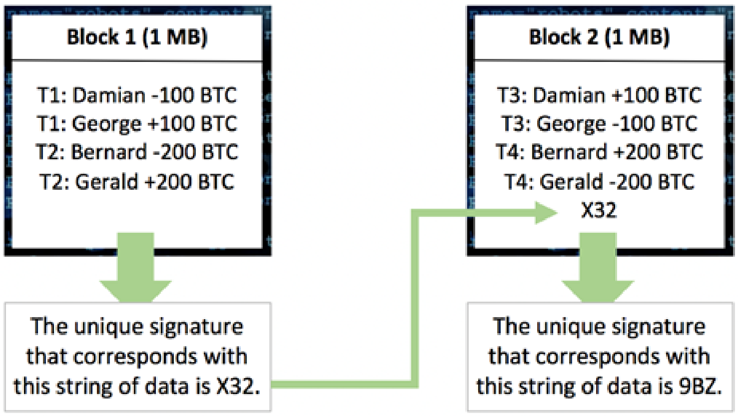

Figure 3.2.1 Linking two transaction blocks through a hash

A payee can verify the signatures to verify the chain of ownership. An easy problem to spot is, that the payee can't check if one of the payers double-spend the coin. In traditional currency systems, this is guaranteed through the use of a third trusted party. One way to prevent this double spending would be being aware of all transactions.

“To accomplish this without a trusted party, transactions must be publicly announced, and we need a system for participants to agree on a single history of the order in which they were received. The payee would need to know that the majority of participants agree he is the first one to receive the coin from the payer.” [3]

After understanding this need for a unified truth about all the transactions that happened in the network since day 1, we can move to understanding the basic mechanisms of Blockchain at its simplest form. This unified truth is built as its name suggests is a chain, adding a link one by one to the chain, a link being a portion of the truth or history of all the transactions that happened within the network, updating it every time a link is added. A link is added on average every ten minutes, adding then all the transactions that happened within these 10 minutes to the unified truth. At this point a question begins to form, does the chain get bigger by itself? Who adds this links to the chain and detains the truth? wouldn't that be the third party who the very goal of the Blockchain was to eliminate?

To answer these questions we'll have to introduce the so famous “coin miner”. These miners are the foundations of the Blockchain network, they are as a whole, the consensus of the network over the unified truth. What they do is to compete with each other to be the first one to find the hash of the next link of the chain, in simpler terms, to be the first to find the key to link the next block to the last block in existence. In order to make these miners compete with each other, the network has to provide some kind of incentive, as we'll see later on, mining can be expensive, and without any incentive there is just no intelligent reason to do it. The incentive being, electronic coins given to the miner who gets to the hash first.

Now let's add our knowledge of SHA-256 to dig a little deeper. As we've seen earlier on, SHA-256 spits a 256 long string of bits given any file; this string of bits being called the hash, and as discussed it can be seen as the fingerprint of the data . With a basic understanding of electronics/digital signals we can calculate what is the probability that given a file to the algorithm, the first number of the string of bits will be a zero, which would be 50%, the probability for the two first numbers of the strings be zero would be 25%, the first three 12,5% and so on. Defining the number of zeros at the beginning of the hash is known as choosing the target, the greater this number, the harder the task. Right now in order to do the amount of calculation it requires finding a hash who meets the target in the Bitcoin Blockchain you would need some serious hardware, a hardware that didn't exist 5 years ago, powerfull CPUs and especially chips that have been specifically designed to optimise the iterations throughout the steps to increase the speed of creating a hash from an input.

In the case of mining this means you can calculate more hashes per second by iterating through the nonce and extra nonce parameters and have a higher probability of winning the block reward. This chips require an enormous amount of power, forcing the miner to spend resources in order to mine.

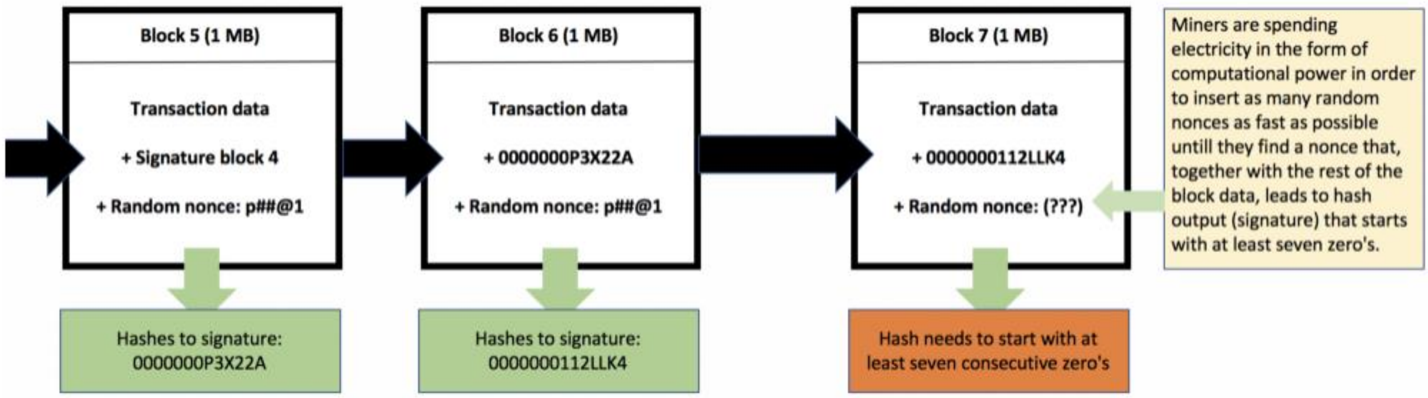

Figure 3.2.2 Illustrative representation of the Bitcoin Blockchain

The principle of mining is as follows, miners will be given the *header*, which is information about the last transactions that happened within the network (date, amount…), miners will then have to add a series of numbers to the *header* in order to obtain a hash with a certain number of zeros as first bits, these series of numbers are known as the nonce. Once a miner has found a valid nonce he will submit it to the rest of the miners to obtain validation from them which is easily done (this is where hashcash comes in), and thus consensus is achieved once again, miners can move on to finding the next hash.
We've just seen that in order to mine, miners have to spend money, this is critical, the amount of work it requires to find a valid hash is so massive, that there is no way a miner could have found it without doing the work, obtaining the hash is then proof of work. Usually mining is seen as a waste of electricity, it should be seen as electricity being used as a mean to guarantee security of a given information.

3.4. Some limitations

Despite all the advantages seen in the previous point, Blockchain technology has still to mature in order to get impactful at the global scale.

3.4.1. A matter of size

The main limitations it faces are related to its size; on the early stages of a Blockchain, it's too vulnerable to attacks, the smaller the number of nodes, the easier it is to launch an attack on a Blockchain, as we've seen before, the Blockchain is based on consensus, so if a single party owns 51% of the nodes, it can rewrite the truth, compromising the whole point of such BC which is to provide trust without a third party. Such attackers find themselves in a position of power, they can send a transaction, then reverse it, making it appear as though they still had the coin they just spent. This vulnerability, known as double-spending, is the digital equivalent of a perfect counterfeit and the basic cryptographic hurdle the blockchain was built to overcome, so a network that allowed for double-spending would quickly suffer a loss of confidence. Bcause.
Despite being a big weakness, it has its own restrictions, the first being that attempting to change old history Blocks, prior to the attack would be very difficult, even in the case of a 51% attack, as the further back the transactions are, the more difficult it gets to modify them. The second one revolves around a paradox of size and value, new Blockchains are by norm small, with a few miners and users in its network prior to snowballing into a big one, and due to its small size, the value of their digital coin is very low, this is where the paradox begins. Small Blockchains are "attackable" because of their small size, reaching 51% of the nodes in a small Blockchain is feasible, and whereas in a big one it's so hard we might as well call it impossible. In short, attacking a small Blockchain would be the equivalent of

mugging a child for candy with a small army, doable but at a high cost and for poor benefits, whereas attacking a big Blockchain would be attempting to open several thousand locks in ten minutes with a spoon, quite impossible but the benefits would be grandiose.

The possibility of attacks isn't the only concern to small Blockchain, as seen earlier on, Mining is quite resource consuming, and in the earlier stages of a Blockchain the value of its digital coin can't be seen as too rewarding. The lack of miners in a Blockchain is what prevents it from scaling and maintains it prone to attacks.

3.4.2. The main advantages it brings, take a toll in scalability

At this point, we're already familiar with Blockchain technology, a very secure way to store data in a peer to peer network, who needs consensus from all the nodes every block. This translates in a limit of transactions in a period of time, currently the theoretical maximum number of transactions in the Bitcoin Blockchain is around 7tx/s, some other Blockchains have managed to get to 20tx/s but both of these numbers pale in comparison to paypal 193tx/s and visa 1667tx/s. This obviously raises some questions about the role of of Blockchain as a substitute to traditional methods or at least about its ideal size to be optimal.

3.4.3. Environmental considerations

It has to be mention that Blockchain can be perceived as wasteful, and not environmental friendly due to the amount of energy employed in mining, some comments have to be made on this subject, instead of seeing it as wasteful Blockchain has to be seen as a power being employed as data protection and in regard of how wasteful it is, it is worth mentioning that proof of work can be modified, the number of zeros needed can be lowered, making the mining easier and less energy consuming at the cost of security decrease as it decreases its proof of work.

4. Internet of things

After getting familiar with Blockchain, a promising tool to secure information, we'll be studying the notion of Internet of things as it is said to be the way information is going to get acquired and act upon in the future.

4.1. A brief introduction

The core concept of Internet of things (IoT), is fairly simple, bluntly put, it consists in connecting everything to the internet, and by everything we mean everything. It is fair to ask before getting there, what are the benefits of doing such thing. What it means to be connected to the internet is being able to receive and/or send information.
To advance further in the subject we can categorize all devices being able to be connected to the internet in three groups:

- Objects capable of collecting data and sending it.
- Objects being able to receive data and act on it.
- Objects that can do both.

4.1.1. Sensors

The variety of sensors we have nowadays allows us to measure practically any variable we're interested in: moisture, air quality, motion, light... The list is quite extensive. These sensors allow us to take action based on more accurate data than what our bodies allow us to capture and by relaying on them to inform us when a parameter has reached a critical value that needs some action to take place (watering the crops based on soil moisture, repairing a water pipe, adding sugar to the mix in a cake factory…) it allows to drastically improve systems efficiency.

4.1.2. Actuators

As sensors collect data and send it, actuators receive data and act on it, some taking tasks far more complex than others from opening a car door to printing a 3D model.

4.1.3. Mixing both

Both previous points can't be considered groundbreaking, however the mix of them seems to be promising, by connecting all data together the possibilities seem endless.Smart farms being able to determine if the crops have to be watered not only by the humidity measured by the sensors in the soil but by meteorogical data recorded over the last days kilometers away; a factory robot putting itself to work based on trends at the other side of the world. Granted this examples may seem a bit farfetched now, but this kind of automatization may end up being a feasible feat according to IoT.

4.2. The Triade of telecommunication

4.2.1. Power Consumption

When deciding to use sensors, actuators or any device able to do both roles, there are some factors to be considered, power consumption is one of them. Power consumption's importance for these devices will vary drastically depending on the case they are being put to use. For instance if sensors are installed in a factory, power consumption is not likely to be an issue, as they are close to a power outlet and don't have to rely on battery life to keep working as opposed to sensors installed across a plantation. If it turns out to be the case where we'll be relying on battery life, then the method to approach this issue is by treating battery life as we would treat a water bottle in the middle of the desert, it becomes a precious resource and have to be used efficiently. Therefore we have to continue to specify our needs, after defining the location to our IoT devices, we have to define how often we want to communicate with them, knowing that every communication implies a cost of our precious energy. The next specification would be what kind of information we'll be transferring, is it going to be a few bites indicating whether or not moisture is between two given values or is it going to be a video?

The specification doesn't end here, let's take a worst case scenario for example, lots of sensors, distributed across kilometers of crops with relatively short battery life, how are we going to change batteries? One by one, as sensors's batteries die out? By batches? How much is all this battery replacement is going to cost?

All these questions have to be asked and carefully studied when deciding to use IoT, in order for it to be successful a lot of planning ahead has to be made.

This is also why it's so critical that we have a clear, measurable impact we're trying to achieve with our solution

4.2.2. Range and Bandwidth

The next two factors will also have to be taken into consideration when choosing to install IoT devices. Range referring to the maximal distance the data can be transferred to, and Bandwidth to the amount of information that can be send at a time.

As a matter of fact we already introduced Bandwidth when we questioned ourselves about what kind of information we will be wanting to transfer. This is due to the fact that these three factors go together hand in hand. An ideal IoT device would consume barely any battery and could communicate huge amounts of data even in remote areas. However technology isn't here yet, and when working with limitations, compromise has to be made. Here are the three most common situations:

	Scenario 1	Scenario 2	Scenario 3
Power Consumption	High	Low	Low
Range	High	High	Low
Bandwidth	High	Low	High

In scenario 1, we could be talking about sensors in a factory or building with no restrictions whatsoever, allowing us to be constantly send or receive information no matter the size. In scenario 2 we could be talking about a smart farm, where sensors send small packages of data to a control center far away. In scenario 3 we could be talking of a security camera sending images to a nearby station.

This is also why it's so critical that you have a clear, measurable impact we're trying to achieve with our solution.

4.2.3. Some helpful solutions

In order to making this balance between data send and power consumption limitation more bearable, some tools have been developed.

We'll be focusing on the ones consisting in taking a load off batteries. One first way is by introducing Gateways, which are intermediaries between sensors and the internet. Why the extra steps? By reducing the range sensors need to communicate with, and letting Gateways do the "heavy lifting" we'll be saving some of that precious battery life, and not have to change it every few months. As discussed this supposes an issue for specific cases but overall it's a more efficient way to communicate. The second way Gateways whether helping increase battery duration or reduce cost of implementation is by doing all the processing work each sensor would have to do before sending data. Gateways can pre-process and filter the data being generated by sensors/ devices to decrease transmission, processing, and storage requirements.

4.3. Main advantages

From the last chapter we might have ended up with the idea that using IoT seems to be an unnecessary expensive logistic nightmare, so let’s focus on why we would want to venture in such project.

4.3.1. Efficiency

Overall, most of the benefits IoT brings converge to the same end, to increase efficiency, whether it is by reducing or removing human interaction with machine to machine communication or by allowing to take smarter and more accurate decisions based on the data collected.

4.3.2. Big data technology

Despite the notion of Big data is in the title of this project and a subject worth studying, we won’t be able to give it too much attention due to scope limitations.

However we’ll be covering the basics to give a general Idea of what it is, how it relates to IoT and what are its immediate challenges.
The quantity of computed data generated on planet earth is growing at a exponential rate for many reasons. For start retailers are building vast databases of recorded customer activity; organizations working in logistics, financial services, healthcare and many more are capturating more data. Link to our problem. Big Data is often characterized by the three Vs, Volume, Velocity and Variety.
Where Volume poses the greatest challenge and the greatest opportunity as big Data could help many organizations to understand people better and to allocate resources more effectively. However traditional computing solutions like relation databases are not scalable to handle data of this magnitude. Big Data Velocity also raises a number of issues with the rate at which data is flowing into many organizations now exceeding the capacity of their IT systems. Finaly the Variety of the types of data to be processed is becoming increasingly diverse. [10]

By installing enough and appropriate IoT devices in a given supply chain, besides obtaining the mentioned benefits in the previous point, we would obtain enough Data to start using Data science tools. Which could have the potential to help us see a bigger picture on subject as potential cost savings, time reductions and market trends.

As all the technologies mentioned before, some caution is advisable, as good as it sounds on paper some issues have to be discussed. The first and more important is that it is a technology still in development, and data scientists are still getting used to it. At the end of the day it is what it is, huge amounts of what seem to be unrelated data. There is not yet a clear method to crack open the insights it can provide for us as traditional statistic methods apply to a certain degree given the amount of information.

However what we can be certain to be true is that using accurate data is a necessity in order to pursue this path, a good use of IoT could help us rely on this data, with the added point that it lays the ground to add other IoT devices if proven to be needed by data scientists, in case they need to cross the data with a new few variables.

On an end note, we could wonder if by having data stored in a decentralized network such as Blockchain, it could help given a correct acquisition of information allow us to rely on this data without having to fear said data to be tampered with. It would however suppose some serious challenges given the amount of data we would be talking about.

4.4. Why now?

4.4.1. Sensor price

As it goes for every industry, the higher the volume of production needed the faster the industry optimizes itself, allowing not only to diminish costs of productions over time but to improve the product as well. IoT is no exception to this process, sensor price and IoT go hand in hand, as IoT spreads around the need for sensors increases, leading to inevitably a considerable drop of price.

According to Goldman Sachs and BI Intelligence Estimates, the cost of IoT sensors has been steadily decreasing since 2004 as we can see on the graph provided by their data.

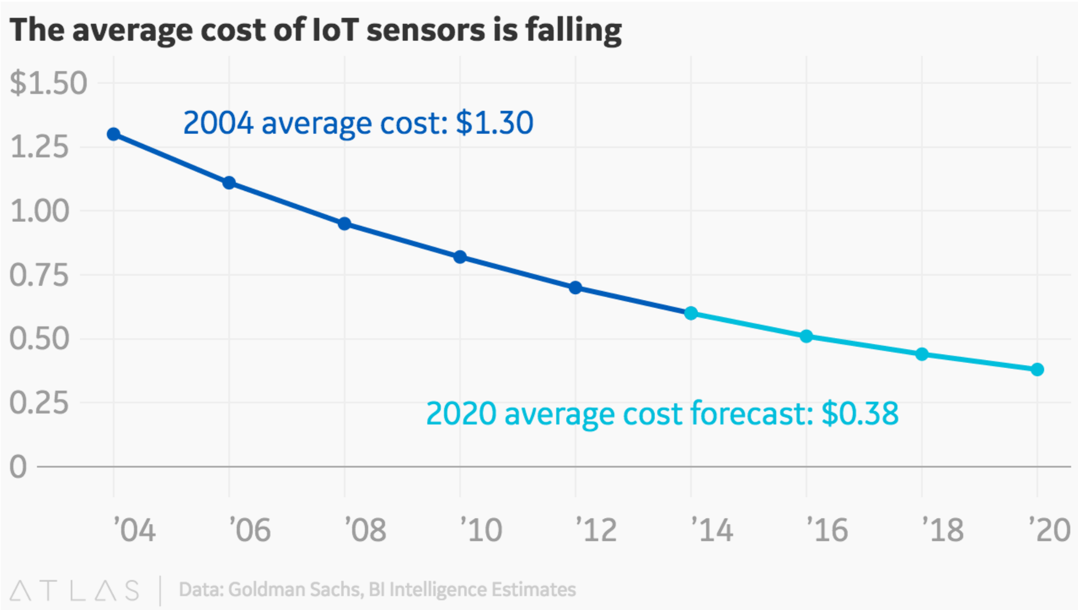

Figure 5.4.1 Sensor Price over the years

But as mentioned before, not only the costs are getting lower, but products are getting better. Over the years sensors are getting smaller, capable of collecting data over larger areas, and more energy eficient.

All these improvements are making IoT implementations look far more realistic than ever before. By reducing the number of sensors needed and by improving their batery autonomy it allows companies to rely on these sensors without requiring a major workforce to accommodate them.

4.4.2. Data Transmition and Data Storage

Sensors aren't the only field that has drastically improved over the last few decades, according to the American Nation Cable Television Association (NCTA) the price per megabit per second, has decreased a 90% from 2006 (9$) to 2016 (0.89$) , making data transfer considerably cheaper as internet speed increases[11].

4.5. Limitations

4.5.1. Still expensive

Despite the hardware's reduction cost over the years, doing a massive sensor implementation in a given supply chain can be expensive, especially for industries where hardware updates hasn't been a necessity in the last couple of decades.

4.5.2. Still technology limited for now

As we've seen in the previous chapters, electronics industry has been making big steps every year, nevertheless we're still far from ideal sensors and we're not yet able to capture all the data constantly and send it anywhere from remote zones. This forces us to be more restrictive for now and think about which data is more critical to obtain right now.

A good approach to it would be to start small, by testing sensors on a fraction of a parcel for example, and try to figure out what challenges come up before going massive, as no amount of planning ahead is going to prevent us to run into unforeseen issues.

5. The Supply Chain

After studying how data is captured or atleast might end up being captured almost exclusively in the future, we'll be focusing on getting familiar with the supply chain in order to be able to refer to some specific terms later on.

5.1. Some key concepts

Despite supply chain being an important part of the subject we're studying, we won't be studying it in too much depth, as a matter of fact we'll be covering just the basics in order to better understand how the implementation of Blockchain to it, can be positive.

5.1.1. Definition of supply chain

What we understand as supply chain is "a system of organizations, people, technologies, activities, information and resources involved in moving materials, products and services from the original supplier of materials to the end customer" [2]

In this definition the importance of the flow of goods shines by itself, all the activities regarding the movement are the basic core of the supply chain.

However, we should not confuse supply chain with logistics, although they are heavily linked. The difference being that supply chain is not limited to the distribution of a product but also englobes the raw materials needed for its production, the production itself and the distribution mentioned before. We can spot it in the previous definition, from the original supplier of materials to the customer.

Another point to help differentiate both concepts would be that logistics usually are a way a company chooses to organize itself, while a supply chain can englobe several companies. A helpful way to picture it, would be a network between different actors (usually companies) that each of them have a different role in it, from suppliers to retailers.

5.1.2. Definition of supply chain management

Now that we are more familiar with the supply chain we can tackle supply chain management, where we'll see in the next chapter is where the integration of Blockchain is going to prove itself useful.

Simply put, supply chain management would be the management of the different kind of flows found in a supply chain, materials, products, services as mentioned before but also information and financial flows.

Good supply chain management has as main goals:

• To ensure that products are available when they are needed, thereby reducing the need to store large amounts of inventory.
• To reduce costs along the entire supply chain in order to offer a more competitive product and increase benefits.

In order to achieve such goals a close look has to be drawn to the next issues [5]:
• Supply chain network configuration: the number and location of suppliers, production facilities, distribution centers, warehouses and customers (markets).
• Distribution strategy: questions of operating control (e.g. centralized, decentralized or shared), delivery scheme (e.g. direct shipment, direct store delivery or closed loop shipment), mode of transportation (e.g. truckload, railroad, ocean freight, airfreight or intermodal transport), replenishment system (e.g. push or pull) and transportation control (e.g. owner operated, private carrier, common carrier or third[party logistics companies).

• Information: integration of processes through the supply chain in order to share valuable information, including demand signals, forecasts, inventory, transportation and potential collaborations.
• Inventory management: management of the quantity and location of inventory, including raw materials, works [in[process and finished goods.

All this has to be done taking into account not only the final customer but also intermediate customers as distributors or retailers. Actually, in a holistic approach of the supply chain, companies don't include only the suppliers and the customers but also intermediaries and third party logistics providers, so that they can gain collaboratively through synergies.

Finally, note that the supply chain is like a link chain to satisfy the needs of the customer. Each link produces a part of the final product (e.g. acquiring, manufacturing, storing, distributing) and adds some costs to the chain. As these links are heavily relying in each other it is critical that no link fails, as a failing link can end up affecting the whole supply chain.

5.1.3. Flows in supply chain management

According to "basic supply management" the three main flows in supply chain management are as follow [5] :

- Product flow: it involves the movement of goods and materials through the manufacturing process from supplier to customer.

- Information flow: it consists of a two way exchange of data between the different actors of the supply chain. It involves the demand forecasts, purchase orders, inventory status information and tracking goods through delivery.
- Financial flow: it consists of payment schedules, credit terms, consignments and title ownership agreements.

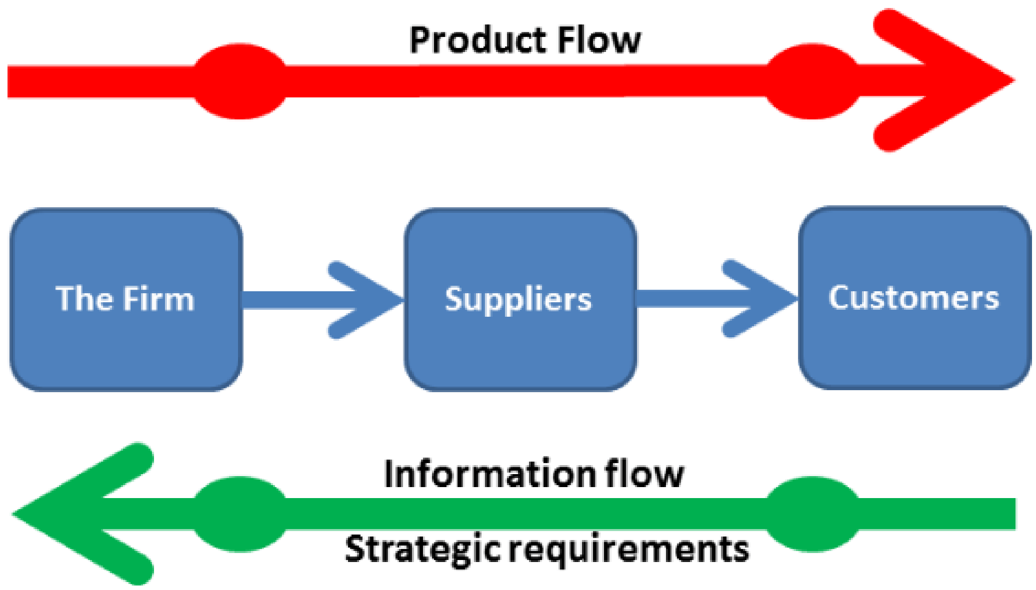

Figure 5.1.3 Flows in supply chain management

5.2. Supply Chain Configuration

5.2.1. Supply Chain Network

The average Supply Chain consists in a network of Suppliers, Manufacturing Sites, Distribution Centers and Customers. Below, we highlight the main features of each of these elements.

- Suppliers

They are external companies, cooperatives or even particulars that provide raw materials

needed to manufacture products.
Depending on the supply chain, these suppliers can be spread around the world or spread around local factories.

- Manufacturing Sites

Manufacturing sites, also called factories, are where the raw materials are transformed into the final products. Each site is responsible for manufacturing a different type of product.

- Distribution Centers

Distribution centers are the next step in supply chains. Once the products are manufactured, they are sent to the distribution center that is closer to their final destination. Therefore, distribution centers are strategically placed to reach the maximum number of potential points of sale.

- Customers

Finally, the products are delivered to the customers, either directly to stores or to their own distribution centers, if they have some.
Once again depending on the supply chain, customers can be the final consumer of the product or a final layer of distribution such as a retail store or drug store.

5.2.2. Physical Distribution

In terms of distribution, it not only refers to the final products transport between distribution centers and customers, but it covers all the process from the suppliers to the customers. Specifically, there are three types of transport according to their function:

- Inbound transports:

These are the transports of raw materials from the supplier's factories or farms to the appropriate factories. Depending on the case, these transports may have to move across different continents which can be long and expensive.

- Primary transports:

This group refers to products already finished which have to be moved to the appropriate distribution center.

- Secondary Transports:

The final step is the transportation between distribution centers and the customers or stores. These transports are usually shorter, faster and cheaper because the distribution centers are strategically placed to cover a specific number of outlets.

6. Linking such Technologies to the supply Chain

6.1. Use of Blockchain in Supply Chains

Despite two industries being able to be as different to the other as possible, their respective supply chains or at least their supply chain issues are in most cases quite similar, the structure remains the same, they both need producers, suppliers, manufacturers, distributors, retailers and customers. The aim of this paper is to study of Blockchain can help all of them.

Different Blockchain thus has different solutions. Ethereum, for example, proposes smart contracts offering ledger records that can secure both parties when conducting business. Additionally, transfer information can be constructed as to provide an accurate account of all transactions, deals, and parties involved. Some Blockchain systems can offer a complete network of supply chain, where customers can directly purchase goods and have them delivered by using the token/coin as a result of Blockchain technology, easily, safely, and cheaply.

Goals vary depending on the field:

- Certification to the costumer about his food quality/provenance (Bio, ethical origins…)
- Verifying the authenticity of the product (either brand of a shoe or the authenticity of a pill)
- Make sure the product follows strict regulations (temperature, humidity of a medicament) from exiting the factory till the acquisition from the costumer/patient.
- Smoothing transactions between partners through the use of smart contracts.

6.1.1. Main Advantages to implement the BlockChain to the supply chain

As we've seen in the previous point, Blockchain can be seen as several small locks protecting the information from hacks, compared to the tradicional model consisting in a big and only lock.

This difference makes information drastically way more secure.

The second main advantage to using Blockchain would be the elimination of the third party, making transactions easier and cheaper. The field of supply chain could certainly benefit from these advantages as the product usually can switch from several hands from point A to point B.

The third advantage consists on the transparency it provides, we agreed that in order to eliminate the third party, all transactions had to be made public. Providing a much-needed transparency to the field of Supply Chain. This transparency could simplify the supplier's and vendor's work, as the Blockchain provides consensus, issues regarding who needs

what or who owes what should practically disappear as everyone on the Blockchain can see the chain of ownership on the ledger. Another interesting way to put it to use Is as a tool to track the provenance of the different products, either in order to trace the source of a serious issue (food poisoning from a sick animal from a particular farm) or to simply allow the customer to verify the product really comes from a company they share the same ethical values that made him choose this specifical product on the first place.
In short, Blockchain could reduce costs, time delays and human error, all of these very present in most of current Supply Chains.

“It’s a contract that self-executes, and the contract handles the enforcement, the management, performance, and payment” [5]
Smart Contracts are an automated process com6letely customizable process of sending and receiving information and funds, by being customizable you can add terms to the contract that need to be satisfied in order for the funds be transferred from one party to the other. This could prove to be very useful in a field such as the supply chain, where several payments take place during the day. Blockchain could take the heavy task off the supply chain management back’s by setting the accorded conditions on a smart program and relying on the blockchain to provide consensus over the conditions being met or not.

Tokens/Coins—Many corporations operate worldwide nowadays, with manufacturers, suppliers, and even customers spread around the globe. The use of single token/coin form the blockchain technology can speed up payments and keep fees and exchange rates very low. At the same time, making the money standardized under one cryptocurrency would do wonders for accounting and results measurement.[7]

Finaly, one last interesting application it can bring is ledger records, with good programming skills blockchain can put all the information regarding bills, transported goods, inventory level and more in the blockchain’s irreversible ledger providing not just a financial reporting tool but also a inventory tracking system being able to provide information regarding the inventory from the day it was shipped, its value on that specific day the origin of said product and its future owner.

6.1.2. Curb your enthusiasm

We’ve seen the main advantages Blockchain can bring to the plate. However, we can’t ignore a major vulnerability of such blockchain-enabled tracking; it relies on the authenticity of the initial data associated with the tracked asset. The famous term in computational science “Garbage In—Garbage Out” means that when the input is nonsense, the output will

also be nonsense. Similarly, a blockchain ledger will hold and maintain the integrity of whatever data is entered into the system—despite the data being nonsense.
A Blockchain ledger helps to track any product of its supply chain chronologically to its point of origin, but one cannot help to wonder what is to stop someone from matching its origin data with a different product. The fact that a block chain ledger is such a potential help to bring some transparency to the field of supply chain is due to the fact that numerous supply chains are in severe need of such transparency, food, medical and precious stones are just some of them.

In order to minimize this problem, the use of RFID tags or similar tagging impose itself in order to reduce human tinkering with supply chain data. The idea would be to tag a product before it leaves the area of production, allowing its RFID tag to be scanned at every checkpoint of its journey. This method could help provide some authenticity to the product itself and its data.
A tag is an element set on the product itself, generally on top of the packaging that provides information about the product and its identity. 1D/2D barcodes and passive electronic RFID stickers are examples of common tagging systems. A tracer is a natural compositional feature of a product or an added component inserted into a product, while a sensor is a device that detects and responds to some type of input from the physical environment.
As said before, this solution is not fullproof, but an attempt to bring transparency and limit the data entered by humans in order to minimize potential malicious behavior.

6.2. Introduction to Ethereum

As seen in the precious chapter, smart contracts are a promising solution for supply chains, being able to remove all third parties intermediaries (banks and lawyers mainly). Blockchain's technology can provide the trust such entities used to bring to the supply chain by using its self-sufficiency and decentralization. It is true that the concept of smart contract exist prior to the blockchain, however in order to achieve its full potential, smart contracts have to be implemented in a decentralized network, removing third parties. An example would be crowdfunding, for instance the famous platform kickstarter is an example of digital contracts implemented through a centralized platform it acts as a third party, the concept being simple, if a funding target is met in a specific timespan the money gets transferred to the project if these conditions are not met, the money gets returned to the participants. Smart contracts allow to do the same actions, without have to trust a third party, reducing the intermediary fee. This can be extrapolated to a number of different fields, making decentralized business models able to reduce the number of intermediaries though the use of smart contracts.
In order to smart contracts to work efficiently they need a well-developed infrastructure, this

infrastructure taking place as a blockchain network. Prior to Ethereum appearance, any decentralized application had to build its own blockchain to provide its services, Vitalik Buterin a young Canadian blockchain researcher and programmer noticed this issue and in late 2013 proposed Ethereum to solve this problem, in July 2015 Ethereum went live providing a blockchain allowing developers to build their decentralized apps without having to implement their own blockchain.

“Lower costs, increasing efficiency, and higher control of shared information are discussed benefits of moving from a centralized regulator to a peer-topeer network of blockchain technology in the supply chains”.[7]

Blockchain 2.0 applications with the operation of smart contracts are however also dependent on a stronger scripting system to track any coin, protocol or blockchain transaction, called ‘Turing-completeness’. Ethereum is the Turing-virtual machine, explained to have the qualities to track transactions from project of coins, scripts or crypto currencies needed for the utilization of smart contracts [7]. Nakasumi [7] further presents Ethereum as the most advanced public decentralized platform for smart contracts.

The current way of sharing information between parties within the supply chain is mostly carried out through Enterprise Resource Planning (ERP) systems such as SAP. The technology behind the solution requires the usage of intermediaries to store the shared information. Nakasumi [7] argues that companies should consider moving towards blockchain solutions with the benefit of eliminating the dependency and vulnerability of third-party providers.

Blockchain solutions enable supply chain partners and stakeholders to track bottlenecks in the flow of products. The system can detect whether the products were in one place for a too long period or at a wrong location which is especially important for refrigerated goods (Casey & Wong, 2017). [8]

With help of blockchain solutions, potential problems such as proving if a supply chain verify a given regulation or ethical practices. All company transactions are recorded in the ledger which makes it possible to proof responsibility and company shadiness in sustainability related questions. Additionally, blockchains offer correct and accurate information about potential suppliers and customers’ liquidity as well as current financial positions. In general, it is an indicator of reducing risks and improves trust among supply chain partners

6.3. “Immediate” beneficiaries

Blockchain’s potential applications in supply chain boundaries are far from clear; nevertheless we can spot what seem to be the three main industries that could benefit from its support right now.

6.3.1. The pharmaceutical industry

The pharmaceutical Industry is a clear candidate because it consists on dealing high quality goods who need to be maintained in very specific conditions during its life. If this conditions aren’t met human lives are at risk. Moreover, medication’s authenticity is of critical importance, firstly because of the dangers medical counterfeit supposes to the public and secondly for the losses it causes yearly to the sector. This is a serious issue as these falsified products may cause harm to patients, they lead to a loss of confidence in medicines and health systems and they affect every region of the world. It is true that most developed countries with effective regulatory systems currently have a small proportion of counterfeit medicines <1%, however there is indication of an increase of prevalence of counterfeit even in developed countries. Sadly the rest of the world is flooded with counterfeit medecines, many developing countries have an estimate of 30% of counterfeit medication in circulation, even in some former Soviet republics have a proportion of counterfeit medicines above 20% of market value. Finally, it is estimated that 50% of medicines bought over the internet from sites that conceal their actual physical address are counterfeit.

Dealing with this issue hasn’t proved to be an easy task as it hasn’t been solved in the last 20 years when it started to be reported as a serious issue by several organizations (WHO, FIP). It is mainly due to the fact that in order to detect a counterfeit a chemical analysis has to be made which can be expensive and time-consuming.

Therefore, any useful help to fight counterfeiting and improving the tracking of any drug’s journey from the consumer to the manufacturing site is more than welcome to the sector.

Giving support to the pharmaceutical Supply chain using IoT and BLOCKCHAIN has the potential of dealing with these issues effectively. A good IoT implementation could allow to track any drug’s information considered of importance through its journey, from the temperature/moisture/sunlight it has been subjected to (with appropriate sensors), to the different persons or entities who’ve been in control of the product (RFID tags). Combining this IoT with BLOCKCHAIN would allow us to rely on the information by preventing it to be tampered with, along with providing consumers a way to verify its authenticity by checking the BLOCKCHAIN ledger.

6.3.2. The food industry

The food industry is a good second candidate as it shares some reasons with the pharmaceutical industry we have just seen, as they both product goods which end is to be consumed by humans (mostly). Whenever a product may raise some concerns to a population's safety, regulations get stricter, making both industries in need of high quality controls and to have high traceability of their products as discussed in the previous point.

However there are some differences worth focusing on. Besides from the point of consumers safety already discussed, the reason worth acquiring IoT and BLOCKCHAIN to this industry would be to offer consumers the possibility to verify the products they bought (or are about to) come from sources they ethically agree on based on their morals or beliefs, whether its GMO free, Kosher, from sustainable sources, Cruelty free… the possibilities are as numerous as the trends. Making it more of a marketing tool, rather than a population's shield against counterfeit (which it still is) as seen in the previous example.

Another difference worth mentioning would be the use of IoT, while medication is made in factories which can be massive, their size pales in comparison with the extension the food industry takes. This difference of size translates itself as a higher number of sensors needed, although as technology advances sensors may be able to capture more information from longer distances, reducing the number of sensors needed over the time, however it is an issue to be taken in consideration. But as discussed in the previous chapters IoT can provide much more than data from plantations or farms to the food industry, by implementing the appropriate hardware we can turn farms much more efficient, for example by watering the crops the exact amount needed, when needed, even taking weather forecast considerations in order to save water in case it is said to rain on a given afternoon. So said implementation of IoT and BLOCKCHAIN support the industry with more than just a Ledger and traceability system, it has the potential to increase the whole SC efficiency by automating actions and provide the appropriate data to take proper decisions based on it.

6.3.3. High value products

High value products is quite a wide notion, we'll be referring to small to medium objects in size having a relatively high purchase cost, these are some examples:

- Luxury Goods

- Consumer Electronics
- Precious Metals
- Perfumery and Cosmetics
- Fine Art
- Collectibles
- Wine and Spirits
- Clothing, Footwear, Apparel

As seen in the previous chapter regarding the food industry, the reasons for wanting to increase their traceability can vary, it can be either to provide a certification a perfume is animal test free, a diamond isn't artificial or acquired through the use of child labour but at the end of the day it comes down to the same main reason, to provide authentication to the product.

In this case there is a major difference regarding some of these products with both of previous industries seen before: some of these products aren't made to be consumed or are not one time use only. We'll be drawing our attention to these products as they pose a challenge given their lifecycle.

Most of these products share a common characteristic that makes them to be considered as high value, the fact that their value increases over time or at least it stays relatively stable. This characteristic makes them prone to switch hands over their lifecycle after arriving to the costumer.

To sum up, the main characteristics of these products are as follow:

- High value
- Long lifecycle
- Prone to changing owner

Which all add up to a fair concern, if we'll be relaying on the tag of these products for their authenticity, what stops some ill-intentioned person to remove the tag, sticking it to a counterfeit, sell it as a genuine item and keeping the original.

In order to rely on BLOCKCHAIN to provide trust for this items on the authenticity of the product, some creative solutions have come up, as the technologies we're implementing are just starting to bloom in this field some more are expected to arrive. These are just a few:

- RFID tags sticked on gold ingots that self-destroy if removed from them. (Chronicled)
- RFID tags on wine bottles to allow the resell of the bottle between two entities plus a chip that indicates the BLOCKCHAIN if the bottle has been opened.

As a note, despite the removing of a tag and sticking it to a counterfeit is a valid concern to the medical and food industries, there is still a considerable difference in the chain of responsibility between these industries. If a pill turns out to be fake it is easier to determine guilt of forgery in the pharmaceutical supply chain using BLOCKCHAIN ledger.

6.4. Smart contracts as a gateway to restructuring Physical distribution

Unlike the traditional centralized business model, smart contracts foster a new kind of business relationship built on trust, allowing us as discussed before skipping all third parties, this could prove to be a major step in providing trust between entities allowing different supply chains to interact with each other in order to optimize their logistics.

7. A promising example

7.1. Ambrosus

7.1.1. Main function

Ambrosus envisions a system of interconnected quality assurance sensors that can reliably record the entire history of a product. A blockchain is then used to protect the integrity and verifiability of this sensor data. Finally, smart contracts are used as seen in the previous chapters to provide automated governance of supply chains and manage commercial relationships between actors along them.

7.1.2. Technology they bring

Ambrosus is an end-to-end integrated solution that includes hardware, software, a protocol layer and developer tools. The Ambrosus protocol and the software layer on top of it are built on the Ethereum blockchain as well as other distributed technologies that allow information from IoT devices to be recorded onto a decentralized network. At the same time, the Ambrosus team is developing hardware sensors sharing compatibility with their blockchain network. The hardware products they have built to date include a range of non-invasive and rapid analytical devices for on-site measurement of biological samples.

Their goal is to use passive supply chain components into smart and intelligent systems by assembling IoT sensors around containers.

These products connect to their blockchain through different gateways customized for different use cases.

7.1.3. Amber as a way to reduce network costs

In order to stay competitive and reduce network costs, as running transactions on the Ethereum blockchain gets more expensive Ambrosus has shifted to the Ambrosus Blockchain as a main transactional network. Coining the term Amber as their digital currency.

7.1.4. Tag, Tracer and Sensor Systems

The Ambrosus network primarily collects data from tags, tracers and sensors. A tracer will remain stable throughout its entire supply chain journey, whereas the correct sensor solution would need to be designed for each counterparty on the supply chain and will likely require more upfront investment and knowledge of product properties. Tracers are the ideal solution to track and trace products. When implemented in a supply chain, sensor solutions assess quality, safety and logistical conditions.

7.1.5. Detection Systems

Specific detection systems are selected and deployed by Ambrosus at various stages in the supply chain to offer the most effective and cost-efficient assessment of each product at each stage. A product's physio-chemical structure, composition and quality attributes may vary throughout the supply chain and must be continuously assessed to verify conformity with standards set by participants in the network. There are several types of sensor systems that can be used to detect a product's physical state. Analytical systems are based on physical methods of analysis, including optical, electrical, acoustical and nuclear techniques. Biosensors and chemical sensors are further types of analytical systems which may be used to detect pH levels, allergens and other types of physical properties. Where appropriate, further methods such as immunological and enzymatic techniques or DNA and protein assays are also used to assess food. Environmental attributes such as temperature, light exposure, humidity, movement and oxygen are also recorded. Hardware devices provide a platform to automate the input of data into a system and create a trusted basis of data input. [4]

7.1.6. Data Transmission

When information is transmitted from a device to the Ambrosus network, the data is bonded to an Amber token and sent to the network. Common information that may be sent in a data transmission includes:

1. Tag IDs, location and time, tracer, sensors and gateway IDs;
2. Digitized certificates and transaction IDs;
3. Product quality and safety attributes;
4. Transportation, handling and storage conditions as measured by sensors;
5. Producer operability, capability and workability;
6. Integrity of detection systems;

An Amber token follows a product or batch along the supply chain, acting as a digital certificate that ensures the transparent transfer of information. All prior information can be retrieved at any supply chain stage. [4]

Conclusions

This report enables to see a glimpse into what the future of supply chain could look like, as both technologies are still in development, it is still too soon to guarantee if both technologies are going to be used in the way they are currently intended to be used, or if they have their place guaranteed in the supply chain's future at all.

Technological revolutions don't happen with the snap of a finger, all the supposed game changer tech over the last couple decades are proof of this, RFID tags were supposed to change the world, graphene circuits were supposed to be everywhere by now and so on.

In order to avoid disappointment we have to be careful not to overrate the use of Blockchain and IoT in the supply chain. However this doesn't mean there is no reason to be enthusiastic about it.

As we've seen during the last chapters, Blockchain is already having an impact on businesses, successful and promising use cases for the blockchain and smart contract technologies in particular are laying the groundwork for the future of business.

Acknowledgements

I'll be brief regarding this subject, I'd like to thank my tutor for suggesting me this subject, I must say it has been very interesting subject to further my knowledge in during the past 4-5 months, and for providing some useful insight when I was struggling with shaping all the information I was acquiring. I'd also like to thank my parents for supporting me during these last years as a student. Lastly I'd like to express my appreciation to all the authors who published information open and free with the sole motivation to inform whoever finds himself interested on the subject, it is a great time to be alive.

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