FACULTY OF SCIENCE AND TECHNOLOGY

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Title page for Master's Thesis
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Acronyms

- Project Management – PM
- Project Management Office – PMO
- Project Management Body of Knowledge – PMBOK
- Additive Manufacturing – AM
- Electric Vehicle – EV
- Multi Version Concurrency Control – MVCC
- Proof of Work – PoW
- Work Breakdown Structure – WBS
- Life Cycle – LC
- Engineering Procurement Construction and Installation – EPCI
- Project Life Cycle – PLC
- Atomicity Consistency Isolation Durability – ACID
- Return On Investment – ROI
- Internet of Things – IoT
- Technology Readiness Level – TRL
- New York State Energy Research and Development Authority - NYSERDA
- Research and Development – R&D
- Additive Manufacturing – AM
- Food and Drug Administration – FDA
- Centres for Disease Control and Prevention – CDC
- Information Technology – IT
- Structured Query Language – SQL
- International Telecommunications Union – ITU
- Database Management System – DBMS
- Proof of Stake – PoS
- Practical Byzantine Fault Tolerance – PBFT
- Special Purpose Vehicle – SPV
- Utility Settlement Coin – UTC
- Workflow Management System – WFMS
- Event Condition Action – ECA
- Active Party Clauses – APC
- Blockchain Approach for Supply Chain Additive Manufacturing Parts – BASECAMP
- Green Mountain Power – GMP

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Glossary

- Algorithm: A specific process or ruleset, followed during calculations or during execution of problem-solving operations
- Sybil attack: When a single user generates multiple virtual identities or has control over a large number of computers. The user can then use these computers to influence the consensus process for personal gain.
- DDOS attack: A malicious form of cyber-attack in which a site is bombarded with requests, overloading the server and thus making it impossible for users to access the site.
- Skin in the game: To have accrued risk, or as used in the thesis; To be financially invested
- Hash: A function in code that converts letter and number inputs to an encrypted output, with a fixed length. The hash is created with a mathematical algorithm.
- Trust Tax: The price paid to secure authenticity, quality and integrity of financial transactions, through third parties such as banks or solicitors.
- Plug-n-Play or Turnkey solution: Deliverable that requires no additional assembly, installation or setup before use. It is delivered fully functional and ready for its intended use.
- Additive Manufacturing: The process of joining materials together, to create a 3D object. 3D-printing.
- Cyber Security: Protecting software and computerized systems against theft and malicious attacks.
- Encryption: The process of encoding data or messages, so that they are only accessible or readable for the intended user or party.
- Principal: The owner of the project, which contracts with the Principal.
- Agent: The part contracted by the Principal.
- Coinbase: A trading platform for Blockchain 1.0. The platform facilitates the trading of cryptocurrencies such as Bitcoin and Ethereum.
- Script: A programme or sequence of instructions, performed by another program.
- Prosumer: Someone who both uses and produces a product. Used in the context of electricity-production and consumption.
- Grey literature: Information and material from sources outside traditional, commercial or academic publishing.
- Multisignature wallet: Wallets who require more than one cryptographic key to authorize transactions.
- Platform: A group of technologies used as a base for development of other applications and technologies.
- Ad-hoc: Created or performed for a specific purpose
- Bug: An error, flaw or failure in a computerized programme or logic.
- Network Partition: Refers to a network split by nodes, due to a local failure of the network.
- System: A group of interacting, separate entities working together as a whole.
- Explicit contracting element: A contracting element that is completely and strictly defined, with no room for interpretation.

- Implicit contracting element: A contracting element where all aspects are not strictly defined, and open to interpretation.
- Pseudocode: An informal, high-level description or representation, of the operating principles of a computerized programme. Uses same structural components as a normal programming language, having been altered and simplified to fit human reading, and not a specific computerized machine or system.
- Pseudonymous: When a user`s only identifier is a pseudonym, not related to his/her actual identity.
- Call: Calling a function/class means invoking the call method of said object. Activates a function or object.
- Wi-fi bridge: Any device that connects 2 separate networks, together through Wi-fi.
- Peak: Used in reference to grid engineering. Refers to an instance in which the produced power reaches the max amount of power, the system can sustain for short amounts of time. Also referred to as Peak Surge Power.
- Open Source: Computer software in which users are licensed to study, change and distribute the software at will.
- Parity: The quality or state of being equal or equivalent
- KILE-Cost: The KILE-initiative ensures that grid companies must reimburse the costs associated with insufficient power-supply or downtimes as a result of insufficient grid capacity.
- Token: Represents a store of value or permissions on the blockchain. Usually given as compensation for spent processing power. Holds monetary value depending on the specific blockchain.

1. Introduction

Blockchain technology first reached popularity through cryptocurrencies such as Bitcoin in 2008 [3]. The concept attracted users with anonymity, high levels of security, no trust-tax and international peer to peer trading of currency [4]. Blockchain for purely financial purposes are referred to as Blockchain 1.0, and since the emergence of early cryptocurrencies, the technology has matured significantly. Blockchain 2.0 (Smartcontracts) and Blockchain 3.0 (Other) have opened a large amount of new applications and potential business-opportunities.

Although much research has been conducted on blockchain, papers often focuses on cryptography, data science, security and strict financial applications for blockchain 1.0 [5]. Many of which are seeking to improve the currently available blockchain technology, by focusing on technical aspects such as scaling-properties or increasing security through improved consensus algorithms. As a result, little research is available on industry-specific challenges of current blockchain 2.0 and 3.0 technology. Untraditional use-cases such as Project Management (PM) tools are also largely left underexplored [5] in current research. This may create an inflated focus on theoretical challenges regarding the current state of blockchain technology, and subsequently ignore many of the unique incentives and challenges not discussed in data science and cryptography publications.

To cover the gap in existing research on the current state of blockchain technology, the following problem statement was used:

"What is the current level of technological maturity, with subsequent challenges and advantages to implementing blockchain technology with focus on selected industries and areas of implementation, outside strict Blockchain 1.0 applications?"

This qualitative thesis uses a purposely wide scope to evaluate the main aspects of current blockchain technology, outside traditional, pure blockchain 1.0 applications. Challenges and advantages to implementation are explored through literary research and review of existing blockchain-projects, hoping to create a more well-rounded snapshot of the technology and its current maturity. The thesis explores Grid engineering, Internet of Things (IoT), Smartcontracts, Distributed manufacturing and supply chain management. Possibilities within PM is also explored, as very little available research is available on PM applications.

The thesis researches both peer reviewed and grey literature to evaluate blockchain technology. The theoretical portion of the thesis starts by exploring the general characteristics of blockchain technology, focusing on technological features and current state of technology. Based on the theoretical foundation, research is extended to include and evaluate existing projects to provide a more complete view of the current state of blockchain technology. In addition to commercial projects, the thesis investigates platforms such as IOTA, Ethereum and Hyperledger. The presence of a functioning platform greatly reduces implementation difficulty for the relevant area of application.

To gauge whether blockchain is more than just an overly marketed trend, key challenges of each selected area of interest is summarized and reviewed. Blockchain functionality is then assessed as a means of solving or improving the current most common challenges for each area of implementation, or the unique features it may ad. In most cases reviewed, blockchain offered clear improvements and/or solutions, to several key issues faced in the respective area of implementation.

To assess the maturity of current blockchain technology, the NYSERDA Technology Readiness Level (TRL) algorithm was used to assess 1 concept from each area of implementation (Highlighted below in bold letters):

Application/Area of interest	Project	Technological Summary
Smart Contracts	- Utility settlement coin - Hyperledger - **Ethereum**	- Computerized logic running on blockchain network. - Used to automate tasks

		and reduce paperwork
Grid Engineering	- Smart grids - Wien Energy - **LO3 Energy**	- Enabling peer to peer trading of electricity - Local trading of solar energy - Flexible power-services to reduce KILE cost - Handling large amounts of transactions with perfect auditability
Supply chain management	- Provenance - Walmart - Norway in a Box - **Hyperledger Fabric**	- Safe and fast origin tracking of items - Proof of authenticity - Performing automated payments and reduce paperwork
Internet of things	- Factom Iris - **IOTA** - Tile data processing - IBM Watson IoT - Hyperledger	- IoT device identification over block-chain - No single point failure and resilient records - Automated explicit tasks from collected metrics - High levels of security and resilience
Distributed Manufacturing	- **Genesis of things** - Moog Aircraft group and the U.S Airforce	- Platform for enabling additive manufacturing with no trust-tax and high levels of protection for intellectual property - Cost efficient production - Greener production - Enables Agile manufacturing and increased competitiveness

Table 1: Areas of interest

TRL scores ranged from low 3 to a perfect 9, showing clear differences in the level of current maturity within current blockchain concepts and use-cases. Issues such as scaling, lack of engineering skill, lack of supporting hardware, lack of standards and legislative frameworks are reoccurring across concepts. Some areas such as Grid engineering and supply chain management seem far more ready and applicable for the move to blockchain than distributed manufacturing systems and PM.

The main reoccurring challenges to current blockchain technology are not exclusively a result of immature blockchain technology. Technological faults such as the scaling-problem and selfish mining, are considered the most noticeable technological hurdles when implementing current blockchain technology. Although blockchain systems may be beneficial for PM, these positive effects are usually carry-over effects from implementing blockchain technology to the supply-chain or manufacturing process of a project, and not as a tool tailored for PM. Smartcontracts are also identified as the key functionality, necessary for full utilization of current blockchain technology.

2. Theory

This section aims to provide a theoretical foundation for evaluating and understanding current relevant blockchain technology. Once we have established a proper theoretical understanding of blockchain, the focus is shifted to include real-world projects and platforms.

In addition to specific blockchain concepts and technology, the thesis also explores Project Management (PM), as a potential use case for the currently available technology. The goal being to further explore the possible areas of application and evaluate how current blockchain technology might reduce risk or simplify technical projects or identify the current main inhibitors of the technology.

2.2. Blockchain

A Blockchain is a shared immutable ledger, that facilitates the process of recording transactions and tracking assets in a business network. Assets may be both tangible (cash, property, raw material) or intangible (intellectual property, maintenance records, reports) [6]. The technology made its public debut in 2008, with the launch of Bitcoin. The world's first example of anonymous, peer to peer, online transactions, made possible by blockchain [4]. Since then the technology has grown significantly, with several cryptocurrencies seeing the light of day. Furthermore, other applications than simple cash transfers have emerged, as engineers and industry have realized the disruptive nature of blockchain technology.

2.2.3. Technology Overview

There are multiple forms of blockchains, with highly varying functionality. A common characteristic is their general system architecture. A blockchain is made up of a long chain of individual "blocks", that come together to form the blockchain. A traditional block consists of [7]:

1. Merkle tree root Hash: The hash value of all blocks in the chain
2. Block Version: Describes the rules and routines for the current version of the blockchain
3. nBits: The current hashing format
4. Timestamp: The current timestamp for when the block was created by a node
5. Nonce: Usually a 4-byte field, which increases by n+1 for each block added to the blockchain, with the first block of the chain being 0 or 1.
6. Information to be transferred: This may be monetary funds, data or metrics from a system, depending on the specific blockchain.

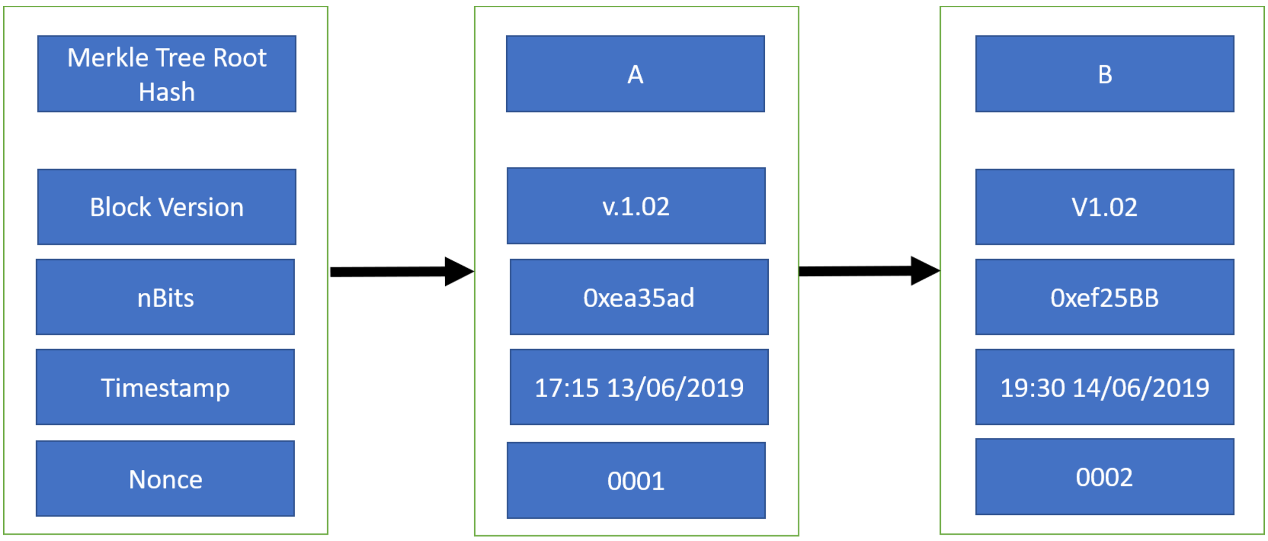

Figure 1: General Blockchain Architecture

Currently, 3 main categories of Blockchain technology have been defined [8]:

1. Blockchain 1.0

Refers to currency and monetary applications. Using blockchain-technology in relation to cash, payment-systems and transfers of monetary value between peers.

2. Blockchain 2.0

Refers to contracts. More extensive than simple cash-transfers, and includes bonds, mortgages, titles and smartcontracts.

3. Blockchain 3.0

The most "fluid" type of blockchain technology. Refers to all applications beyond currency. May include peer-to-peer grid-services, vehicle to grid, maintenance-control and Internet of Things. Any blockchain concept of platform that utilizes more than strict Blockchain 2.0 or Blockchain 1.0, falls under this category.

Blockchains use cryptographic proof in place of a trusted third-party to authenticate and facilitate transactions of either information or monetary funds. In a classic monetary transaction between 2 people (A and B), each party holds 2 keys; a private key, and a public key. The private key is only held by the owner of funds, and is used as the marker for who owns the funds or asset. This private key is completely unique and only accessible to its original owner, holding no pre-set conditions for length or characters. The hash is used to transform a private key with n variables, to a code with a set number of variables depending on the hashing format. This way, all blocks in the blockchain have the same number of unique identifiers, and public keys can be authenticated by the network. The public key can be imagined as an address or account-number, and is publicly available to the entire network [7].

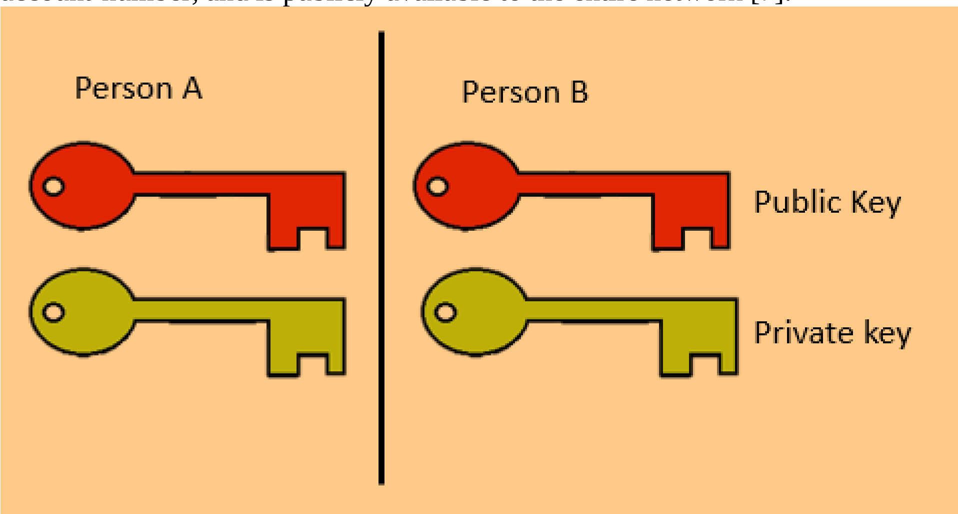

Figure 2: Cryptographic keys

Most blockchain transactions are anonymous (exceptions being permissioned, consortium controlled blockchains such as Hyperledger Fabric. See Section 2.8.3). Thus, identification is done by the combination of the public and private key. Once combined by users, the two keys form a digital signature, authorizing the transaction or action from person A to person B. This is how blockchains control for identification and initiates a transfer or transaction [9].

After the private key has been linked to a public key, a transaction is initiated between the owner of the private key (transferring funds), and the public key of the recipient. The blockchain network must then authorize and authenticate said transaction before it can be approved. For blockchain-applications this is done through a distributed network and nodal confirmation. Nodes verify a transaction by observing it from multiple locations in the network at the same time, by mathematical verification (Proof of work, see section 2.2.4). As a result, security increases by the overall size of the network, as you may be able to cheat a single observer, but not 100 000 observers. When enough nodes in the network complete the blockchains consensus protocol, it is deemed authentic and verified [6].

When a transaction is initiated by person A, we create the first block in the chain, known as the Genesis Block. The genesis block contains a time-stamp and other relevant information such as amount and currency. It is then broadcasted to all the nodes in the network for control. The process of authentication is cyclic, and is repeated until we reach the required consensus in order to validate the transaction [7].

A sufficient number of nodes and miners is critical. The system only works if we have enough processing-power to secure, store and verify every single block created. To attract processing power, we need an incentive to manage and control the network. This incentive is usually referred to as "mining". Users of the network supply computational power to solve Proof-of-Work equations or other consensus protocol. As the block is checked by the network and okayed through PoW algorithms (or other consensus protocol), a new block is added as a "proof of authenticity" that the block and subsequent transaction is checked by the node. As new blocks are added by other nodes, we create a "chain" of blocks, hence the name Blockchain [9]. Once the required number of blocks and subsequent consensus is reached, the transfer is allowed to pass through [7].

A public address is embedded inside the output script so that it can only be spent using the private key corresponding to that public address. If we consider this output to be a database row, what we have is a database with per-row permissions which are based on public key cryptography. Furthermore, every transaction presents a publicly auditable proof that its creator(s) had the right to delete/modify its prior rows [10]. Thus guaranteeing complete transparency for the network.

The general task of blockchain nodes is to verify:

1. Spender owns the cryptocurrency being transferred by checking the private and public key used.
2. Spender has sufficient funds on their account, as well as required access credentials (Unique Private key).
3. Perform Proof-of-work calculations to verify that the transaction has been controlled.

These requirements can be altered and tailored to unique blockchains.

The type of blockchain network also plays a role in determining the functions of the nodes and overall blockchain. There are 2 main types of blockchain platforms; permisionless and permissioned. In a permisionless network, everyone is free to use it and nodes are not verified or screened. This is the most common form as it facilitates a larger network, usually associated with Blockchain 1.0 applications. This provides added security, but may lead to increased risk of issues such as scaling, forking and selfish mining (see section 2.3) [11].

In a permissioned network, participation is close ended, and nodes must receive permission to verify blocks on the network. Nodes and users are commonly not anonymous. It's mostly used by consortiums and for niche-applications, with the main difference being that the number of nodes is fixed, as well as run by the consortium members. This version gives less security, but reduced risk of scaling issues and selfish mining. Both types however have the same need for consensus-algorithms to secure transactions and verify the integrity of the blocks in the blockchain [11].

Regardless of network type, miners offer available processing power to the network as a node and are compensated with value-tokens. The miner can accumulate value by providing security and service to the users of the network. After the transaction has been complete, it is recorded in the public ledger, that is distributed to every node in the network. This creates a backlog of all transactions made in the past, available for all nodes on the network at all times, with no single point failure [6].

As a whole, blockchain technology offers 4 key characteristics [7]:

1. **Decentralization**: As members contribute to the network by working as nodes, there is no need for a centralized agent. This also creates a highly resilient system, with no single point failure.
2. **Persistency**: As each transaction needs the verification of a set number of miners or nodes, the system is tamperproof and immutable.
3. **Anonymity**: Each user can utilize the network with their unique private key, which allows users to use the blockchain without disclosing personal information.
4. **Auditability**: Since all transactions are given a timestamp and recorded, it is easy to perform

backlogs and trace the specifics of a transaction.

Blockchains are written in a multitude of programming languages, with C++ being the most popular. This largely due to features such as memory control, runtime polymorphism, function overloading and the ability to bind data with methods, to manipulate and alter them together. Java is also commonly used for its portability across computational platforms [12].

2.2.4. Proof of Work Algorithms

Users can read and update blockchain transaction-logs from a shared ledger. This ledger is serviced and controlled by network members. To update said ledger, a consensus protocol is used to guarantee the safety, immutability and integrity of the blocks in the blockchain. The consensus protocol forces nodes in the network to solve hard cryptographic puzzles. Once the puzzle is solved, the node is allowed to add a block to the blockchain [11]. These puzzles are referred to as Proof of Work algorithms and can take a variety of forms, depending on the specific blockchain platform.

Any node in the network can gather unconfirmed transactions and create a block, which is then broadcasted to the entire network, altering the correct succession of blocks in the blockchain. Multiple blocks can be created at the same time, and the order of which these blocks appear can be wildly different and may in some cases create a blockchain fork (See section 2.3.4 Forking). A block is only accepted into the blockchain, if it holds a very specific answer to a very unique mathematical equation [13]. Or put simply; The block is accepted once the required amount of nodes has reached the same answer to the proof of work algorithm.

If the consensus mechanisms are not sufficient, the blockchain may face a number of problems. Poor choice of mechanism can render an entire blockchain useless as the data may be compromised. Below are some of the most common issues faced as a result of poor PoW-algorithms or consensus mechanism [11]:

1. **Blockchain Fork**
   In a blockchain fork, different nodes in the system can correlate to different blocks, as if they were part of the same chain. Such a fork can destroy a chain, as data becomes untrustworthy due to multiple chains being created from the same transaction.
2. **Consensus Failure**
   In consensus Failure, we may not have the required consensus to approve the transaction, even though the transaction is safe and should be accepted. For instance, if there are not enough nodes in the network to reach the required amount of consensus, the transaction will not be accepted.
3. **Dominance**
   If one group of nodes controlled by the same entity is large enough, they may force a “bad” transaction though by inflating the consensus to push the transaction through. This problem also occurs if one entity controls more than 50% of the total mining power of the network. The concept is also referred to as “>51%”.
4. **Cheating**
   By validating blocks in collusion with other nodes, one can get approval for fraudulent transactions. The control mechanism needs to manage collusion and other exploits that can be used to brute-force a transaction. The concept is also referred to as “Selfish Mining”.
5. **Poor performance**
   If the mechanism is too complex, a large amount of energy will be wasted. If the network has issues with cheating or dominance, this effect is worsened and may present itself as increased latency and instability. As the network grows, the ledger increases in size. This adds to issues with poor performance, as miners will have to sift through and store, an ever-growing public ledger. The problem is otherwise referred to as “the scaling problem”.

In a permissioned network, nodes are controlled and approved by the consortium. As a result, the PoW-algorithms are often simpler and more energy-efficient. This also allows for alternative consensus-methods such as PAXOS to ease the required computing-power for verification of blocks in the network [11].

Permisionless networks expect a large network as more people have access to the platform. Examples of permisionless networks are Bitcoin (Blockchain 1.0), Ethereum (Blockchain 2.0) and IOTA (Blockchain 3.0). These networks are more susceptible to Sybil-attacks and other malicious cyber-threats as nodes do not undergo control. The PoW used thus needs to be a very hard problem, so nodes are required to spend a significant amount of energy. The process is wasteful, but necessary to provide the required level of security in the consensus process of permisionless blockchain networks [11].

2.2.4.4.Alternatives to Proof of Work

Outside PoW, Proof of Stake (PoS) or variations of it, is common. The technology originated in 2011, to provide a proof of ownership, for valuables on the blockchain. PoS has also been mentioned as a way of reducing the risk of forking in some blockchains [14].

The difference between proof of work and PoS is best formulated through an example. In proof of work, miners must purchase 2000 USD with of equipment to become miner. Use the equipment and subsequent energy to mine blocks, then collect the monetary reward. In proof of stake, users can purchase 2000 USD worth of tokens, and use said tokens to buy block creation chances, becoming a validator. One uses funds as a proof of stake. Validators “vote” on the correct block, and if the right block is selected, receive a monetary reward, incentivising correct voting. The system is much less energy-intensive, and lowers the bar for users to join as nodes [15].

Early research has shown a reduction in overall security of a blockchain, when implementing PoS instead of PoW. Mainly due to “the nothing at stake issue” and “the long-range attack problem”. The nothing at stake issue describes a phenomenon where the less advanced algorithms of PoS, allows miners to build on both blocks from a fork. Thus, creating two identical chains from the same initial block, with miners voting on blocks at both sides of the fork. Generating serious issues with ownership, security and resilience. The problem have however yet to occur in actual blockchains [16].

The long-range attack problem refers to a scenario in which a selfish miner starts a separate chain from the genesis block, overtaking the main chain. As most blockchains follow the “long chain rule” this may allow miners to steal or inhibit transactions on the blockchain [16]. Although the protocol is not widely used in current blockchains, efforts are focused on improving proof-of-stake as a means of reducing the amount of energy spent on consensus algorithms in current PoW-systems [17].

Another popular consensus protocol is the Practical Byzantine Fault Tolerance (PBFT) algorithm. The algorithm is based on PoW theory and was developed as a solution to Byzantine failures. A problem in distributed systems where one component may fail, and not provide enough information to other components in the system. PBFT solves this issue by making regular replicas of each component. Thus, if a component should fail, the replica would be used as a substitute. The method has however only been scaled to 20 replicas, and implementation to larger systems have not been researched or tested [15]. Some platforms have however used the protocol, the most noteworthy being Hyperledger.

Other consensus protocols are also being developed. Seeking to improve security, reduce scaling issues or provide custom functionality for specialized blockchains. Examples include PAXOS, SIEVE and Crash Fault Tolerance, which all build upon PoS, PBFT or PoW [15]. Although these might prove highly efficient, they are not commonly found in established current blockchains, and will not be researched further.

2.2.3. Engineering Skill and Education

Engineers who are skilled in blockchain development may often be essential to successful implementation of relevant blockchain platforms and concepts. Lack of skills and poor user understanding of the blockchain, are one of the main weaknesses of blockchain-endeavours [18]. A 2019 report from the tech-talent marketplace Hired, saw an increase of 517% in the average salary for blockchain engineers, hired in the last few years. The survey interviewed 98 000 job seekers and more than 10 000 participating companies in the relevant industry [19].

As a response to the growing need for blockchain engineers, universities such as Colombia, Stanford and Massachusetts Institute of Technology, opened blockchain research centres in the summer of 2018 [20]. The U.S hiring platform Glassdoor.com, at the time of writing, lists between 2800 and 3240 blockchain-related job-openings in the US alone [21]. European universities have also started to implement blockchain-related courses and educations. The Norwegian University of Science and Technology has started courses in blockchain and cryptocurrency, but not a full master's degree [22]. Some European universities such as Montpellier Business School, University of Malta and IEBS business school, offer master's degrees in blockchain-based technology. There are however few schools in the EU today, that offer such programmes, and many only cover related economic theory, not specific blockchain engineering and development [23].

Many of the newer applications of Blockchain 2.0 and 3.0, have seen little research and little available literature. A 2017 European commission report, concluded that there were little peer-reviewed published literature in the area, covering blockchain-applications. To fill the gap, the commission utilized grey literature such as white papers and blogs, with the addition of conferences [24]. As blockchain technologies is such a new concept, there is a definite need for software engineers to develop specialized tools and techniques to better facilitate the use of blockchain technologies outside Blockchain 1.0 [25].

2.3. Technological Concerns and Challenges: An overview

There are several issues and challenges to current blockchain technology. This section covers issues which are a direct result of blockchain technology and system architecture. Other issues such as legal aspects, will be covered in order of appearance, as we research specific blockchain projects and platforms.

There are several examples in which blockchains have been successfully attacked and exploited by malicious users. Most of which are public permisionless cryptocurrency networks such as Bitcoin, as hackers have a direct financial incentive to manipulate the blockchain. Their reward being value-tokens of high monetary value.

The most commonly found threats to blockchain platforms and networks, listed in current research, can be summarized as [26]:

Type of Attack	Target of Attack
Scaling Problem	As the amount of users and transactions increase, so does the size of the public ledger. Eventually, the ledger becomes so large, that Proof-of-work algorithms take a considerable amount of power and time. This increases latency, decreases throughput and makes the network highly expensive to maintain.
DDOS	Online cloud-based services for blockchain application. DDOS attempts to disrupt the normal traffic to a blockchain-site. Making other attacks easier to execute.
Timejacking	Transaction and mining process. A process in which the miner announces an inaccurate timestamp, to gather transactions for higher fees. Facilitates selfish mining.
>50%	Mining process. Occurs when a single entity gains control of more than 50% of the total mining power. Allowing them to brute force transaction approvals, create forks, and inflate mining-cost.
Double spending	Transactions. When a user successfully uses one unit of value for multiple transactions.
Selfish Mining	Mining Process. Allows a group of miners to

	achieve larger monetary reward, than their ratio of mining power, at the expense of other users on the network.

Table 2: Common threats

In addition to those mentioned above, there are other concerns, which also regard permissioned networks and blockchain 3.0 applications to a larger degree than those listed, as these networks have different protocols and often highly limited access. Mainly malware, implementation vulnerabilities and lacking technology [27].

Malware refers to infecting a node or device with malicious software. Usually holding the system for ransom or creating instability in the network. HiddenTear, (an educational tool for malware-creation) has recently seen use as a platform to build various types of malware. HC7 is another popular malware that attacked the Ethereum network in early 2018 [27]. Malware is usually customized in order to more efficiently attack the targeted blockchain-platform.

Implementation vulnerabilities refers to anything that poses a threat to the direct implementation of a blockchain platform or concept. Usually such vulnerabilities are simple exploits or deficiencies in existing system architecture or IT-systems, that interfere with or hinder the blockchain. In some cases, difficulties with the implementation itself can be detrimental. In 2017 as IOTA was implemented, users created Hash-collisions with forged signatures, allowing them to steal value-tokens from the network. The exploit was made possible by a cryptography-fault in the IOTA blockchain [27]. The exploit was quickly fixed, but shows how final implementation could offer unwanted surprises, not discovered during small scale testing on a private, permissioned network with limited network size.

A simple software bug may cause extensive damage to a blockchain network. Another such example can be found on the Ethereum platform. A blockchain technology that aims to create and facilitate smart contracts (see section 2.5.4.). The platform used a wallet library called “The Parity wallet library”, to facilitate transactions among users. In 2017, users discovered (by accident) that one could render multisignature wallets unusable, and inaccessible to its owners. The exploit resulted in assets worth 150 million USD, being frozen on the platform. Ethereum has since corrected the fault, and little information is available as to the specific workings of the exploit [27].

Technological concerns refer to issues in the blockchain technology itself. When the technology does not perform adequately, there could be large consequences for users. Issues such as hash-collisions and lack of supporting technology could prove troublesome [27]. A hash-collision is a result of the blockchain architecture. The hash has an infinite input length, but a definite output-length. Per simple statistics, we will eventually have a situation where 2 Hashes from 2 different transactions, will give the same output as a result of their transformational algorithm. This could create problems with not only proof of origin, but general ownership of blocks and reduction in the original value of tokens [28]. Other examples include insufficient security of IoT devices, or other weak points which allows for bugs or cyber-attacks to occur and affect the blockchain negatively.

Technological issues are heavily researched, and the main reoccurring technological issues in current blockchains are the scaling problem, Forking, selfish mining, the double spending problem and maintaining user privacy.

2.3.3. Scalability

The Bitcoin public ledger reached 66 GB in 2018, and increases with about 0,1 GB per day in stored transactions [29]. As the ledger grows, efficiency is reduced due to increased latency and energy expenditure from the mining process. Miners often prefer large transactions with high transaction-fees, as small transactions often take longer to process and/or are rewarded less. Increasing the overall size of the blocks, would only entail a reduction in the speed of chain-formation. As a result, the blockchain becomes less efficient, and more expensive to run, the larger and more secure it gets [7].

There are 2 main strategies to managing the scalability-issue in current blockchains [7]:

1. **Storage Optimisation**

In storage optimisation, old transaction-records are removed from the network. A database is used to store all non-empty addresses or transfers. This solution allows nodes to not store the entirety of transactions at all times. Nodes only store active addresses and transfers. If needed, nodes use the database to recover older transactions or data.

2. **Redesigning the Blockchain**

In 2016 Bitcoin-NG was announced. NG stands for Next Generation. The concept is to separate a traditional block into 2 parts; a key block for leader election, and microblock to store transactions. Miners compete to hold the spot as leader, being responsible for generating microblocks until a new leader appears. The strategy creates much longer chains of blocks, but the microblocks hold no "weight" and the overall chain is smaller than the current version. Alternative design may help reduce the effect of the scaling problem for large blockchain platforms.

The scalability-problem is easily visible on public blockchains. There are large differences to the transaction-throughput displayed, as well as latency experienced by users on different platforms. Hyperledger (see section 2.9) can handle up to 400 transactions per second, while Etherum only handles 14. This difference is due largely to how the platform optimizes for scaling, as the hyperledger platform is private, and uses PBFT consensus protocol. Ethereum utilizes PoS, with a significantly larger network size, and transactional density [30].

The main issues felt as a result of scaling, can be summarized as:

1. Significantly reduced throughput, with low transactional density
2. Increased latency
3. Increased energy-expenditure from consensus protocols
4. Increased hardware demands for legacy systems, supporting systems, miners and other devices such as IoT
5. Increased size of public ledger

Such issues may affect a system in various ways and can drastically inhibit the implementation of current blockchain technology. Especially for use-cases that require the transfer of large files amongst a high number of individual users.

2.3.4. Forking

Forks may take varying forms depending on the specific blockchain we differentiate between soft and hard forks. Either a hard or soft fork may occur, if:

1. New nodes are reaching consensus with a block, currently being verified by an older node
2. New nodes are not agreeing or reaching consensus on a block, initially approved by an older node
3. An older node reached consensus with a block, currently being verified by a new node
4. The old nodes not agreeing or reaching consensus on a block, initially approved by a new node

If any of these instances occur during the consensus-process of a blockchain, a fork will in most cases occur. The forking problem is usually associated with updates to the blockchain [31].

A hard fork refers to a situation in which the new version of the network, is not compatible with the old version. This creates 2 separate chains of blocks. The old nodes will continue to maintain the old chain, as they have not been updated with the latest protocols. The new nodes continue theirs, as they are operating on the updated blockchain protocols [31]. The chain thus reaches a state in which it is not backwards compatible. For blockchain 1.0 applications, a hard fork would give the user independent funds on the old and new version of the blockchain [32].

A soft fork differs from the hard fork, in that it is backwards compatible, and non-updated nodes can continue transactions with updated nodes in the network [32]. To better illustrate a soft fork, we will create an example. Let's say we are to reduce the size of blocks in the blockchain, from 1MB to 0,2MB. If all nodes are not updated simultaneously, the soft fork occurs. Old nodes would continue to accept blocks that should have been discarded due to their size being >0,2MB, whilst updated nodes will reduce the size of blocks and continue to trade. If then, one of the older nodes would create a block with a larger size than

0.2MB, the newer nodes would reject the trade, despite it being a legitimate transaction.

Figure 3 shows a soft fork. The same concept applies to hard forks, with the difference that hard forks are not backwards compatible, as the old nodes will reject any block that follows the new updated protocols. In a soft fork, old nodes may still function if the new protocols are somewhat unified with old protocols.

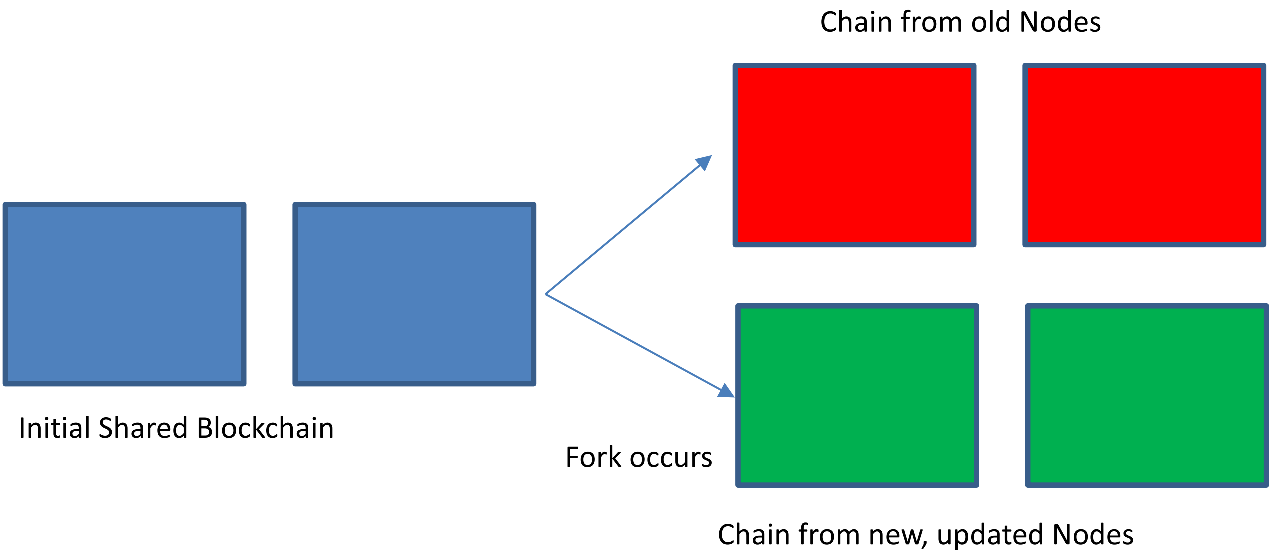

Figure 3: Fork Illustration

These forks can be used to modify and exploit the rules of the blockchain. Selfish miners often attempt to create forks for their own personal gain. Without proper routines and control, forks may pose a serious problem for a blockchain network and its users [32].

2.3.5. Privacy

Since all transactions are publicly visible, they cannot always guarantee transactional privacy [33]. Certain blockchain technologies have flaws, that may allow someone to link transactions to specific user information or pseudonyms [34]. This may also apply to specific systems or components in an IoT system. In some chains, one can also identify a unique user by the set of nodes it has been connected to. To improve and guarantee the anonymity of blockchain, 2 main strategies are common [7]:

1. **Mixing:** A concept where funds from multiple input addresses, are transferred to multiple output addresses. Ensuring that no one can use nodes to identify a specific user.
2. **Anonymous or zero-proof:** A concept where miners don't need a digital signature in order to validate transactions. The payments origin is thus unlinked from the transaction and cannot be backtracked to the individual that transferred the funds. Here both the transaction values and coins held by users are hidden from the public.

The scale and severity problem vary depending on the size and nature of the blockchain in question. Some users may not require full anonymity to be satisfied with a blockchain platform.

2.3.6. Selfish Mining

Selfish mining refers to the practice of collusion amongst miners, allowing them to ascertain greater monetary reward than their actual contribution to the network. It was until recently believed that one would require at least 51% of network nodes in order to reverse transactions and cause damage to the blockchain. Research has however shown that even nodes operating with less than 51% of the network capacity, can be dangerous, particularly for permisionless Blockchain 1.0 applications such as cryptocurrencies [34].

In selfish mining, miners hide their already mined blocks from the network. Once their requirements are met (such as high amounts of user activity, and increased pressure on the network), they release the premined blocks. Once released, the chain is much longer than the public block, and the public, legitimate block is discarded. This allows miners to “win” more blockchains and create more revenue than other miners, at the expense of security and efficiency for the rest of the network [35].

In stubborn mining, miners time their mining activity with sybil-attacks. Combining selfish mining with other tools such as malware, allows selfish miners with as little as 25% of total network power, to gain much larger financial benefit than normal miners on the same network. In order to combat this problem, concepts such as ZeroBlock have been developed. ZeroBlock works by forcing blocks to be accepted and generated by the network within a certain time. Not allowing miners to hoard and prepare blocks in advance [7].

Selfish mining not only introduces risk and opportunistic behavior, but may significantly reduce the security and transparency of the network. Particularly in industries such as IoT and supply chain management, selfish mining could be used to alter metrics from IoT devices or create incorrect timestamps for shipping records.

2.3.7. The Double-Spending Problem

The “double-spending” problem, is when a user may be charged several times due to overlapping transactions and latency (often associated with scaling problems) [36]. If not solved, it may cause accountholders to spend more money than available or be overcharged for a single transaction. Much effort is therefore spent on controlling and updating account-data.

A blockchain normally does this by enforcing a set of rules applied to every node in the network [10]:

1. Every input in a transaction must prove that it has the right to spend the prior output to which it is connected. That right is restricted by conditions encoded within the prior output.
2. A transaction must have a sufficient amount of coins in its inputs to cover the total written in its outputs. The only exceptions are Coinbase transactions which create new units of the currency.
3. Each output can only be spent once, in other words, it can only be connected to one input in one subsequent transaction

As a result of the third rule, we need a consensus to determine which transactions are valid. The blockchain will only accept one of the two transactions as valid, avoiding overlapping the transactions as may often happen in traditional banking and electronic value-transfer. This is one of the essential functions of blockchain-applications in finance and value-transfer.

2.3.7.4.Concurrency Control

Concurrency control is the current solution to the double-spending problem and is best explained through an example. Lets say you are to pay a bill this month of 400 USD (Credit card) and also withdraw 500 USD from an ATM, with only 500 USD in your account. If you first withdraw 500 USD from the ATM and later attempt to pay your credit-bill, the system will have registered a lack of funds. If, however you were to make both these payments at the same time, the system would read a 500USD balance on your account for both the credit-bill and the ATM withdrawal. This problem is currently being solved by applying Concurrency control, in which a system checks and controls transaction-data regularly, with trade-offs in efficiency and speed. It does this by freezing or locking parts of a database while they are in use by one transaction [10].

A popular type of concurrency control is called Multiversion Concurrency Control (MVCC). In MVCC each transaction is sees as a snapshot of the data at a certain point in time. It works by allowing multiple versions of a row to be maintained simultaneously, alongside a timestamp that clocks the date it was last modified. After a row has been modified, the current version of the row is set for deletion, while updating the c*opy* of the row. Each transaction has its timestamp, and only interacts with rows where the timestamp is older than its own. As a result, old versions of a row are deleted once there are no ongoing transactions that might need to access these older rows[10].

The MVCC is present to avoid contextual issues amongst the various operations. More specifically, if more transactions were to delete the same version of a row, only one action would go through as to avoid permanently deleting the knowledge of the transaction. MVCC acts as a standardized mechanism to register and avoid such conflicts within financial databases [10].

2.4. Project Management

In current PM practice, the traditional framework is a top-down hierarchy with ultimate responsibility being put on the Project Manager (PM) or the Project Management Office (PMO). We define PM as managing the process and people who participate in a project [37]. We will extend this definition to focus on engineering-related and technical projects, for the purpose of simplicity and relevance to the scope of the thesis. PM is essential to engineering endeavours and improving PM could have large potential benefits [38]. Traditional PM theory is researched in this section, to better understand whether blockchain technology might improve current practice.

Many have uttered that a top-down approach, is an inefficient way of running projects, as many managers are not even certified for the position, and many lack the required tools to see a project to full completion. For instance, as much as 44% of PM`s don't even use PM-specific software [39]. Keyedin also estimates that as much as 50% of PMO`s are shut down within the first 3 years [39].

The PM has a wide set of tasks, unique for each project. As a general outline we can say that the PM`s tasks consist of [37]:

1. Planning
2. Organising
3. Controlling
4. Leading and motivating

These tasks fall under the total lifecycle of the project. For our purpose, we will define a project as a system, consisting of inputs, processes and outputs.

Inputs include:

1. Business need and requirements
2. Human Resources
3. Physical resources
4. Project Constraints
5. Organisational and environmental factors
6. Information resources

Outputs include:

1. Reports
2. Presentations
3. Goods and services
4. Software
5. Systems
6. Buildings

The processes are timebound and uses the available inputs to create the desired outputs. It is within the project processes we find many of the standardized and "mundane" tasks, such as reporting and billing the same vendor or agent.

There are few products specifically geared towards PM, in regard to blockchain concepts. There is however an interest amongst banks and consulting-firms, to implement blockchain based technology and systems. The Russian governmentally owned bank VEB, announced in 2017 that they had plans of implementing blockchain-based project management technology. In a press release from 8. November 2017, VEB stated that "The use of blockchain technology in industrial production is aimed at optimising management processes and reducing production costs".

Specifically, applying Blockchain to PM, could be beneficial in all 4 phases of the PMBOK project phases [40]. Within a typical project, blockchain`s transparency, smartcontract functionality and security, could provide benefits to the PM in the following phases [3]:

1. Initiation and definition
    a. Stakeholders may receive higher trust in information recorded due to the transparency of blockchains.
    b. Change-recording. Every change made to the project is recorded and stored
2. Planning and development
    a. Adding additional tasks to initial scope
    b. Increased transparency and control for stakeholders
3. Execution
    a. Increasing flexibility by removing intermediaries and bureaucracy
    b. Provide secure and reliable communication
    c. Improved workflow management [41]
    d. Component tracking
    e. Provide a more effective requirements management and efficient acceptation tool
4. Closure
    a. Increased efficiency through smartcontract automation
    b. Valuable lessons learned, stored permanently and safely
    c. Auditing database.

Projects vary significantly depending on size, industry and overall complexity. Some of the advantages listed may not always be present, and said advantages does not include potential drawbacks of implementing and developing a blockchain-tool for PM.

When developing blockchain tools for PM, several potential challenges are present [3]:

1. Technological complexity of blockchains. Mainly through issues such as scaling and technological architecture [42].
2. Distinct lack of legal frameworks
3. Interoperability. Outside smartcontracts, there is no interoperability between the blockchain and existing supporting IT systems.
4. Cultural. The fear of applying new tools and technology to projects may reduce a manager's willingness to use the tool.
5. Resources. Developing and implementing such a specific tool, would entail large costs.
6. Nodal confirmation. If there is no monetary incentive (as for private networks), reaching required numbers of miners could prove difficult.

2.4.3. Project Lifecycle

There are several types of projects, ranging from purely standard to hardcore research projects with high failure-rates and large associated risk. As a result, the lifecycle and critical success-factors change depending on the project. As a general example however, we will use a common form of PM template from the PMBOK guide, containing 5 major steps[37]:

1. Initiation and Definition

The early stages of a project are some of the most critical. It starts out with a project charter, in which the PM tries to ascertain the critical success factors of the client, as well as stakeholders. The goal of this is to ascertain exactly what is to be delivered, to who, and the participants of the project. Much effort is also put on gaining management approval in order to plan the project.

2. Planning and Development

The planning and development stage start by defining the work of the project. This involves estimating time for completion, resources, total cost and sequence of work. Finally, the step needs to gain management approval in order to launch the project.
This stage also formulates the Work Breakdown Structure (WBS). The WBS is a top down deliverable-oriented representation of all areas of work involved in the project. It helps generate and create a common understanding of what various team members needs to accomplish, in order for the project to succeed [37]. It is critical that as much of the project is planned out in this step, prior to execution. The better the planning, the better the project.

3. Execution

This step evolves around the recruitment of the project team, writing the project description, establishing operating rules, scope change management process, managing team communications and writing the work-packages for the team.

A typical change management plan can be formulated as:

1. Identify the change
2. Analyse the effects of change
3. Develop Response Strategy
4. Communicate strategy and gain acceptance
5. Revise the project plan and monitor the effects of change.

4. Monitoring and Control

The controlling-section is all about making sure the project stays on track. Paying vendors, checking timetables, quality-control and stakeholder-management are only some of the tasks that are highlighted in this step. Throughout the step, baselines and initial plans such as the WBS are compared to actual events. A large part of this step is deciding what to do when plans are not met, as well as tracking planned versus actual progress. If a critical step is delayed or insufficient, it can drastically affect the rest of the project. Delays and cost overruns are typical examples.

5. Closure

Upon project closure, there are several critical components that needs to be addressed. Mainly:

a. Making sure learnt knowledge becomes accessible to the organization
b. Delivering the deliverables to the client
c. Securing and controlling assets used during the project
d. Mapping possible future business-opportunities that arose as a result of the project.

The closing-phase should also start as early as the planning phase, and be ongoing throughout the project [37].

2.4.4. Why Projects Succeed

Based on a 2002 survey, the most critical factors for project success based on relevant feedback from project participants in a wide range of industries, can be summarized as[43]:

Critical Factors	1st most critical	2nd most critical	3rd most critical	Sum of counts
Clear goals and objectives	76	40	18	134
Support from senior management	28	25	24	77
Sufficient funds and resources	14	35	23	72
Realistic schedule	17	27	22	66
End user commitment	23	18	23	64
Effective leadership	9	8	21	38
Flexible approach to change	7	15	12	34
Clear communication channels	4	13	16	33
Taking count of past experience	15	5	7	27
Effective risk management	6	10	9	25
Contextual	5	8	11	24

awareness				
Effective monitoring and feedback	3	8	12	23
Recognising complexity	8	3	8	19
Provision of planning and control systems	3	9	7	19
Taking account of external influences	8	3	6	17
Effective teambuilding	3	4	8	15
Training provision	2	3	3	8
Considering multiple views	2	0	2	4
Talented people	2	0	2	4
Appreciate the effect of human error	0	1	1	2
Support from stakeholders	1	1	0	2
Having clear project boundaries	0	0	1	1
Total	236	236	236	708

Table 3: Why projects succeed

2.4.5. Why projects fail

There are several reasons as to why a project "fails", and they vary depending on the type of project as well as industry. For instance, R&D projects see much higher failure-rates than standard projects, where the organization has prior experience [37]. Factors such as complexity, level of prior experience and stakeholder-support play a large role in the overall success of a project.

It may be difficult to define a successful project. The most obvious factors are budget, time, customer satisfaction and stakeholder-satisfaction. Other parts of the project may however also play a large role in determining its overall success. For instance, gaining experience, new relations or first-mover advantages are still possible, even though the overall budget was blown, or the prototype didn't work. For every project however, the PM needs to balance cost, stakeholder-wants, as well as uphold motivation and secure communication to the different parts of the project.

Time is one of the most critical factors. For instance, for infrastructure projects, cost of delay is estimated to 4,69%/day [44]. Any reductions made to project time, should thus significantly help reduce the overall cost of the project.

In his book, Robert Wysocki lists the top 10 reasons why projects fail [37]:

1. Lack of user input
2. Incomplete requirements and specification
3. Changing requirements and specifications
4. Lack of executive support
5. Technology incompetence
6. Lack of resources
7. Unrealistic expectations
8. Unclear objectives
9. Unrealistic timeframes
10. New technology

A project exhibiting one or several of the above features, are more likely to result in failure. Any tool or process that eliminates or mitigates these features, would most likely contribute to an increased probability of success for the project.

2.5. Smartcontracts

A smartcontract (blockchain 2.0 technology) is a computer based logic that uses pre-set conditions and data stored in the blockchain to activate and execute its pre-programmed actions [45]. Smart contracts can be classified as “a contract modelled, specified, executed and enacted (controlled and monitored) by a software system (such as, a workflow system)”. Smartcontracts translate business process into the computational process, greatly improving operational efficiency [46]. Current smartcontracts are event-driven, autonomous, distributed parts of an external application program, usually written in Solidity. The smartcontract uses the consensus-algorithm of the platform in question, to monitor and verify the completion of a contract. Thus there is no need for human monitoring or intervention, once the smartcontract has been implemented [47].

In regard to a project we can create the following example:

1. The employee of a contractor completes a work-package for the project. This work-package is to be paid upon completion by the project-organization. Let’s say this work-package holds the form of a deliverable. A CAD-sketch.
2. The sketch is uploaded to the blockchain used by the project organization. Once uploaded, the first block in the chain will contain information describing:
    a. The date in which the deliverable was completed
    b. The engineers who worked on the deliverable
    c. CAD-data for the part
3. The sketch is then checked by engineers, acting as nodes of the permissioned network. Once enough nodes have okayed the deliverable against pre-set conditions, it is approved by the blockchain. During this process, more blocks are added, giving immutable information regarding who checked and okayed the sketch, for future reference and audits.
4. Finally, the sketch is deemed complete. This triggers the smartcontract, as its predefined conditions for completion (An approved CAD-file) has been fulfilled. This triggers an automatic payment to the contractor, with no additional need for approval or human labour.

There are two major parts of an active smartcontract; Monitoring and enforcement mechanisms. Monitoring refers to the mechanism or process of making sure the clauses and requirements of the contract have been fulfilled. Enforcement is the process of activating or carry out the actions specified upon contract completion. Types of enforcement include manual human labour, automation through mechanical systems or approval of pre-set computational algorithm in a different third-party programme. These mechanisms are vital in order for the smartcontract to function, and should be considered throughout the development of a smartcontract [48].

Smartcontracts are extremely versatile and can be made to fit a wide range of explicit tasks. We can classify the varying forms of smartcontracts, into 3 main categories [49]:

1. **Sequential**
   Executes sequentially in a step by step manner, until it reached completion.
2. **Cyclic**
   The contract stays in effect even after completion of a cycle specified in the contract. The contract holds good for an agreed upon timeframe or amount, not depending on the number of times the contract is fulfilled.
3. **Turnkey**
   A turnkey contract has a specified “goal” that needs completion, within agreed time and cost. The contract details a deliverable that is delivered to the customer, fully functional and ready to be used. Once implemented, the contract completes its task based on specifications set by its designers.

Blockchain platforms such as Ethereum have allowed users with limited experience in blockchain, to develop their own customized smartcontracts on an established open network. Although the tools are available, a smartcontract is not really smart. The contract is only as good as its maker, and only registers TRUE or FALSE when checking for fulfilment. Contracting elements must also be completely explicit, as the contract is not capable of evaluating information from the blockchain. Variables or contracting elements are either completed (TRUE) or not completed (FALSE). The fulfilment of said contract is thus only dependant on the available metrics or manual inputs provided.

Despite the relative “newness” of the technology, several possible use-cases for smartcontracts have been identified and explored. Specifically, within IoT applications, the technology seems highly applicable. Particularly for addressing issues regarding access control (see section 2.6.3) and efficient automation, based on IoT data collected from a system [50].

The technology is also receiving increased attention for use in shipping and financial services. Specifically, within shipping, smartcontracts can be used to automate and approve toll-payments and fees for international shipping. Such expenses are completely explicit and are the source of often large costs as a result of human labour [51].

Similar use-cases are found within Grid Engineering, smartcontracts are being explored as a possible solution to the current large costs associated with paperwork in microgrids and Peer-to-peer grid services, where the transactional density may be very large. The application of blockchain also guarantees stability and security to its users. Something particularly important for micro-grids and trading of green energy, with the added perk of tamper-proof storage capability [52].

2.5.3. Concerns and Challenges

There are a number of current concerns to implementing smartcontracts, as direct result of the current state of blockchain technology and available smartcontract functionality [53]:

1. **Timestamp dependance.**
   Many smartcontracts trigger actions based on the timestamps contained in the block. If the miner is located in a diffenent time-zone, or has the possiblity of altering said timestamp through selfish mining, the contract is vulnerable.
2. **Mishandled Exceptions.**
   Some contracts call on other existin contracts during execution. Say contract A calls on contract B. If contract B is running abnormally, it will send signal FALSE to contract A. In some cases. A must verify the return value from B, to verify that the call has been properly executed. If the call is not checked correctly by A, contract A may be vulnerable.
3. **Re-entrancy vulnerability**.
   Once a contract is completed, the state of said contract is changes after the call is completed. In the intermediary state, an attacker can conduct calls to the smartcontract. If the contract involves transfer of value-tokens, it may allow the attacker to steal additional value-tokens by calling the contract.
4. **Contracts are not smart**
   If the contract is not modelled correctly and has access to required metrics, it will not be fulfilled. With limited frameworks for development and a high degree of uniqueness, this ads to the difficulty of developing smartcontracts.
5. **Legal issues**
   Smartcontracts may have difficulty adhering to and adapting to current legal frameworks that span multiple jurisdictions [54].

As with a traditional blockchain-network handling a simple transaction, smartcontracts are executed and monitored by all nodes of the network. This guarantees immutability and security but takes up massive amounts of computing power. If the network is not scaled properly, a large and extensive smartcontract could be rejected as the network runs out of computing power. A so called Halting Problem [55].

The price of computing-power on the Ethereum network is determined by its users. By paying more for the execution of your contract, the nodes of the network prioritize said contract. This however makes Ethereum inefficient. It is generally more expensive to compute and store things on Ethereum, compared to other platforms such as Bitcoin or Ripple [55], although such platforms does not facilitate transfers outside monetary funds.

2.5.4. Smartcontract Modelling

There is no singular way to formulate and implement a smartcontract. A smartcontract or blockchain 2.0 function is nothing but a computerized script and can be written in a multitude of ways and languages depending on the platform and specific use case. There are however some general guidelines and factors, that needs to be addressed in any smartcontract. Mainly [49]:

1. **How is the contract to be specified and deployed?**
   The logic requires adequate metrics, clearly specified area of use and strategy for implementation.
2. **How do we coordinate and manage the contract between different entities?**
   The smartcontract must work across relevant computational platforms and IT systems.
3. **How do we conceptualize the execution of the contract?**
   The contract must have strictly defined, explicit clauses with appropriate enforcement mechanisms.
4. **How are the contracts modelled?**
   The programming language and architecture must support the intended use and system.
5. **How do we monitor the events specified in the contract?**
   Monitoring must be efficient and dependable, with appropriate/adequate levels of automation to ensure increased efficiency.

A major area of focus with current smartcontracts is monitoring and execution of the contract according to its specifications. Even though the contract itself is formulated correctly, it remains useless unless we have appropriate underlying implementation of the supporting technology. Specifically when executing the contract, safe and transparent automated monitoring, as well as a methodology for requirement elicitation are current areas of industry focus [49].

A smartcontract must be formulated so that it facilitates nodal monitoring. In blockchain 2.0, monitoring is performed by the nodes of the blockchain network, through "traditional" consensus protocols. Meaning, the nodes of the platform or network ensures the contract has been fulfilled according to its specifications, through verified, transparent information. This eliminates uncertainty but demands appropriate nodal access to required metrics and information. This may create additional challenges with safety and security, but such issues are easily avoided with a private network or platform. On open networks, current smartcontract functionality demands nodes have full access to what may be sensitive information [56].

Smartcontracts are valid for a specified duration which defines the active life stage for which the contract is expected to last. Contract completion may not occur if some clauses are specified in the contract that exceeds the initial life span. Such activities or responsibilities include maintenance or an extended warranty for deliverables. The contracts need to create a mechanism that facilitates relation-based contracts or other activities that exceed the normal time of a project [49].

For illustration, we will formulate our own basic contract, and then translate said analog contract to a smartcontract, with the help of a basic pseudocode.
We will start by formulating the basic licensing contractual clauses, that will make up the final smartcontract [48]:

- Article 1: The Principal grants the agent permission to evaluate a product

- Article 2: The Agent must not, and cannot publish or share the results of the evaluation without approval from the agent. The approval must in such an event be given prior to publishing. If the product review is published before receiving approval from the Principal, the agent must remove all published material within 12 hours.

- Article 3: No comments are to be published by the agent during or after review of the product, unless permission is granted.

- Article 4: If the agent is commissioned to perform an independent evaluation, the agent is obligated to publish the results of the independent evaluation.

- Article 5: The permission to review is terminated automatically, if the agent breaches any of the articles in the contract.

We will now translate the articles above to a smartcontract, using a simple python script [48]:

```
Initialise getLicence, getApproval, getCommission, use, publish, comment, remove
[Forblicensee] use ← True
[Forblicensee] publish ← True
[Forblicensee] comment ← True
violation← False

Procedure Evaluation_agreement_Contract
if getLicence = True Then
[Forblicensee] use ← False
[Permlicensee] use ← True              •Article 1

if getLicence = True and (getApproval = True or getCommission = True)then
[Forblicensee] publish ← False
[Permlicensee] publish ← True          •Article 2, 4

if getLicence = True and
getApproval = False and
getCommission = False and
publish = True then
[Obllicensee]remove ← True            •Article 2

if[Permlicensee] publish = True then
[Forblicensee] comment ← False
```

```
[Permlicensee] comment ← True          •Article 3

if getLicence = True and getCommission = True then
[Forblicensee] publish ← False
[Obllicensee] publish ← True
[Permlicensee] publish ← True            •Article 4

if([Forblicensee] use = True and use = True) or
([Forblicensee] publish = True and publish = True) or
([Obllicensee] publish = True and publish = False) or
([Forblicensee] comment = True and comment = True) or
([Obllicensee] remove = True and remove = False)then
violation ← True
if violation = True then
[Forblicensee] use ← True
[Forblicensee] publish ← True
[Forblicensee] comment ← True
[Permlicensee] use ← False
[Permlicensee] publish ← False
[Permlicensee] comment ← False
[Obllicensee] publish ← False          •Article 5
```

Figure 4: Smartcontract Example

Or in pseudocode:
Initialise getLicence, getApproval, getCommission, use, publish, comment, remove
[Forblicensee] use ⟵ True
[Forblicensee] publish ⟵ True
[Forblicensee] comment ⟵ True
violation⟵ False

Procedure Evaluation_agreement_Contract
if getLicence = True Then
[Forblicensee] use ⟵ False
[Permlicensee] use ⟵ True   Article 1

if getLicence = True and (getApproval = True or getCommission = True)then
[Forblicensee] publish ⟵ False
[Permlicensee] publish ⟵ True   Article 2, 4

if getLicence = True and
getApproval = False and
getCommission = False and
publish = True then
[Obllicensee]remove ⟵ True   Article 2

if[Permlicensee] publish = True then
[Forblicensee] comment ⟵ False
[Permlicensee] comment ⟵ True   Article 3

if getLicence = True and getCommission = True then
[Forblicensee] publish ⟵ False
[Obllicensee] publish ⟵ True
[Permlicensee] publish ⟵ True   Article 4

if([Forblicensee] use = True and use = True) or

([Forblicensee] publish = True and publish = True) or
([Obllicensee] publish = True and publish = False) or
([Forblicensee] comment = True and comment = True) or
([Obllicensee] remove = True and remove = False)then
violation ← True
if violation = True then
[Forblicensee] use ← True
[Forblicensee] publish ← True
[Forblicensee] comment ← True
[Permlicensee] use ← False
[Permlicensee] publish ← False
[Permlicensee] comment ← False
[Obllicensee] publish ← False   Article 5

The code upholds all the articles set in the initial design of the contract. All that remains before it can be utilized, is deciding on the enforcing and monitoring mechanisms, that will allow the contract to make decisions and act upon the pre-set conditions. Examples of monitoring mechanisms include IoT devices and nodal consensus. Enforcement mechanisms include manual labour, trusted third-party software or other computerized systems, connected to the relevant blockchain. The enforcement mechanism is highly dependant on the use-case of the contract [48].

Having access to an established platform such as Ethereum, allows developers to focus solely on the design of the smartcontract. Security, immutability, consensus protocols and trust are provided by the established network. As a result, development and implementation of smartcontracts is simplified and more easily accessible, by current established platforms [57].

2.5.4.4. ER^{EC} Framework

The ER^{EC} framework was developed for formulating and developing smartcontracts. The framework specifies 4 layers to formulating a contract [49]:

1. **Document Layer**.
   Includes XML based specifications. Focused on document and semantic exchange.
2. **Conceptual Layer**
   Focuses on identifying and track the entities involved. This being parties, contractors, subcontracts, clauses and events etc. Their common lead is they all have a crucial effect on the completion and enactment of the contract specified.
3. **Logical Layer.**
   This layer focuses on monitoring, and is one of the core parts of the concept. ata Model, event-condition-action (ECA) rules, Activity-Party-Clauses (APC) constructs, workflows and Activity Commit Diagrams [58]. This allows the program to track and detect errors or anomalies to the initial contract.
4. **Implementation Layer**
   Workflow Management System (WFMS), software components and Web Services. The final layer of a standard ER^{EC} framework is coordinating the execution software, that will eventually be tasked together with human interaction, in order to enact and perform the contract.

After all 4 layers have been defined, we must specify 5 important parts of the contract [49]:

1. Contracts. A legal agreement between 2 or more parties
2. Clauses. A contract includes many clauses that require completion
3. Activities. A clause is fulfilled when completing one or more activities
4. Parties. One or more party undertake and activity
5. Exceptions. Exceptions are the modelled scenarios that deviate from a fulfilled contract, as per the initial agreement.

When formulating the specific econtract, the ER^{EC} framework can be applied as such [49]:

1. List all contracts in need of automation. Each contract listed should include:
    a. The enacting parties
    b. Performed activities
    c. Payment terms
    d. Deliverables
    e. Legal issues and strategy in case of an unfulfilled contract.
2. All contractors and subcontractors involved with the various components
3. Estimate and document all tasks per activity
4. For each clause, specify actions that needs to be taken when satisfied and not satisfied
5. All particulars must be identified for each party.
6. Collect all relevant information regarding payments.
7. Specify the relationships and links between contracting elements such as clause, activities, parties and exceptions.

By formulating such a system, the work done on the project is tracked and monitored by the activities completed or not completed. When activities are completed, it triggers the clauses of the contract, which in turn triggers payments, exceptions or other pre-specified actions [48]. Although currently rare, frameworks such as ER^{EC} provides much needed guidance for engineers utilizing a blockchain 2.0 platform such as Utility Settlement Coin or Ethereum.

2.5.3. Traditional Contract Design

Constructing a traditional engineering contract can be challenging and is often left to lawyers and specialists. For engineering applications and smaller acquisitions however, this task if often put on the PM or PMO. A large portion of developing a good contract, is creating and controlling the incentives of the contract. Incentives should be used in order to increase customer satisfaction and reduce overall risk for the parties involved. If one party, say the agent takes on more risk, he or she should be compensated in the contract. Each project and contract are unique, with its own set of challenges and requirements. There are effectively 3 components of a contract that allow the PM to tailor incentives; Fixed price, Reimbursables and Target Price [59].

1. **Fixed Price**

In a fixed price contract, the agent receives a fixed sum for the deliverables. Any cost-overrun that is not a direct result of the principal altering the requirements further than the initial contract, is paid for by the agent. These contracts transfer a large portion of the project risk to the agent. It also does not normally allow for the principal to influence and make changes to the project.

The fixed price contracts are normally explicit contracts. Meaning that all the work is clearly defined and specified in the contract. Any work that is not covered by the contract, must follow the agreed upon rules for renegotiation as it would entail additional costs for the agent, not covered by the principal.

2. **Reimbursable**

Reimbursables refers to a contract in which the agent is reimbursed for some of or all the costs of the project. The agent also receives an agreed upon fee. This fee can be reduced, should cost overruns or delays reach a certain level. The reimbursable contract-element moves much of the risk to the principal. It also allows for the principal to directly influence and make changes to the project as it progresses.

These types of contracts require a less rigid contract-type. Much of which can be implicit. This means that some parts of the contract are not clearly and explicitly defined. Some areas are open for interpretation during the Project Life Cycle (PLC). While this is favourable in projects with large degrees of uncertainty, the principal takes on more risk. If moral hazards are not controlled for, the agent has an incentive for underperforming (see 2.5.3.4 *Moral Hazards in Contracts)*.

3. **Target price**

Target price involves the agent and principal sharing cost-overruns and savings, based on a pre-determined price. The contract element has seen a lot of use in projects that are circling the border between development and construction. In such projects, it is difficult to ascertain exactly what needs to be done to

reach the critical success factors of the project. The team can then use target price to alleviate and distribute risk, as well as create an incentive for both parties to come in under budget.
The drawback to such an element is that it may cause conflict if the contract is not properly constructed. The contract needs to include specific routines for renegotiation, conflict management and resources, should the project prove to be more extensive than initially expected.

2.5.3.4.Moral Hazards in Contracts

Moral hazards occur in the presence of asymmetric information, or as individuals engage in risk sharing. The source of which is asymmetric information, allowing one party to act at the cost of the other party [60]. For the purpose of illustration, I will formulate a few common examples of such hazards. The specifics vary, but any moral hazard can be harmful to the successful completion of a project by causing cost-overruns, decrease quality of increase the time until completion. They arise when an individual or business has an incentive to underperform or skimp on the agreed upon contract.

One common form of moral hazard is an agent, not allocating the correct and or best resources available for the task. Say we are contracting the development of an app to a local agent. Our contract is a fixed-price or reimbursable contract, with the required specs listed. If the agent has the opportunity to undertake another project from a different principal at the same time, the agent can choose to allocate less resources to the fixed price contract. Thus, sacrificing quality or other, as the "best" engineers are used on a different contract, with more stringent contracting elements, that requires the agent to manage time and cost more diligently.

If the principal has insufficient experience compared to the agent, the agent may use this asymmetric information, in order to gain increased compensation from the principal. A specialized contractor usually has a better understanding of the required work. The specialist could then undertake a contract that has a reimbursable format and a fixed fee. The contract would then appear to be very favourable and cheap, but as work progresses, the changes and "unforeseen" work starts to add up. In the end, the final cost to the principal may be far above what was initially expected, whilst the agent still receives the agreed upon fee.

If the contract is not properly defined, a principal may demand additional work or specs added to the deliverable, without paying for the work. Let's say you as the principal is contracting a firm to make a car. An insufficient spec would be "Must drive fast". As the principal, you could then stipulate that "fast" means top speed above 200MPH later on in the project, as your competitor`s car has been announced with a top speed of 199 MPH. This would force the agent to spend additional time and resources to meet your demands, that you claim was specified from the onset. This is possible if the contract does not properly define the requirements for the deliverable or has insufficient routines for renegotiation and cost-overruns.

2.5.4. Ethereum

The Ethereum permisionless blockchain, is specifically designed to facilitate the development and implementation of smartcontracts. While most blockchain platforms are highly limited in the amounts of operations one can perform, Ethereum is designed to be as loose as possible. This allows developers and engineers to code any function they might desire, with the most popular ways of coding being Vyper and Solidity [61].

Ethereum has developed tools and guides to help engineers learn and utilize the platform. Tools include [57]:

1. Waffle. A basic framework for developing smartcontracts
2. Truffle. A framework for testing the framework of smartcontracts
3. OpenZeppelin SDK. An indepth and more extensive toolkit for smartcontract development.
4. Tenderly. Debugging and monitoring-programme for smartcontracts
5. Brownie. A python-based tool for smartcontract development.
6. Rich-Thin client: IoT functionality [62]

The Ethereum tool-library is extremely extensive, and tailored towards developing, operation and closing blockchain based smartcontracts. The platform also boasts tools for security, testing, storage, Frontend, Backend API, testnets and much more that engineers might find helpful when developing fully functioning smartcontracts for comercial use [57].

Although Ethereum uses value-tokens to encentivize mining, the platform differs from Blockchain 1.0 in that tokens are programmable. Tokens can thus be traded and transferred with complete trust, containing information, programmes and even games made by network users [63]. Etherum utilizes a custom concensus algorithm based on the proof of stake concept called Ethhash. The model effectively removes 51% of the attacks seen in the bitcoin network, making the platform highly secure, and boasting the most advanced PoS algorithm available [15].

The Ethereum platform has been used for a variety of comercial applications. Ranging from finance, to games and decentralized exchanges. Concepts include Cent (Social media), DAI (A stable cryptocurrency that holds a 1 USD value) and AirSwap (decentralized peer to peer exchange) [64]. Upon the time of writing, the Ethereum platform is the largest and most actively used blockchain platform in the world [63].

Several large backers have entered and supported the platform. The Ethereum board of directors, contain members from J.P. Morgan, Accenture, Intel and Microsoft. The Ethereum organization also has more than 250 members, with companies such as FedEx, Intel, Microsoft, Pepper Hamilton (Legal services) and LG CNS contributing to the ethereum project, or working on their own projects using the platform [65].

The Ethereum Enterprise Alliance (EEA) is an initiative developed to improve the Ethereum platform, in cooperation with relevant businesses and academic institutions. The Project focuses heavily on developing standards and identifying needs to make the platform more suitable and equipped for commercial implementation [66].

2.5.5. Utility Settlement Coin

In 2015, UBS (Swiss bank) started research on blockchain technology. Its main purpose was to make wholesale banking more efficient, by implementing a distributed ledger as used in blockchain. They have later gotten support from other parties such as Santander, CIBC, BNY Mellon and MUFG [67].
Utility Settlement Coin (UTC) focuses on smartcontracts for financial purposes. UTC is researched and developed by large international banks, with the hopes of having the technology work as a new model for digital central bank cash [68].

The concept works as a series of cash assets, with versions for each major currency. The most central being USD, EUR, GBP and CHF. UTC is meant to be convertible at parity to a bank deposit, for any corresponding currency. When you spend your UTC, you are essentially spending its real world equivalent currency. This is believed to reduce risk and improve efficiency for global financial markets, as many of the tasks associated with international trade, is delegated to smartcontracts [68].

The business-opportunity arose as a result of banks having to handle non-operating balances for corporations. Due to regulations, these assets must be fully funded and remain unleveraged at all times. This gives rise to a rather large opportunity-cost for large international banks. If it was possible to transfer these deposits to a Special Purpose Vehicle (SPV) with the purpose of non-profit cash-management, the Return on Capital would be drastically improved. The banking-sector would still be able to utilize the cash, through decentralized bank cash pools [69]. The system is also expected to allow for easier detection of system-wide liquidity-shorts. This as a result of USC balance-sheets approaching zero, would indicate a liquidity issue in the wholesale market [68].

2.6. Internet of Things

IoT is a concept in which parts of a system is fitted with sensors, actuators or other equipment, linked together by access to internet [9]. The concept has been around for many years, and any device connected to the internet, collecting data or accessing a system, can be classified as an IoT device. Common examples include cell-phones, Smart TV`s, computers and GPS devices. Researchers have noted that the combination of IoT and Blockchain is a powerful one, with the possibility of transforming many industries [9]. Specifically, the combination of IoT, AI and smartcontracts may create a powerful and promising combination [70].

Traditional IoT networks are centralized. Information from devices placed in a system is sent to a centralized cloud, processed and analysed, before being sent back to the system for implementation or correction of components. While such an architecture works for systems of limited size, it poses problems in regards to security, user friendliness, trust and resilience. If the cloud goes down, so does all IoT networks connected to it. By applying the decentralized nature of blockchain to IoT networks, the single-point failure risk is removed [71].

There are currently 3 established ways of developing an IoT network:

1. **Cloud Computing**: the most commonly used. The system uses a decentralized or centralized cloud-service, in which data is uploaded and stored from IoT devices. The network is primarily popular due to advantages such as:
    a. Simple maintenance
    b. Automated backlogs and backups
    c. Good scalability
    d. Can achieve high levels of security

2. **Distributed Computing**: In distributed networks, IoT devices may connect to each other, or other devices to complete tasks. The system can operate without WIFI connection, but will not be able to backup files and data to an external database, unless WIFI or similar is supplied. An example of such is a smartphone without internet-connection, connecting to a TV in order to play a movie.

3. **Hybrid Networks**: The concept revolves around a combination of cloud and distributed computing. Devices are moved closer to the cloud processing unit, in order to achieve lower latency. A concept otherwise known as Edge-computing. Such networks also frequently use a Wi-fi bridge in order to achieve connection.

Although IoT-systems have a wide range of possible applications and architectures, few frameworks and standards are available for developers. Several projects such as SPITFIRE, SENSEI, IoT-A and ASPIRE, have attempted to create a general framework for IoT-device implementation. These and several other are funded by the European FP7 programme. The main goal is to remove one of the major barriers for IoT-implementation: Having to redesign and develop system architecture for each system [72].

There is a wide range of IoT architectures, with various forms being developed and proposed by researchers and organizations. According to the ITU (International Telecommunication Union), IoT architecture is composed of 4 layers [73]:

1. Application layer. Such as healthcare, maintenance and monitoring.
    a. IoT applications
2. Service support and application layer. Common capabilities than can be used by various IoT networks and systems.
    a. Generic support capabilities
    b. Specific support capabilities
3. Network layer. Contains devices such as routers, switches, gateways and firewalls.
    a. Networking capabilities
    b. Transport capabilities
4. Device layer. Physical assets that control and alter objects in the IoT system.
    a. Device capabilities
    b. Gateway capabilities

All 4 layers must remain protected against malicious intent. Any security loophole might have significant consequences for the overall transparency and resilience of the system. Even in non-blockchain systems, security is hard to guarantee and maintain. A 2018 paper have shown how a blockchain secures all 4 layers of an IoT system, by using an established platform such as Ethereum or IOTA. The study also concluded with low cost and high efficiency for IoT-systems on a functioning blockchain, compared to current IoT systems, as maintenance and resilience of blockchain-based systems outperform technological alternatives [74].

When implementing blockchain-based systems to an IoT framework, one may obtain a variety of potential advantages, not available in traditional IoT systems, present in all 4 layers of traditional IoT networks. These features can be summarized as [46]:

1. **Publicity**: All information from IoT devices are publicly available, but secure from altering through the innate immutability provided by blockchain technology.
2. **Decentralization**: The distributed nature of blockchain systems removes the risk of single point failure and connectivity issues to servers.
3. **Resiliency**: As each node has a full copy off all data transferred, data is kept secure in the event of failure or cyber-attacks.
4. **Security**: Blockchains can create secure networks without the need for third party firewalls and cyber security.
5. **Speed**: Data can be reviewed and accessed any time, through any node in the network.
6. **Cost savings**: existing IoT systems have high costs associated with infrastructure and maintenance of the system architecture. These costs will increase at higher rate with traditional IT-systems, than with blockchain based decentralized networks [46].
7. **Immutability**: Having complete trust that records are immutable, will increase both security and privacy. Both of which are major challenges in current IoT networks and systems.

In blockchain-based IoT systems, IoT devices take the role as nodes. A 2018 case-explored the validity of blockchain based IoT systems. The study used the Ethereum platform to create a simple smartcontract logic, to collect and evaluate incoming data from IoT devices. IoT devices worked as nodes, with an independent management hub written in JavaScript to connect the two systems. Although the study proved that IoT and blockchain was a viable combo, it also showed how latency increased with frequency, as a result of low processing power in IoT devices. It seems as if the main limiting factor for current implementation efforts, is the hardware contained in IoT devices [75].

Any blockchain platform used in IoT-development, should easily facilitate the main enablers of IoT [76]:
1. Bluetooth
2. Near Field Communications such as RFID and NFC
3. Quick Response Tag and Optical Tag
4. Structured Tags
5. Beacons

These enablers allow for identification of IoT-devices. Without such tools, the devices have no identity in the network, and cannot start any type of interaction with the rest of the system. In places with limited connectivity, such technologies are critical in order to facilitate data-transfer to a Wi-fi bridge.

There are currently several devices being used as IoT hardware for blockchain applications. Currently, Raspberry Pi, BeagleBone Black, Wandboard, Ethcore Parity and ODroid are all capable of functioning as full nodes on a blockchain network, exhibiting appropriate connectivity, functionality, availability and processing power. All of which are low-cost, low powered computers for development efforts. Some software development is however required, and few platforms provide easily accessible development tools for such devices [77].

2.6.3. Concerns and Challenges

In 2016 the US DNS provider Dyn was faced with cyberattacks. IoT devices was infected with a malware called “Mirai”. Mirai uses IoT devices to launch a DDOS attack on the business [70]. Such risks have made IoT a less attractive technology. Its need for a centralized cloud opens the platform up to cyberattacks through phishing and other malicious software. Once one has been infected, the malware spreads through the cloud.

By placing valuable censors on the web, owners and stakeholders accept an added risk of hacking and malicious software. Any data transmitted needs protection to assure the safety and integrity of the IoT system. Utilizing blockchain to ensure encryption and immutability may seem a highly applicable solutions to many of the security-threats of IoT networks. Applying Blockchain does however pose additional problems that needs to be addressed for any large scale IoT system.

If the IoT network is placed on a large network with heavy mining, we may have a conflict of computational resources. As mining is data-intensive, the IoT devices are resource restricted [78]. This may lead to conflict on a commercial blockchain as many commercially available blockchains does not scale well with a large amount of nodes, whilst IoT networks preferably have a large amount of nodes [78].

The threat of selfish mining in blockchain-based IoT networks is very large. By utilizing selfish mining or operating the majority of nodes on the network, malicious miners can alter, remove and even fabricate IoT data on public blockchains. This could cause massive damage to machines and equipment that operates under tight tolerances and high risk [78]. This makes permisionless, open networks the least desirable option for IoT blockchain platforms. By using a permissioned, private network, this risk is greatly reduced.

Outside the unique issues brought fourth by blockchain-based systems, there are also a wide range of general challenges, faced by todays IoT implementation efforts. Mainly [79]:

1. **High investment costs**: Companies often implement IoT for large systems, covering all relevant nodes. This is often associated with extensive cost and engineering effort.
2. **Security:** Transferring critical data through the internet may be risky, as information is susceptible for malicious attacks, and have no inherent security, unless third party applications and programmes are used. Data must be trustworthy and immutable, to achieve the necessary usability for many applications. Even then, IoT devices often present a weak point in the security of the system.
3. **Technology infrastructure**: Companies are often limited in their choice of platforms, databases and supporting technology. This limited selection of tools and products, often force developers to make their own. Examples include IoT devices, databases and user interfaces.
4. **Communication infrastructure**: occasionally, IoT networks are placed outside cellular coverage. This often leads to issues with connectivity.
5. **Immaturity of IoT standards**: Most standards, currently in use were developed in 2016 and 2017. The Open Connectivity Foundation joined the Open Interconnect Consortium in pushing a united protocol, but there are still few available standards for IoT-system development.
6. **Procuring IoT**: When implementing an IoT system, companies must procure devices such as instrumentation, communication networks, storage and data management consultants. Neither having the IoT label. Procuring such assets may be challenging, and the lack of IoT "labelling" can make it difficult for stakeholders to see how various elements should and can fit together in an IoT system.
7. **Maintaining and limiting access control**. Data must be protected so only the right people have access to private or sensitive information [50].

There are also unique and additional challenges that occur when attempting to use the current state of blockchain, for IoT systems [46]:

1. **Legal**: There is no international compliance code available. This may pose issues for both service providers and manufacturers of IoT devices.
2. **Storage and scaling**: The size of the public ledger will continue to grow with time. Current IoT devices have highly limited storage space and processing power to work as nodes, and is this very limited by a large ledger[46].
3. **Processing power and time**: IoT systems utilize a variety of devices. These devices may not have the required computational power to function as nodes, or perform consensus-protocols at a sufficient speed. Specifically once the size of the ledger grows, the majority of IoT devices will not be able to supply sufficient storage [75].
4. **Lack of skill**: There is a distinct lack of engineering and other related skill, in developing and implementing blockchain-based systems for IoT

5. **Naming and discovery**: The blockchain technology has not initially been designed for IoT. As a result, Nodes are not meant to find each other in the network. IoT-devices will “move” constantly, changing the topology of the system.

2.6.4. IOTA

Companies such as Volkswagen, Den Norske Bank, Fujitsu and Bosch have chosen to utilize an existing public blockchain for some of their IoT endeavours and are all invested in IOTA. While some companies are developing their own unique platforms, the vast majority utilize the IOTA-platform [71]. The platform has also expanded to include smartcontract functionality through the Qubic-project [80].

IOTA is a permisionless blockchain especially geared towards IoT implementation. Its uniqueness lies in a technology called the “tangle”. Whereas in normal blockchains, blocks are just that, in a chain. IOTA uses a tangle to store data and transactions as individual blocks, tangled together in a web. This makes for a different consensus protocol than most blockchains. Instead of having designated miners, the “fee” for transferring your data or currency, is that the two parties involved must process 2 other transactions for the network. This allows for fee-less transfer of assets and information, at a much faster rate than other public blockchains, with less scaling-issues. As the blockchain receives information from IoT devices, it uses smart-contract implementation to automate tasks such as paying vendors or managing components in the system [81].

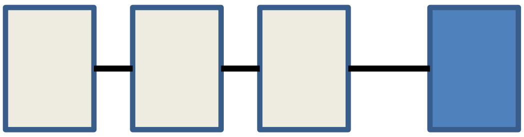

Figure 5: Traditional Blockchain

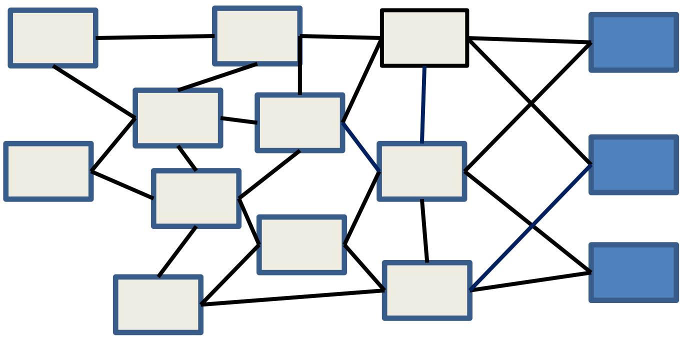

Figure 6: The IOTA Tangle

Initial collaborators have used the platform for various projects. Bosch is using IOTA to develop its Bosch XDK (cross domain development kit), a near-final form, programmable sensor and prototyping platform for IoT applications. XDK is being developed to collect data as an IoT device, and then sell the available data on the IOTA marketplace [82]. Fujitsu has also used the IOTA platform for pilots and proof of concept, by applying the platform to IoT monitoring of production lines [83].

The IOTA team consists of a large group of computer-scientists, engineers, mathematicians and analysts. There are also illustrators, economists and a large amount of outside advisors from various disciplines working on the project [84]. The platform is currently developing solutions for smart-cities, and signed a formal Memorandum of Understanding, to initiate a collaboration with FIWARE in October 2019 [85]. Showing a clear move towards IoT-enabled infrastructure and larger projects.
While IOTA seems the most developed IoT geared Blockchain, there are several others attempting to solve the issues of today’s IoT networks. These include VeChain, Hdac, Waltonchain and Streamr.

2.7. Distributed Manufacturing

Distributed manufacturing refers to the concept of geographically spread out production with often several facilities, that are coordinated using information technology. For instance, how the oil and gas industry is designing their parts in Norway, but having the parts made by manufacturers in EU or Asia. Several hurdles however make distributed manufacturing a tool not easily applicable for smaller businesses. For instance, trust and privacy are often very important when developing prototypes and new designs. This leads to a "Trust fee" in which the designer must pay a third party to ensure that the manufacturer will not steal or resell the design to other competitors in the future.

Central manufacturing currently offers (largely due to economies of scale) significant cost advantages at a lower organizational complexity, when compared to networked decentralized production sites. Industries such as manufacturers of food-items and packing material, are forced to adopt a decentralized production-scheme to save cost and avoid spoiling of merchandise [86].

As production and the need for efficient and fast manufacturing is increasing, distributed manufacturing may prove a viable solution for more agile and efficient production. There are several trends that are causing a development towards distributed manufacturing [86]:

1. **Megatrend Sustainability**
   Customer benefit and satisfaction are critical factors. To achieve full satisfaction and benefit, products must be designed and manufactured in such a way that they are both socially and environmentally responsible, while also remaining economically efficient. To achieve this, the geographical location of production facilities and the design of logistics cycles is critical. By allocating production to a favourable geographical location, one can save both cost, time and reduce the environmental impact as a result of reduced logistical need.
2. **Rising Logistics Cost**
   The rising costs are mainly driven by increased prises for personnel, fuel and transportation. This recent increase in cost, is a clear economic incentive to allocate production so that excessive logistical costs are avoided. Distributed manufacturing gives increased possibilities when selecting production sites.
3. **Correct allocation of resources**
   By allocating production to areas in close proximity to raw material-production might give rise to large savings in both efficiency and environmental burden. Increased focus on green products and ethical production, provides an incentive for co-allocated production of raw materials and finalized product.
4. **Agile manufacturing systems**
   When implementing agile manufacturing, the ability to swiftly and efficiently switch between production-sites is a major advantage. It allows for faster production of one-offs and products can be produced in a closer proximity to the final customer, saving both cost and reducing lead-times.
5. **Democratization of design and Open innovation**
   As the level and complexity of design and manufacturing tools increase, it might very difficult for smaller business to keep up. The onset of distributed manufacturing allows for a larger number of companies, having the possibility to easily access advanced manufacturing and design tools. As part of this development, centralized manufacturing systems are increasingly being replaced with decentralized production structures [87].
6. **Market and customer proximity**
   In saturated markets with high competition, geographic location of production sites give rise to often large and important strategic advantages. The need for fast delivery of perishable products such as food-items, might also create a clear need for customer proximity.

Such trends show a clear incentive for establishing efficient distributed manufacturing systems. There are clear economic, environmental and logistical incentives from both customers and regulatory entities such as governments and trade-unions to develop more effective manufacturing systems.

Distributed manufacturing systems are often highly complex and difficult to execute. In order to achieve an effective distributed manufacturing system, the following requirements must be met [88]:

1. **Integration**: Management systems such as production, planning, scheduling, control transport etc. must be integrated with the relevant manufacturer and its partners. This to ensure rapid responsiveness and to support a global competitiveness.

2. **Distributed organization**: Distributed knowledge-based systems is required to link demand management to resource and capacity planning and scheduling.

3. **Heterogenous Environments**: Distributed manufacturing systems must facilitate heterogeneous software and hardware, for both manufacturing and information systems and environments.

4. **Interoperability**: Even heterogenous systems and environments may utilize different programming languages or represent data differently through a different computing platform. Despite differing IT-systems, they must operate in an efficient manner as they are often forced to communicate.

5. **Open and Dynamic structure**: It must be possible to integrate additional dub systems or remove existing sub systems from the main system, without stopping the working environment or seizing production. An open and dynamic system architecture is vital.

6. **Cooperation**: Full cooperation with suppliers, partners and customers should be fluent and efficient.

7. **Integration of humans, software and hardware**: For the system to work optimally, humans, software and hardware must be able to work collectively at various stages of production and development. Bi-directional communication must be developed to allow effective and rapid communication between humans and IT systems.

8. **Agility**: Product cycle time and response-time should be reduced. To achieve this, facilities must be able to adapt and reconfigure production rapidly, as well as interact with relevant partners to convey changes and new requirements.

9. **Scalability**: Additional resources can be incorporated into the organization and relevant production, if required. This should be possible at any working node in the system, and at any level. The expansion should also be possible without disrupting or limiting normal production or established organizational links.

10. **Fault tolerance**: Both at system level and subsystem level, the system should be fault tolerant. This do detect and recover information and data, in the event of failures at any level, as well as minimize the effects of failure felt by the working environment of production within the organization and its partners.

The same requirements are highlighted in the D3M model, which creates a basic framework for developing current distributed manufacturing systems [89].

The concept of blockchain-based distributed manufacturing revolves around a decentralized database or cloud, for designs and part-geometry. Designers, engineers and manufacturers can upload designs, which the users of the network may download and produce. Designers can also use the network to outsource manufacturing. The nodes of the network provide trust and transparency, to avoid theft of intellectual property, and easily auditable trails for manufactured parts. There is also the possibility of linking machines directly to the web, and then using smartcontracts to automate the production of parts once the conditions of the contract are met [90]. A highly applicable feature for maintenance.

By implementing blockchain-technology in distributed manufacturing of mechanical parts, one would [91];

1. Boost innovation and economic development by enabling more enterprises to monetize their ideas
2. Reduce inventory cost and service time by enabling Just in Time production of spare parts
3. Automate trade finance process via smartcontracts
4. Speed the flow of new products

The recent rise in AM technology provides an additional incentive to implement blockchain-based manufacturing systems. Several agencies have warned that AM significantly increases the risk of plagiarism and theft of intellectual property. Furthermore, it is argued that commercial application of AM systems, is only applicable if intellectual property is protected. There is currently no alternative, offering the same level of trust and security as blockchain-based systems [92].

2.7.3. Concerns and Challenges

There is a distinct lack of research on distributed manufacturing systems. The topic is still young, and will require much development before being a feasible solution in its current state. Largely due to limited engineering skill in both blockchain and distributed manufacturing systems [93]. The main issues facing current distributed manufacturing efforts (For blockchain-based and traditional non-blockchain systems) can be summarized as:

1. **Intellectual property and security must be protected at all cost.**
   In order to ensure intellectual property, new business models must be designed to incentivize participants. This to ensure one entity does note gain control over the network. If this were to occur, the entity would essentially control the intellectual property, available on the network. There is also a lack in smartcontracts that facilitate and critical features needed to establish efficient manufacturing [90].

2. **Implementing contract-based logic for a "one size fits all" approach in manufacturing, may not be feasible** [90].
   The new advent of AM and other manufacturing techniques may create the need for customized and implicit contracts in order for the technology to be economically and practically feasible. Many machines do not have network connectivity. CNC`s and lathes, often operate without internet connectivity. This would entail offline download of part-files, which poses a definite risk for intellectual property [90].

3. **Current models require extensive amounts of data-storage and interoperability.**
   The D3M model highlights the need for extensive capture and storage of data, among smart units in the system. The model also weights the need for concurrently led constitutes, working in real time across both public and private networks [89].

4. **Legality and liability.**
   Machine parameters, layering (in regards to AM), and other factors may prove significant in the performance and longevity of a part. without the designer present it may allow for insufficient quality-control, which may further lead to accidents or financial loss.

5. **Altering a design.**
   If the need arises, it may be challenging for the buyer to make alterations to the design [92]. If however, the buyer could make alterations, who then owns the design for the altered part, and how much alteration is required for the part to be considered a different design?

2.7.4. Genesis of Things

Genesis of Things is attempting to create a commercial platform for the entire supply chain of additive manufacturing, hoping to enable even smaller businesses to utilize the concept of distributed manufacturing. Initial platform collaborators and partners include BMW, Bosch, Airbus, DHL and Volkswagen . The project`s main goal is to develop a platform that solves the 4 selected problems with distributed manufacturing [94]:

1. **Manufacturing closed shop**: Manufacturing assets are largely not shareable. As a result, many businesses don't have the tools required for production.
2. **Manufacturing Trust tax**: In order to outsource production, a large degree of monitoring and control is often necessary, at great cost to the principal.
3. **Supply chain transparency**: Make sure product is handled, shipped and sourced properly.
4. **IP protection**: Intellectual property must be protected. After part is finished, the agent manufacturer cannot be allowed to steal or duplicate the design.

The Genesis of Things project is owned and developed by Innogy, a German-based energy company. While Innogy leads the overall development and product strategy, the blockchain itself is being developed by BigchainDB, a publicly available platform for Blockchain 3.0 applications, based on the Ethereum platform [95].

The figure below illustrates the current use-case scenario of Genesis of Things:

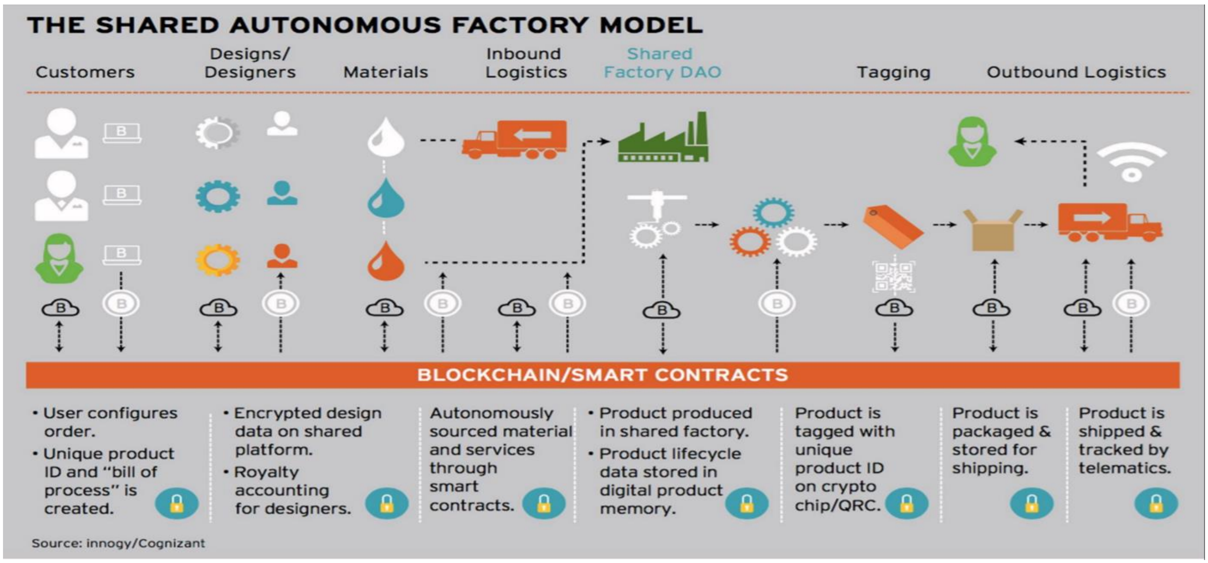

Figure 7: Overview of Genesis of Things, Use case [95]

The concept is meant as a platform covering the entire production cycle of AM-parts, from initial customer solicitation, to production and final shipping.

Despite little public information, the company has demonstrated a proof of concept. The project produced a set of AM titanium cufflinks, engraved with the Ethereum logo and a unique serial number identifying the part. The individual serial-number connects the part with the individual AM-machine and allows for full transparency during and after production. After this Proof of concept however, little new information has been released regarding the inner workings and plans for the project [1].


Figure 8: Genesis of Things, proof of concept [1]

As many other concepts, the Genesis of things uses a combination of Ethereum-based blockchain and custom smartcontracts to achieve proper functionality. Outside genesis of things, there are few established projects working on blockchain platforms for Distributed Manufacturing. One such example, is SIMBA chain. SIMBA chain is being tested by the U.S Airforce for use in the Blockchain Approach for Supply Chain Additive Manufacturing Parts or BASECAMP, in association with Moog and Wipro [96].

2.8. Supply Chain Management

Supply chain management is the handling and managing of the entire product flow of a finalized good or service. It includes all raw materials, components and derivatives that are needed to produce the final product. This is done by creating a network of individual suppliers, that manufacture or process the product until it is finished and sold to end customers. In traditional supply chain management there are 6 parts [97]:

1. **Planning**: Plan and manage the resources needed to meet demand. Determine metrics to determine the effectiveness of the supply chain once finished.
2. **Sourcing**: Find and choose suppliers of materials and goods. Monitor and control suppliers.
3. **Making**: Organizing the activities needed to accept raw materials, manufacturing, quality control and packaging for shipping.
4. **Logistics**: Coordinating customer deliveries, invoices and payments.
5. **Returning**: Create a system to take back defective goods.
6. **Enabling**: Establish a process to support and monitor the supply chain and make sure all parts follow necessary rules and regulations.

A large part of blockchain innovations are focused on improving and managing supply chains. Specifically, aiding in tracking, transparency and traceability of shipped products. From 2013 to 2016 several US citizens were infected by listeria. After much time, the strain was finally linked to a supplier, but as more time passed, even more people was affected. In April 2016, certain frozen foods were recalled with the help of the Food and Drug Administration (FDA) and Centres for Disease Control and Prevention (CDC). The recall was expanded to 353 products from a total of 42 brands. This is a prime example as to how an unsafe or unproperly monitored supply-chain can cause massive damage to a brand, increase cost and even hurt consumers [98]. Showing a clear need for increased security, dependability and transparency.

Traditional supply chains have typically suffered from issues such as [98]:

1. Lack of traceability
2. Risks involved with multiple stakeholders
3. Lack of responsiveness
4. Largely manual processing
5. Regulatory compliance
6. Reconciliation Burden

There is strong belief amongst professionals that the blockchain technology would drastically improve the traditional supply-chains.

Several concepts have emerged with blockchain. Attempting to improve the current state of supply chains. The main areas of application for blockchain in supply chain management are [51]:

1. **Ease paperwork processing**
   The cost of trade-related paperwork is estimated to be between 15% and 50% of total cost of physical transport. IBM and Maersk have experimented with blockchain-solutions, and developed a concept in 2015 to reduce the cost of paperwork.
2. **Identify counterfeit products**
   Selling counterfeit goods is big business. As a result, companies are trying to combat the smuggling and illegal distribution of counterfeits.
3. **Facilitate origin tracking**
   Blockchains allow for faster, secure and transparent tracking of a products origin.
4. **Operate and facilitate IoT**
   Due to the large amount of possible IoT devices (such as vehicles, shipments, ships etc.), logistics may be one of the most promising areas for IoT implementation. One proposed use-case is to utilize smartcontracts and IoT. IoT devices can be supplied with digital cash and can thus through smartcontracts, pay fees and duties automatically to other parties.

Blockchain based systems are also believed to greatly increase value and provide strategic advantages for logistics-providers. Although not easily quantifiable, blockchains are believed to have the possibility of achieving a wide range of strategic supply chain objectives through its unique features and mechanisms. Mainly: a flat reduction of cost, increased speed, increased dependability, overall risk reduction, increased sustainability and increased flexibility of shipping systems [99].

When products are given a block in a blockchain, the information is always available and always correct. Walmart has successfully implemented such technology for tracking mangoes from China. The system allowed them to trace individual packages of mangoes to the origin farm in china in less than a few seconds. This process would normally take several days or weeks without blockchain technology, and not have nearly the same level of resilience and transparency [100].

The application of blockchain technology for supply chains, is still an emerging technology. A 2018 Capgemini study concluded that only 3% of blockchain concepts are capable of being used at scale. 87% are only proof of concepts, and 10% are pilots. In the same study (n=447) 81% of organizations responded that traceability of products was the main reason for investing in blockchain technology for their supply-chains [98]. Investing in blockchain for supply chains would allow for easier tracking, backlogs, increased security and automatic generation of audit-data as the blockchain grows, and there is clear market interest in a working solution.

2.8.3. Use-case Example

To better understand the technology, we will create 2 simple examples of how blockchain technology can aid supply-chains. There are many use-case examples available, but the current state of the technology is particularly well suited for supply-chains where the place of origin holds special value. As such, I have selected the food-industry and the sale of luxury items such as purses or rare minerals.

2.8.3.4. Food-items

First, we will create an example in which we are the manufacturer of Kobe-steaks. The process starts once the calf is born. At this stage it is tagged with a RFID-tag. The information is uploaded to a cloud, and the first block is created. It holds information as to when and where the calf was born. With the private key being the unique tag, on the calf.

As it reaches maturity it is sent to the slaughterhouse for processing. Once slaughtered another block is added in which the location and date of processing occurred. Whenever the steak reaches another part of the supply-chain, its information is updated. Nodal conformation is carried out through manual slaughterhouse input, and verified by the nodes of the network. Avoiding that the unique tag is copied or falsified for another lower-grade calf.

This creates a long tamper-proof trail of blocks that details every step the steak has taken, from the calf was born, until it was sold to the customer. Most blockchain systems (such as NiB-chain), also allow logistics-providers to log additional metrics, such as temperature and type of transportation. Once the steak is sold, the final block is created, registering the purchase date, location and price through the stores IT-systems. In this example, the customer can rest assured that the steak is in fact a kobe-steak, and that it has been shipped and handled appropriately. The unique tag (private key) also allows customers to make sure the calf has not been sold elsewhere (i.e the tag has been copied).

2.8.3.5. Luxury items and Raw Materials

The technology could also be applied to avoid the sale of counterfeit luxury goods. We will create an example with an expensive purse.
The purse is initially created at the manufacturing plant. Here it is given a unique serial-number and a tag that creates the first block in the blockchain. Detailing its origin and proving that the purse is not a counterfeit. Once the purse is sent the logistics-supplier scans the package. Creating a second block, and thus the transporter absorbs responsibility of the purse and can be monitored at later stages to check for inefficiency. As it arrives in the warehouse the package is scanned again, creating the third block. This continues until the purse is finally sold to a customer at the store.

The customer can enter the numbers on the purse tag, and gain access to the public ledger for the purse blockchain. Here, he or she can clearly see if the purse is authentic. The information is immutable, and the customer could rest assure the product is genuine and from the advertised manufacturer.

A similar concept can also be applied to the sale and reselling of rare minerals such as gold and diamonds, or raw materials such as cobalt. The battery-industry for one has extensive issues in guaranteeing that the sourced cobalt used in Li-ion batteries are not mined through artisanal mining (Child labour). If the minerals came attached with a blockchain, such guarantees would be easier to accomplish, and those who profit from child labour would struggle to keep their activities hidden from the market [101].

2.8.4. Concerns and Challenges

Even though blockchain technology holds much promise in regard to supply chain improvement, there are hurdles and issues in implementing the technology successfully. Mainly acquiring an efficient Return on Investment (ROI). From the same companies researched by Capgemini, 49% noted that if they were to implement blockchain technology, it would require significant altering of their supply chain process, posing large investment costs [98].

Other challenges and concerns include[98]:

1. **Regulatory challenges**
   Many countries and businesses are reluctant to allow international tracking of goods. One may see issues with border-registrations and compliance.
2. **Immature technology**
   Although there are working platforms, many support-technologies such as reliable Wi-fi and cheap, reliable IoT devices are needed for full utilization.
3. **Privacy policies**
   Companies may be reluctant to reveal parts of their supply chain, in fear of losing a competitive advantage. Some may also be bound by country policies that forbids them for using decentralized and anonymous networks.
4. **Lack of complementary partner systems at the partner organizations**.
   All nodes in the supply chain needs to use computerized systems that can communicate on the same blockchain-platform. This may be a significant challenge in developing countries, or countries with strict rules and legislation.
5. **Inoperability with legacy systems and other systems**
   As blockchains are improved or bug-fixed, all nodes of the network need to go through an update. Bad service or lacking computer-skills may cause delays and challenges in some areas and countries.
6. **Complete trust.**
   Even if a container is on the blockchain, some may still sneak in and replace the cargo. There is always a risk of fraud, as the blockchain has no way of physically controlling the cargo [99].

2.8.3. Hyperledger

Hyperledger is an opensource, private blockchain platform largely focused on supply chain management through the Hyperledger Fabric project. Its hosted by the Linux foundation and attempts to create a hub for industry to jointly develop and improve blockchain technology for several applications. Its main selling points are customisable architecture in standard languages such as C++, and the facilitation of automated and confidential transactions between parties. Per 28. August 2019, there are 28 corporations, utilizing the Hyperledger platform. Some of the more prominent partners include Airbus, Daimler, Huawei, Intel and Samsung [102].

Hyperledger Fabric has been approved by the consortium Technical Steering Committee (TSC) and has thus reached its first major release. The platform is released and available for implementation, with the next version (Hyperledger Fabric v2.0) being released in late 2019 [103].

Within Hyperledger, partners work on various projects such as Intel`s “Sawtooth” for IoT and financial services. There are currently 4 active and 11 incubating projects on the platform [103]. All these projects fall under the Hyperledger umbrella. The end goal is to build an open source, high scaling industrial applications for the emerging blockchain technology, with particular focus on supply chains management [104].

The platform has been utilized successfully in pilot-testing by Volkswagen, to guarantee ethical sourcing of Cobalt from the Democratic Republic of Congo, for use in EV batteries. The system allows Volkswagen to trace the minerals in real time, from mine to finished battery-grade cobalt. LG Chem (Li-ion manufacturer) and Ford Motor Company have also since joined the platform, in an attempt to improve the transparency and security of their supply chains for Li-ion minerals through blockchain technology [105].

Hyperledger is a private network, owned by the consortium members. Nodes are known and not anonymous. Participants are registered and verified by the blockchain admins. Thus, circumventing large amounts of risk associated with selfish mining and scaling-issues, due to the significant reduction in ledger-size. The platform supports 2 consensus protocols, to provide members with increased freedom for developing new functionality. Both of which are based on PBFT [15].

The project remains very active and constantly expanding. Members from 2019 include Alibaba Cloud, Deutsche Telekom, Citi [106], and Cargill with several more. The concept is now evolving to explore industries outside its initial focus, as a result of market interest in the platform and its applications. The Hyperledger BESU Ethereum client, is specifically tailored for use in consortiums, and has been developed in partnership with Ethereum for Hyperledger. Through the BESU project, Hyperledger receives added Blockchain 2.0 functionality through the Ethereum network [107].

2.8.4. Norway in a Box

Norway in a box is a Norwegian-based company that sells food-items produced in Norway for the Chinese market. All exported food-items come with proof of authenticity verified through a blockchain-based supply chain system [108]. The concept of Norway in a Box is to attach each salmon with a unique QR-code. Whenever the fish reaches a node in the supply chain, the shipping-information is updated through a blockchain-based system called NiB-chain. The system logs dates and has functionality for temperature logs and other relevant metrics. These must however by recorded manually by shipping-workers.

Once the salmon reaches China, the consumer can scan the QR-code with his or her phone. Once scanned, the unique code relates all information regarding the specific salmon, from its point of origin, to the final retailer. This allows the consumer to be completely certain, that the fish purchased, is in fact from Norway. As fish as scanned and eventually sold, information is logged and processed on the blockchain. That way, old QR-codes cannot be used to mark other fish as Norwegian in the future, and tags cannot be diluted geographically to turn a 10-fish shipment into 20 [109].

The Chinese consumer is willing to pay added cost for complete transparency and trust, in the authenticity of the product [109]. The Chinese food industry has had major problems with fake and unsafe food-items. Food which are either fraudulent (Claiming to be of different origin or quality), and unsafe (Not been treated properly or quality-checked) are common in the Chinese market. Such issues has caused the average Chinese consumer to distrust the origin of food items [110]. Through the complete trust and transparency of blockchain-networks, Norway in a Box, is attempting to capitalize on Chinese consumer scepticism, hoping they are willing to undertake extra cost for the fish in exchange for complete trust that the product sold is authentic and safe.

NiB-chain is based on the Vchain platform, a permisionless open network that specializes in supply chain management through Blockchain 2.0 implementation. Norway in a Box and Friend software Labs, have developed a browser and subsequent User Interface, tailored to the Vchain functionality. This way, the company utilizes premade and tested blockchain cryptography, and greatly reduces the potential risks associated with implementation and development [109].

2.9. Grid Engineering and Energy Applications

Grid engineering refers to an engineering specialization in design and consulting for the power systems industry. Traditional power-engineering has been based around the development and maintenance of classic grid-systems and stations. As green energy has become popular, and the need for electricity has increased, the power-grids are in need of an update to meet demand. Trading of power in international markets has also seen an increase, specifically in the demand for power generated through renewable energy-sources such as solar and hydropower [111]. Power-companies such as Kristiansand based Agder Energi AS have specialized trading companies, tailored for the international power-market [112].

When trading power, the nature and origin is a major concern. Green power (Power collected from renewables) holds increased value in the international market, compared to energy from non-renewable sources such as coal and gas. As a result, being able to guarantee the origin of power is an area of effort for most suppliers of electric energy [111]. Platforms such as Enerchain are attempting to use blockchain networks to reduce trading-times and improve security for international power trading [113].

Today's electricity trading is done online through a broker. The trader uses an index agency to gather prices before closing the trade. After closure, both parties enter the transaction details in their respective IT systems. Back offices then use the transaction details from the system and exchange said information with the broker and each other, as a way of reconciling and confirming the trade. The trade is then settled physically with a transfer of power through international grids, and financially through a third-party clearinghouse or bank. Parties then transfer the transaction-details to relevant auditors and regulators according to local rules and regulations. The process is highly labour-intensive and repetitive, and the costs associated forces large trades to achieve profitability. Some believe blockchain and smartcontract implementation could make brokers and clearinghouses obsolete. By reducing the transfer-costs, and the paperwork burden, blockchain could also allow for trading of smaller volumes, as smartcontracts could be used to automate large parts of the process [114].

Another major area of focus for Norwegian power companies, is KILE-cost (Regulation of quality of supply). KILE-cost amount to between 1 and 1,5 Billion NOK for Norwegian consumers each year [115]. The problem is ever more significant as the world makes its transition to green-energy sources such as wind and solar energy, causing increased frequency of peaks in power and potential grid-burnouts.

The problem with KILE-cost is a direct result of favourable conditions for green-energy production. During peaks, one may observe negative power-prices. Consumers are using less power whilst the wind turbines, hydropower plants and solar energy-panels are producing far more than usual. This causes a massive surge of electricity (a peak) that may max out the capacity of the existing grid, causing a blackout if energy is not spent. When this happens, the power-company will pay consumers to use electricity, in order to get rid of excess power. Companies such as Agder Energi AS, are exploring smart-grid solutions to this problem. Facilitating flexible power-consumption for consumers during times of high production and low demand.

The switch towards smart power-systems is clearly evident. There is a massive amount of smart-meters being deployed in grids, providing basic IoT functionality. The UK plans to install more than 53 Million smart-meters within 2020, one for each home and small business. By using a blockchain based system, information from such devices can be stored safely and more efficiently than in current database technology [116].

In a smart grid, power is diverted automatically depending on supply and demand from end-users. The power-company may for instance turn off the power to your electric car for short period of time during times of low power or use the battery in your electric car as a way of storing some of the excess energy created during peak hours. This is a concept referred to as vehicle-to-grid service. Similar to international trading of electricity, blockchain could improve retail electricity markets by using cryptocurrencies for bill settlement and other "meter-to-cash" processes. By facilitating instantaneous trading, blockchain could reduce the variable costs of payment processing and accounting to that of executing a smartcontract [114].

Requirements for future power systems can be summarized by 3 principles; decarbonisation, decentralization and digitalisation. The current structure of power systems is however insufficient and cannot facilitate all 3 principles. Functionalities such as Peer-to-peer trading and IoT functionality is critical [116]. Blockchain-enables transactions are believed to offer reduced operational cost, increased efficiency, faster and more automated processes, transparency and a reduction of capital requirements for energy companies [117].

Microgrids have previously been limited by the added fees and costs put on prosumers by third parties such as banks and clearinghouses, which reduces the potential gains for end-users. When implementing blockchain-technology for microgrids and Peer-to-peer services, users reap several benefits. The users are pseudonymous, data is easily verifiable and immutable, decentralization removes single point failures for added security and lowered threats from denial of service attacks. These features allow blockchain to be used as an information and communications technology backbone for the open energy market. The concept is also greatly improved through the implementation of automated smartcontracts [118].

A 2017 EU commission report titled "Blockchain in Energy Communities", used an Ethereum based smart-contract design, to provide a proof of concept for blockchain implementation in energy markets. By using the Ethereum platform, users received several benefits, as a result of blockchain implementation [118]:

1. Enables the engagement of prosumers to create energy for communities
2. Enhanced trust and transparency
3. Guaranteed high level of security, integrity and resilience
4. Guaranteed accountability while still maintaining required levels of privacy
5. A large potential for other business-opportunities, beyond the concept of energy community and microgrids.

The concept used a smart-meter to track the power used and produced by a household. Excess energy was stored in a local battery, owned by the prosumer. A controller running on smartcontracts, distributed power and value-tokens, equivalent to the amount purchased or produced by individual consumers and prosumers. The controller invokes smartcontracts on one end, and on the other, receive readings from the grid to facilitate communication between the IoT devices (Smart meters) and the blockchain-based smartcontract. Value-tokens named "Helios Coins", were then used to provide lower prices and monetary rewards for prosumers and customers, depending on their level of production [118].

When implementing a functioning Peer-to-peer grid, we need to fit communication-hardware to a smart electricity meter. The meter reads how much power is consumed and produced, and the communication hardware reads off the meter. When electricity is produced it creates blocks of value, equal to the amount produced. The customer is then only charged for the deficit used, at the end of the month. The excess power can be bought by a third party or a consumer. When he or she purchases power from another consumer, he or she effectively purchases blockchain tokens, equal to the value of power requested. Once paid, the power company makes the physical transfer of power, gaining a small fee. This concept is currently being tested by companies Verbund and Salzburg AG in Austria [114]. By implementing Peer-to-Peer grid services, consumers may save up to 11%, and increase the profitability of their solar panels by 2% [119].

When power-consumption and maintenance-information is logged and stored in blocks, technicians and engineers have access to real-time information, in addition to previous logged information about the grid-section in question. A US-based project was launched in 2019, with the hopes of using a combination of IoT and Blockchain, to better detect malfunctioning devices on the grid [120].

There are a number of active blockchain-projects in the power and grid industry. The table below summarizes some of the largest by user-base and number of collaborators:

Area of application	Proposed Benefit	Project
Energy trading	Reduced costs, latency and improved security in international transactions.	- Enerchain - Interbit
Peer-to-Peer grid services	Lower consumer prices and reduced stress on transmission networks	- Brooklyn Microgrid Project [121] - LO3 - Verbund and Salzburg AG
Grid Flexibility	Improves ability to balance	- TenneT

	power during peaks and increased customer demand. Reduce cost for both consumers and producers	- Electron - Drift - Grid+ - LO3
Vehicle to Grid	Allows for balancing of the power-grid by utilizing the onboard battery of EV`s	- Share&Charge - eMotorWerks
Green Energy Trading	Allows for increased transparency and safety, when trading in green certificates and renewables on the open market	- Solarcoin - Ideo Colab
IoT functionality	Allows for easier implementation of IoT-systems for blockchain-based systems on power-grids.	- Slock.it - Filament

Table 4: Blockchain in power-industry

There is clear interest in applying blockchains for power grids. Companies such as Filament and Slock.it, have also started to develop IoT hardware and supporting architecture, to aid in enabling blockchain implementation [116].

Blockchain is believed to have a significant impact on existing power-systems and power suppliers. Mainly in areas such as [116]:

1. **Billing**
   Automated, safe and correct billing.
2. **Sales and Marketing**
   The ability to accurately track a customer's energy use through IoT and backlogs stored in the blockchain.
3. **Trading and markets**
   Automated transactions and increased trust in green certificates for renewable energy.
4. **Automation**
   Improved control of decentralized grids and microgrids.
5. **Smart grid applications**
   Blockchain enables IoT implementation and safe storage of data.
6. **Security**
   Cryptography enables safe, correct and trustworthy payments as well as data-storage.
7. **Transparency**
   Immutable ledgers could significantly improve auditability and regulatory compliance for larger energy companies.

Blockchains severely disrupt the traditional business models used by energy companies today. Enabling not only increased efficiency and security, but also opening up new potential areas of business [116].

2.9.3. Limitations and Concerns

The main drawback to implementation of blockchain architecture in today's Power Grid, seems to be the slow speeds and high energy costs of permisionless, PoW-based blockchain networks [114]. This stems from the previously mentioned problems of PoW-algorithms and extensive ledger-libraries taking up large amounts of both energy and storage space. A current dilemma is that PoW-based blockchains only exhibit 2/3 of our required properties of Scalability, decentralization and security [114].

A second risk is the unknown threat of cyber-attacks. Once the system is implemented, there is no surefire way to guarantee its integrity. Blockchains with bugs can last without evidence of attack if they are not valuable enough to entice said attacks [114]. One such example can be found from 2016, when a black-hat hacker found an exploit in the Ethereum-based application "The DAO", 70 million USD worth of tokens was stolen due to a software-bug in the blockchain [122].

A related issue is the one of legal responsibility. In distributed systems, it is not always clear who is the liable party in the event of negative consequences from users of the network or service. Furthermore, the EU policy on consumer data (GDPR) is a recent example of legal challenges that affect how private information is stored on the blockchain. As data is forever stored in the public ledger, private information and the right to be deleted, must be protected. [116]. Legal frameworks must be defined and standardized.

We know that if one were to lose his or her private key, there is no conceivable way of retrieving the key. Effectively, this would cause the user to lose all built-up credit and control over ones private blockchain. There is also the risk of forking within large systems. Upgrades to existing blockchains require considerable stakeholder-buy in and can thus be challenging. Without upgrades however, we run the risk of digital assets becoming adversarial [114].

A well-functioning blockchain platform needs to both automate and simplify the billing process, as well as differentiate between community and traditional suppliers of electrical energy due to taxes and legal aspects. If the production and consummation of energy is not accurately monitored and kept, the system becomes highly ineffective. The value-tokens from produced electricity, also needs to have value that reflects the current market price of electricity. Vandebron (A Dutch power-company) has successfully integrated Peer-to-Peer services, in which private contributors are billed monthly, and total value of energy-produced/consumed is calculated based on the information contained in the customers blockchain, from the time the energy was produced [119].

There is a distinct lack of standards and flexibility in current blockchain platforms for grid applications. Standards are vital to ensure interoperability between various technological solutions and systems. An added challenge occurs if one were to make changes to an existing system. Any change must be approved by all nodes in the network, this has historically caused issues with forking and disagreements between developers [116].

The final major hurdle to present implementation efforts, is the large general investment cost, associated with developing and implementing a blockchain for grid applications. Although there is significant cost reductions to be made, these may not be significant enough when compared to existing solutions and technology. One example is the possibility of recording transactions from units of energy, in a traditional database. Such solutions are readily available, with large amounts of engineering skill. In addition to development costs, implementing blockchain may also entail large costs in regard to infrastructure, custom supporting technology and devices. Current smart meters also have limited computational capacity, might require hardware updates to function appropriately as nodes. As the ledger grows, and scaling becomes an issue, the subsequent costs of energy and computational power also increases [116].

2.9.4. LO3 Energy

LO3 Energy is a U.S Based energy company who are already incorporating blockchain based systems into their power-grids and systems. The platform is called Pando, and is marketed as a current, commercially available product [123]. One of the first examples of a commercially available product for grid applications, based on blockchain technology [124].

LO3 focuses heavily on peer-to-peer grid services. The company has successfully implemented several blockchain-based micro-grids and marketplace services in Australia, Asia, Europe and the USA after the first successful microgrid pilot in Boston NYC [125]. Their latest located in Japan, developed with the Kyocera Corporation. Its goal is to facilitate an IoT based, flexible power-service for Kyocera`s customers [126]. The company have also started a collaboration with Shell, and LO3 CEO announced in July 2019 that the company will be releasing their second commercial product “This time next year”. Specifics regarding the launch has not been released [121]. The current LO3 platform deliver solutions for peer-to-peer trading of energy, microgrids, load balancing and EV charging [123].

LO3 is implementing Peer-to-peer trading of green power amongst prosumers in New York [127]. The company has also sold their products to US based Green Mountain Power (GMP), for use in local energy marketplaces in Vermont [128]. The system is meant as an initial pilot, with 200 commercial customers to gauge the initial functionality of the product. GMP has also signed up, and will handle transactions, billing and other administrative functions [129]. Although the Pando platform is commercially available, it is not currently a turnkey solution for blockchain based grid systems, and initial implementation might be slow.

LO3 has obtained partnerships and agreements from a wide range of relevant organizations. Investors include Siemens, PECI, Centrica, GMP and Braemar Energy Ventures [130].
The LO3 core team consists mainly of technical personnel. Developers, engineers and cloud architects. In addition to technical expertise, the project also employs business developers, economists and other non-technical personnel [131].

There is a wide range of other concepts, attempting to create solutions for power-grids. Developments include Energy web, Alastria, Hyperledger and Blockchain futures lab. The Energy web concept for one, can be scaled for several thousand transactions per second, mitigating the scaling problem from traditional blockchains. It is clear that the proof of concept stage for blockchain in the power industry, has already passed. Most concepts however, still require additional development in order to reach the desired functionality and requirements for full scale systems [116].

2.10. Technology Readiness Level

Technology Readiness Level (TRL) refers to a 9 point scale, initially defined by NASA in the early 1990`s. It is used as a means of evaluating the maturity of a technology and spans over 9 levels [132]:

Technology Readiness Level	Description
1	Scientific research has just begun and will be translated to and prepared for future research or development.
2	Basic principles of technology have been studied, with practical applications tied to initial findings.
3	A technology is elevated to TRL 3, once active research and design begins.
4	The technology es elevated to TRL 4 once proof of concept is obtained, and parts of the technology is tested together
5	A continuation of previous level. With the addition of more vigorous testing and requirements for the technology
6	At this stage, we require a fully functional prototype or a representational model
7	The prototype needs to be demonstrated in its working environment to reach this level
8	The system must be fully complete, and work intentionally
9	The actual system must be tested in its intended environment, under realistic conditions. At this stage the technology is deemed mature and ready for market.

Table 5: Technology Readiness Levels

The scale is commonly used in rating a start-up or technology`s current level of maturity. Organizations such as ENOVA, use the TRL scale to determine if a technology is viable for financial support during development, as well as in estimating the remaining time to market [133].

A lower TRL of 1-4 would indicate a more basic research concept, whilst a higher level of 6-9 indicates an applicable solution or product for the intended scope of the project. The scale might seem arbitrary and somewhat loosely defined, as a result, several organizations have developed TRL “calculators” to accurately and consistently determine TRL. It is important to note that TRL analysis only evaluates a specific technology. It may not provide an efficient image of the specific technologies integration, into a larger and more advanced system where unforeseen issues with complementing technologies and systems may occur [134].

Both the US Air Force Research Laboratory and New York State Energy Research and Development Authority (NYSERDA), have developed calculators or algorithms, that determine the TRL of a relevant technology. The calculators take the form of an excel-spreadsheet, where the user fills in information available for the technology at its current stage in development. For reference, below is the NYSERDA calculator based on NASA, DOE and ARPA-E systems, with questions rated from scale a-e. E being the highest rating, and a being the lowest rating (see attached excel-file for full reference). Once the form is filled out, we are given a calculated TRL score for the technology or concept.

1. **Technology**
   a. Project work is beyond basic research and technology concept has been defined
   b. Applied research has begun, and practical application(s) have been identified
   c. Preliminary testing of technology has components have begun, and technical feasibility has been established in a laboratory environment
   d. Initial testing of integrated product/system has been completed in a laboratory environment
   e. Laboratory scale integrated product/system demonstrates performance in the intended applications
2. **Product development**
   a. Initial product/market fit has been defined
   b. Pilot scale product/system has been tested in intended applications
   c. Demonstration of full-scale product/system prototype has been completed in its intended applications
   d. Actual product/system has been proven to work in its near-final form under a representative set of expected conditions and environments
   e. Product/system is in final form and has been operated under full range of operating conditions and environments
3. **Product definition/design**
   a. One or more initial product hypothesis has been defined
   b. Mapping product/system attributed against customer needs has highlighted a clear value proposition
   c. The product/system has been scaled from laboratory to pilot scale and issues that may affect achieving full scale have been identified
   d. Comprehensive customer value proposition model has been developed, including a detailed understanding of product/system design specifications, certifications and trade-offs.
   e. Product/system final design optimization has been completed, required certifications have been obtained, and product/system has incorporated detailed customer and product specifications.
4. **Competitive Landscape**
   a. Secondary market research has been performed and basic knowledge of applications and competitive landscape has been identified
   b. Primary market research to prove the product/systems commercial feasibility has been completed and basic understanding of competitive products/systems have been demonstrated
   c. Competitive analysis to illustrate unique features and advantages of the product/system compared to competitive products/systems have been completed
   d. Full and complete understanding of the competitive landscape, applications, competitive products/systems and market has been achieved
5. **Team**
   a. No team or company in place
   b. Solely technical or non-technical founders running the company with no outside assistance

    c. Solely technical or non-technical founders running the company with assistance from outside advisors/mentors and/or incubator/accelerator
    d. Balanced team with technical and business development/commercialization experience running the company with assistance from outside mentors/advisors
    e. Balanced team with all capabilities onboard running the company with assistance from outside advisors/mentors
6. **Go-to-Market**
    a. Initial business model and value proposition has been defined
    b. Customers/partners have been interviewed to understand their needs, and business model and value proposition have been refined based on customer/partner feedback
    c. Market and customer/partner needs and how those translate to product requirements have been defined, and initial relationships have been developed with key stakeholders across the value chain
    d. Partnerships have formed with key stakeholders across the value chain
    e. Supply agreements with suppliers and partners are in place and initial purchase orders from customers have been received
7. **Manufacturing/Supply Chain**
    a. Potential suppliers, partners and customers have been identified and mapped in initial value chain analysis
    b. Relationships have been established with potential suppliers, partners, service providers and customers and they have provided input on product and manufacturability requirements
    c. Manufacturing process qualifications have been defined and are in progress
    d. Product/system have been pilot manufactured and sold to initial customers
    e. Full scale manufacturing and widespread deployment of product/system to customers and/or users has been achieved.

The NYSEDRA TLR calculator will be used later in the thesis to determine the maturity of selected blockchain concepts and platforms. The TRL scale has been selected as it offers a consistent way of benchmarking emerging and often disruptive technology concepts. Many of the criteria are loosely defined, as most research and development projects have some degree of uncertainty tied to development. By using the TRL scale we are also able to create a consistent comparison between different technologies and applications [135], allowing for quantifiable comparison of blockchain concepts.

2.11. Database Technology

There are many features of blockchain-based systems, not unique or exclusive to blockchain technology. Features such as high security, immutability and backlogs, can also be achieved through the use of database-technology. Main features of databases include storage of large amounts of data, hashing, readily available engineering skill, in addition to functionality for transactions and concurrency control [136].

A Database Management System (DBMS) is a collection of interrelated data and a set of programs to access said data. The collection of data, usually referred to as the database, contains information relevant to an enterprise. Such as shipping-records and data from IoT-devices. The primary goal of a DBMS is to provide a way to store and retrieve database information that is both convenient and efficient [136]. Representative applications of databases include:

1. Banking: To maintain customer information regarding loans and transactions.
2. Airlines: Registering tickets and keeping track of departures.
3. Telecommunications: Keeping records of calls made and available data.
4. Supply chains: Logging and tracking a package or item in international transit.

There are a multitude of domain-specific languages designed for database applications. One of the more commonly used is Structured Query Language (SQL). The application is however coarse, and holds limited value for operations and applications that involve a high volume of individual users. To mitigate this problem, solutions such as Tuple-level authorization applications have been developed. The application deals with large amounts of users, outside of the original database system. Although the tool is developed, it has not reached a point where it has become well known in database development and design

[136].

When developing a database for use in financial transactions, each transaction is required to have ACID properties: Atomicity, Consistency, isolation and durability [136].

- Atomicity: Ensures the effect of a transaction is reflected throughout the database, or not at all. Any failure to the database cannot allow a transaction to become partially executed.
- Consistency: As long as the database is initially consistent, a new transaction must leave the database consistent after its completion.
- Isolation: Concurrently executing transactions are isolated, so that no transaction is occurring concurrently.
- Durability: Guarantees records of executed transactions are not lost or damaged, in the event of a system crash or failure.

There is often extensive design-work required for proper implementation of databases for financial applications.

For a database to operate sufficiently, there are numerous design-considerations that must be made. For instance, not all users of the database should have access to all available data. Someone accessing their grades on the school network, should not be able to access other students` grades as well. In cases where the database is to store varying forms of data, tailored programmes must be developed, to ensure efficient use of the database.

As the number of individual users, and frequency of transactions increase, we may see issues regarding concurrency control for the database. If several transactions are executed simultaneously, the data may no longer be consistent. It is vital for the system to control and limit the interaction amongst concurrent transactions. For use in databases, most common strategies are locking protocols, timestamp ordering, validation techniques and multiversion schemes such as MVCC [136].

Modern databases allow for distributed databases, that greatly limit the risk of single-point failure and accessibility for users. A distributed database system is made up of several geographically spread out sites, each maintaining a local version of the database system. Each of which is capable of recording and processing local transactions and inputs. The site may also participate in the execution of global operations and transactions, but such features require stable and secure communication between sites. Sites may either use a common scheme and database code (Homogenous system) or use different schemas and code (Heterogeneous system). Issues with decentralized database systems include replication and fragmentation of information. It is essential to operation that the system is designed to minimize the need for the user, to know how a relation of information is stored, and which server the information is located [136].

Risks to a distributed system are often the same as for a centralized system. In addition, distributed databases are also susceptible so failure of a site, failure of a link, loss off communication to the site, loss of a message and network partition. If these problems are not considered during the design and development of the database, it may cause significant damage to the operability and dependability of the finished database [137].

In response to a need for cloud-based storage of data from extremely large-scale web applications, several data-storage systems and concepts have been developed. Such systems have excellent scalability for several thousand of nodes. The issue with these systems, is their inability to maintain the ACID principles mentioned above, and not achieving geographical availability at the expense of consistent replicas. Most of these current storage systems, based on cloud technology for traditional databases, do not support SQL and only a simple put() / get() interface is available. There are also issues in regards to data-placement and geographic replication in larger systems, which may render the system unusable for financial applications that require high degrees of certainty [137].

3. Methodology

The methodology used in this qualitative paper, aims to answer the previously formulated problem statement:

"What is the current level of technological maturity, with subsequent challenges and advantages to implementing blockchain technology with focus on selected industries and areas of implementation, outside strict Blockchain 1.0 applications?"

Research on emerging technology is often challenged by the accelerating speed of development, and presence of fragmented interdisciplinary research. Much literary research is often conducted ad hoc, and thus often ignores synergetic effects, carryovers and reoccurring issues outside the often narrow initial scope [138]. To better assess blockchain technology, a research methodology of literary research was conducted, in hopes of creating a more in depth and broad snapshot of the current state of blockchain technology. The information gathered in the literary research, is assessed and put into context for all selected concepts and areas of implementation, focusing on the main aspects relevant to current blockchain technology and implementation.

The literary research was conducted following the "Typical purpose" approach, aiming to synthesize and compare available evidence. The method offers the possibility of analysing whether a concern, advantage or hurdle to implementation, is present in other areas and explored use-cases for current blockchain technology [138], and thus create a more rounded and updated evaluation regarding blockchain technology. This approach differs from much of the currently available research on blockchain, where focus is often put largely on a single area of implementation or technical challenge [5].

The following order of methodology was used:

1. **Initiation and exploration**
   - Research began on general features of blockchain, its main identifiers and proposed areas of implementation. Sources included journals and various online news-stations.
   - Initial foundational theory regarding current blockchain technology was written.

2. **Definition and initial research**
   - The scope was defined, focusing on technical aspects, advantages and possible hurdles of current blockchain technology and implementation.
   - Thesis layout was created.
   - Literary sources included journals, books and reports from consulting agencies.

3. **Selecting focus and areas of implementation**
   - Scope was expanded to include real-world applications of blockchain technology to better gauge the associated challenges and opportunities of successful implementation.
   - The IOTA, Hyperledger and Ethereum platform was selected and studied, as a result of the initial scope.
   - Areas of implementation, with subsequent concepts was identified and selected through grey literature and whitepapers. Grid engineering, Supply chain management, Distributed manufacturing and IoT.
   - PM was added as an area of focus, due to its potential carry-over effects to and from the areas of implementation.

4. **Further literary research, with the addition of grey literature**
   - Grey literature was used to fill in the gaps regarding concept metrics and current state of technology for the chosen areas of implementation. Mainly regarding platforms and the latest news on selected concepts, for use in the TRL analysis.
   - Chosen areas of implementation was researched to identify key industry characteristics, current challenges and any information regarding on-going implementation efforts

5. **TRL analysis conducted**
   - Selected concepts were put through the NYSERDA TRL calculator, with metrics based on

the previously mentioned grey literature study.
  - When metrics were not easily available, technical reasoning or estimation was used and the lowest reasonable score was chosen.

6. **Conclusion and evaluation of concepts.**
   - The results of the literary study, TRL analysis and recent news on chosen concepts was used to gauge the current maturity of blockchain technology for each area of implementation. Blockchain technology is evaluated based on its features and current drawbacks, within each chosen area of implementation.
   - The selected concepts are reviewed and used as markers to identify the current most applicable use for blockchain.
   - An overall conclusion regarding blockchain and its current challenges was derived, with heavy focus on the most critical challenges to large scale implementation, and its potential positive impact.
   - Identifiers of attractive areas of implementation, concept synergy and requirements for successful implementation is derived.
   - Smartcontracts are evaluated and discussed, as the technology makes appearances in all reviewed concepts.

I have utilized literary study from journals, whitepapers and books to gain a sound theoretical understanding of the relevant technology. The need for grey literature arose as a result of limited information in journal articles, regarding ongoing projects and areas of implementation. In addition to commercial products such as Norway in a Box and LO3 Energy, blockchain-platforms such as Ethereum, Hyperledger and IOTA have also been researched and evaluated. These platforms form the basis of several commercial implementations, in a variety of industries [139].

In line with the problem statement of this paper, the thesis must evaluate the current state of blockchain technology. Real world concepts became a necessity in order to explore the latest version and functionality of blockchain technology. By exploring specific concepts, and subsequent industry, the incentives to incorporate blockchain technology becomes more prevalent.

3.2. Selecting Concepts and Areas of Implementation

When selecting areas of implementation and subsequent concepts, 4 factors were weighted:

1. **There should be industry interest in blockchain technology.**
   If there is little perceived interest in the industry to implement blockchain, this may be a sign of either lacking technology or superior alternatives to blockchain. This paper aims to research the current state of blockchain in relevant industry and will thus not include areas of implementation that might become attractive in the future, or offer limited increased functionality. The focus is areas of implementation, currently attractive for the relevant industry. Industry interest most likely indicates either a technological or financial incentive to implement blockchain.
2. **There should be several of concepts at various stages in development, for the relevant use case or industry.**
   A larger number of concepts and products were taken as a sign of either industry interest, consumer interest or clear business need. If there is a business opportunity present, it shows that the technology offers solutions to or improvements to existing systems, or has the possibility of achieving value through the unique features of blockchain, not found in current systems.
3. **There should be clear advantages and incentives to incorporate blockchain.**
   The technology is highly disruptive and offers unique attributes. As a result, areas of implementation should benefit highly from blockchain features, or have current issues, not solved by traditional systems.
4. **There should be at least one concept with a perceived high level of maturity, or finished commercial product**
   In order to gauge the current maturity of blockchain for a relevant use-case, a concept or platform with a high level of perceived maturity creates a more in depth view of the current state of

blockchain. Newer concepts often have limited functionality, and suffer from issues and challenges not representable for the finished product. In order to evaluate the technology, the most far-along concept was chosen for analysis. This concept or platform should more accurately provide insights to the advantages, challenges and incentives for blockchain implementation.

After reviewing possible areas of implementation based on the factors listed above, the following main areas of implementation was selected:

1. **Internet of Things**
   The IoT concept is highly relevant for a large number of technical industries. Current issues in regard to IoT systems are highly in line with the added features of blockchain. Showing a clear possibility of improvement.

   There are several platforms and concepts working on IoT-implementation, with a perceived large interest from relevant industry. Evident through partnerships and press-releases. Several of the platforms are seemingly well developed.

2. **Supply Chain Management**
   Blockchain offers solutions or improvements to several areas of supply chain management. Large corporations including Airbus and IBM are showing interest, with several available projects and concepts being developed.

   By applying blockchain, it seems several of the key functions of an effective Supply Chain system can be improved. Blockchain also offers technological characteristics that seem highly favourable to shipping systems, such as transparency, trust and high levels of security.

3. **Distributed Manufacturing**
   There are few examples of successful large-scale distributed manufacturing. As blockchain has evolved and increased in popularity, more concepts regarding Distributed manufacturing platforms have emerged. Blockchain might offer solutions to some of the main hurdles in creating a successful platform for distributed manufacturing. There seems a clear business opportunity is created, as blockchain allows for a higher level of transparency and trust, than current technologies such as SQL databases.

4. **Smartcontracts**
   The technology and application are frequently mentioned, and reoccurring in blockchain products. There is a large industry interest, evident through projects such as Ethereum quickly becoming one of the most prominent and popular blockchain networks.

   The application is relevant for a large amount of industries, as it facilitates automation and efficiency. Smartcontracts are used in a large number of commercial products and implementations, with some platforms and concepts having reached high levels of commercialization.

5. **Grid Engineering**
   Ideas such as Peer-to-peer trading and smart grids are highly attractive, but offer challenges and hurdles, not easily solved with today's technology. Evident by the very low availability of such systems and services.

   From the identified challenges of grid engineering, blockchain was considered to have technical attributes not found in other technologies, highly applicable to solve challenges regarding resilience, automation and security. There are several concepts in development, with some even having reached commercialization.

6. **Project Management**
   There are clear incentives to incorporate blockchain for PM, as it may lead to increased success-

rates of projects, reduced risk and more efficient reporting. There are however no available concepts, or high degree of industry interest. The section has been included to gauge potential carry-over-effects from other systems and industries, as well as non-traditional uses of current blockchain technology.

3.3. Interning at Agder Energi AS

During the summer of 2019, I was a summer intern at Agder Energi AS. The company has received the “Innovative Star of Energy Efficiency; Power Generation & Supply Award” for their work on smart grid systems in cooperation with Microsoft [140]. The company is heavily focused on innovating and improving the power grid, with focus also spent on exploring more flexible and smarter grid-systems [141].

I was part of the 2019 Summer Internship as a project manager and mechanical engineer. Although my project was focused on the development of battery-systems, blockchain was a reoccurring theme of discussion and interest amongst my co-workers. There was considerable interest in the technology amongst engineers and managers at Agder Energi, as well as in the power grid industry.

As I had already decided on the topic of my thesis, preliminary interviews with my supervisors and co-workers was conducted, focusing on blockchain applications for grid engineering. These interviews gave me an initial understanding of the possible problems that might be solved by implementing blockchain, specifically for grid-engineering and IoT.

3.4. Scope and Initial Research

During the summer of 2019, I had many talks with senior grid-engineers and executives regarding their thoughts on the future of blockchain in power grid engineering. All of which seemed very eager and had high hopes for the technology, even though few appeared to have a sound technical understanding for the technology behind blockchain implementations. This was a trend I observed throughout my preliminary research on blockchain: People seemed to be largely positive and optimistic to blockchain, without any technical understanding or knowledge regarding the technology. As a result, it became increasingly important to me to make sure I didn’t fall to temptation and overly focus on the positive aspects of blockchain.

The challenges and drawbacks to blockchain technology has been a consistent focus. Largely due to the fact, that issues and concerns seemed much more rarely mentioned in journal articles and press-releases. With a technology this powerful and disruptive, one should assume that it would already see efficient implementation? Yet I have never heard of a properly implemented, full-scale use case of blockchain technology in technical industry upon starting work on this thesis. The scope was then expanded to also include challenges, unique to each area of implementation. This significantly broadens the area of focus, limiting the possibility of going into detail for each area of implementation. As a result, general industry-specific challenges, opportunities and specific blockchain technology was prioritized.

Limited focus was put on data-science and subsequent system architecture behind blockchain. My academic background has revolved around Project management, mechanical engineering and industrial economics. As a result, I wanted to explore venues in which I had tangible skills, or that would allow for a proper understanding of technology applications. I thus included traditional contract design and PM, as these areas seemed to hold carry-over effects for developing smartcontracts (traditional contracting theory) or benefit from blockchain technology implementation. Particularly PM was identified as an area with possible carry-over to a large amount of industries, both technical and fiscal [38].

3.5. Reviewed Literature

Literary review revolved heavily around the journal libraries of IEEE, Journal of Cryptography, Journal of artificial intelligence research, SIAM and more. Though articles were plentiful, many appear to render similar, and highly theoretical information with little emphasis on real world applications outside Blockchain 1.0. Other papers focused largely on fiscal applications of Blockchain 1.0, with little emphasis or thought to technical aspects or challenges, outside cryptography and legal aspects [5].

Trade articles and grey literature proved very useful and were used as a means of getting the latest news on ongoing projects. As with any disruptive technology, innovation is rapid. So rapid in fact that the latest concepts and thoughts may not have had the time to make it into peer reviewed journals. Technical Consultants, investors and blockchain-developers do however write so called whitepapers, detailing the technology and business case of their respective concepts. These whitepapers were a great source of information as they also included actual use-cases, more up to date information and potential issues with the relevant concept or area of implementation.

Grey literature such as blogs, workshops, twitter-feeds and podcast became important inspiration and help regarding specific projects such as LO3 and Norway in a Box. These are however not cited, as I do not consider them trustworthy sources. They were however great help in navigating potential concepts, industry professionals and promising areas of implementation that currently surround blockchain technology. Developers and CEO`s of blockchain-platforms and companies, frequently appear on tech-podcasts to discuss technology and ideas. From these podcasts I did further research in journals and articles, to verify and support the claims made.

3.6. TRL-Analysis

TRL-analysis was performed to gauge the current level of maturity for blockchain technology. TRL analysis was conducted for each of the following concepts:

1. Grid Engineering: LO3
2. Smartcontracts: Ethereum
3. Supply chain management: Hyperledger Fabric
4. Distributed Manufacturing: Genesis of Things
5. IoT: IOTA

The analysis is based on NYSERDA`s TRL algorithm which is publicly available online. The algorithm calculates and gives the TRL based on the 7 key areas identified and listed in section 2.10. This information was used to rank and ascertain the current maturity of blockchain-based concepts in platforms, within the relevant industry.

The NYSERDA TRL algorithm uses a set of 35 questions that must be answered to get a final TRL score. Each of which are associated with a specific TRL, and a TRL is only given once all questions associated with said TRL are satisfied. For instance, if we are to ascertain TRL 6, all assumptions for TRL 1 through TRL 6 must be true. The questions used are formulated as Yes/No, and I have chosen to go for the lowest reasonable answer, whenever information was difficult to obtain, or non-reputable. This may lead to a slightly lower TRL for some concepts [142].

There were issues in obtaining specific and true information regarding R&D [41], beta-testing, market-insight and specific supply chains for several of the chosen concepts. This information is often not public and difficult to obtain. When in doubt, I applied a basic technical logic. For instance; since Hyperledger Fabric`s full version is available for use by its members, it is safe to assume that “Actual product/system has been proven to work in its near final-form under a representative set of expected conditions and environments”, which is the second to highest TRL level in the “Product Development” section of the test. As the concept is not in full use at major shipping-corporations, the highest level was not chosen. A similar logic and “common sense” were used for all analyzed concepts when information was not obtainable.

Platforms were sometimes chosen for the TRL analysis, over a specific commercial product such as Norway in a box. The aim is to better evaluate the current state of blockchain, by assessing the functionality and current challenges of the established platforms that enable further development of commercial products. If the platform is easily accessible and has the required level of technical maturity, further implementation efforts and development of various commercial products, should be made subsequently easier. In Industries such as Grid engineering, issues and perceived areas of utility are considered to be largely similar, as there are clear incentives and areas of application for the technology. Thus, commercial products such as LO3 was chosen over platforms.

3.7. Conclusion and Final Results

The final conclusion aims to evaluate the current state of blockchain technology, through the literary review and analyzed concepts/platforms. The conclusion focuses on unique incentives and challenges, currently facilitating or hindering blockchain implementation, not limited to strict technical aspects. Selected concepts and platforms are also evaluated individually in section 5.2, to better assess the possibility of implementing blockchain for the relevant unique industry or use case. Although some areas might be primed for blockchain implementation, technical or even non-technical aspects (such as legal and financial) might have a significant effect on the current viability of blockchain technology.

In addition to unique industry challenges, advantages and potential rewards from successful implementation of blockchain technology is discussed. In order to undertake the large cost and development effort associated with blockchain, there should be considerable upsides for the relevant industry. These upsides are used to assess how current blockchain technology, provide technological advantages not found in competing technology.

Concept synergy is explored and evaluated to assess how current blockchain technology benefits from increased technological functionality. Several of the reviewed projects use more than 1 blockchain technology and functionality. If a concept with extensive blockchain functionality beyond simple 1.0 or 2.0 achieves a higher TRL score and commercial success, it may indicate a need for other projects and platforms to support increased functionality. The most successful concepts are used as markers to identify the current most critical blockchain functionality, across industries.

The lessons learned and subsequent analysis of each selected concept, is used to identify the key markers for applicable areas of implementation, as well as requirements for successful implementation. The markers and requirements are based on the collective characteristics of the reviewed concepts and areas of implementation, as well as the identified main strengths of current blockchain technology.

Section 5.4 explores if there is an actual need for current blockchain technology across industries. Features such as data-storage and no single-point failure is accessible through simple and easy to obtain SQL technology. The section investigates the key features of blockchain, not found in competing technologies.

3.8. Methodology Drawbacks and Limitations

Literary study of a wide range of blockchain-applications, create a general overview of the current state of technology, and the subsequent challenges and advantages to implementation. The study does however, not go into explicit detail in any of the reviewed areas of implementation. This may create issues regarding the final conclusion, and evaluation of the current state of blockchain technology, as perceived smaller issues, might be more significant than they appear.

Technology and industry-specific challenges are explored in the context of blockchain technology. As a result, the complexity of some issues may be underappreciated. This may create an overly positive or negative image of the current state of blockchain technology, as subsequent conclusions are based on a general understanding of the unique challenges faced by each industry. This is a direct result of the broad scope, selected in this thesis. I have however relied on several publications and sources, when researching current challenges to both the industry and relevant blockchain technology. Attempting to include the most important aspects for both the industry and current blockchain technology.

When evaluating reoccurring issues in the reviewed areas of implementation, the individual complexity of reoccurring issues is not properly ranked. In order to properly rank and assess challenges, we need additional detail and preferably additional metrics for the relevant industry or use-case. Although legal aspects are frequently mentioned, the complexity of creating said legal frameworks are not covered due to my limited academic background. Current improvement-projects for blockchain are also not covered. Such projects may solve several of the challenges listed in this paper. They are however not relevant to the current state of blockchain, and is thus largely omitted, unless highly relevant for the specific use-case.

Some of the more detailed technical aspects regarding smartcontract enforcement and monitoring, have been largely unexplored. Although smartcontracts has been a large focus, the supporting technology has not been heavily researched. This may create an unfairly high perceived maturity, as the issues with supporting hardware and legacy systems are not heavily explored outside blockchain-related literature. The limitations and current availability might create larger challenges than expected in some cases. There is also little available literature, that formulates and explores the specific challenges to final stage implementation, monitoring and enforcement of smartcontracts. Both on the Ethereum network, and private permissioned networks [5].

Areas such as Grid engineering, IoT and supply chain management, are all capable of being the sole focus of the study. The areas are highly complex, with industry unique properties and challenges. When reviewing areas of implementation, literature focusing on current issues for the industry has been prioritized. This to create the general understanding of the industry, required to evaluate subsequent blockchain technology. This may cause underlying industry issues to not receive the deserved focus, as they are not unique or highly relevant to current blockchain technology.

The study does not calculate, estimate or heavily research the specific requirements of blockchains for the relevant use-case or industry. Although scaling is addressed, the study does not cover the specific point in which scaling becomes an issue, or whether the relevant use-case can function at a smaller network-size. Such metrics must be estimated through analysis, not covered by literary research.

IoT considerations does not include specific research on currently available IoT hardware. The topic is explored to some degree, but the specific system requirements of blockchain-geared IoT devices are not explored. Conclusions are based on reviewed literature, where IoT devices are mentioned or explored. Such secondary technology is vital to achieve successful implementation, but due to the focus of this paper being a broader look at blockchain technology, further research into specific hardware and legacy systems have not been prioritized. This may cause the evaluated maturity of blockchain for IoT, to be slightly elevated or reduced, in the event of hardware being easier or more difficult to obtain than assumed.

By analyzing a platform over a specific product, the TRL will not reflect issues and concerns regarding non-technical problems or potentially relevant issues in other or secondary parts of the industry. Evaluating IOTA as a marker for IoT maturity, will not include or evaluate how the supporting technology and hardware. Largely due to how the TRL is conducted, focusing on the technology and capability of the project or technology in question, not the industry as a whole, or availability of supporting technology. The literary research will be used in hopes of mitigating such gaps when evaluating platforms in the conclusion, but may not provide sufficient level of detail, due to the broad scope of the thesis.

Required information for the TRL analysis was not always available. The questionnaire requires specific information regarding product development and market research, that is not easily accessible for several of the reviewed concepts. Mainly Genesis of Things, with some minor lacks in information for other concepts and platforms. Whenever information was insufficient, the technological reasoning explained in section 3.6 was used. As a result, grades were consistently lowered in the absence of information. For projects such as Genesis of Things (where public information is highly limited), this might result in a far lower TRL score. For other projects (despite the harsh grading), perceived lower complexity from lacking research (particularly regarding IoT hardware and non-technical aspects), might result in higher TRL scores.

Although PM is a selected area of focus for this thesis, no relevant project was used in the TRL algorithm to assess the maturity of PM blockchains. PM is explored as a possible venue for current blockchain based on the literary review and perceived strengths or limitations of current blockchain technology and PM practice. There were no current projects on PM coinciding with the selection criteria in section 3.2. The subsequent conclusion is thus drawn from traditional PM theory and the main strengths of current blockchain technology. Unique aspects might be overlooked, as a result of lacking case-studies or peer-reviewed literature on blockchain for PM.

4. Results of TRL analysis

This section covers the results of the NYSERDA TRL algorithm for the following selected concepts and platforms:

1. IoT: IOTA
2. Distributed Manufacturing: Genesis of Things
3. Supply Chain Management: Hyperledger Fabric
4. Grid Engineering: LO3 Energy
5. Smartcontracts: Ethereum

Each segment includes the reasoning for each given score, and the final estimated TRL of each project/platform from the NYSERDA TRL algorithm.

4.2. IOTA – Internet of Things

Technology: Grade 5
The platform is publicly available and has demonstrated the ability to satisfy initial technology demands. The unique "tangle" technology is unique for IOTA, and recent collaboration with FIWARE show that the technology is ready for use. The platform is considered to be highly limited by IoT-hardware and frameworks. The technology is however considered highly developed and given grade 5.

Product development: Grade 4
Near-final form of the platform has been successful under a representative set of expected conditions and environments.

Product definition/design: Grade 3
The application struggles with concerns regarding scaling, selfish mining and lack of engineering skill/IoT frameworks. As a result, it is reasonable to believe that certification, customer research and design optimization required for higher TRL-levels, are still ongoing.

Competitive Language: Grade 4
There is no platform with the same singular focus on IoT-applications as IOTA. The platform also boasts the tangle-technology, unique to the platform. Later additions of smartcontract-features however, indicates that the platform is still expanding and working to understand the market needs for the platform.

Team: Grade 5
The IOTA platform receives extensive support from interested investors such as Microsoft and Bosch. Large industry partners are contributing with interdisciplinary knowledge and resources, outside IOTA`s core development team.

Go-To-Market: Grade 4
The platform has formed relationships and collaborations with key stakeholders and corporations, across the potential value chain. The platform is missing official purchase-orders, or large-scale commercial projects using the platform.
Manufacturing/supply chain: Grade 4
Initial partners are attempting to utilize the current version of IOTA, with no example off a full-scale use or commercial use outside initial partner organizations and pilot projects. Although used by initial collaborators, there is no widespread deployment of the platform in commercial products or projects.

Final score:

Technology Readiness Level 8

Commercialization Readiness Level 8

Category	Answer
Technology	Laboratory scale integrated product/system demonstrates performance in the intended application(s)
Product Development	Actual product/system has been proven to work in its near-final form under a representative set of expected conditions and environments
Product Definition/Design	The product/system has been scaled from laboratory to pilot scale and issues that may affect achieving full scale have been identified
Competitive Landscape	Competitive analysis to illustrate unique features and advantages of the product/system compared to competitive products/systems has been completed
Team	Balanced team with all capabilities onboard (e.g. sales, marketing, customer service, operations, etc.) running the company with assistance from outside advisors/mentors
Go-To-Market	Partnerships have been formed with key stakeholders across the value chain (e.g. suppliers, partners, service providers, and customers)
Manufacturing/Supply Chain	Products/systems have been pilot manufactured and sold to initial customers

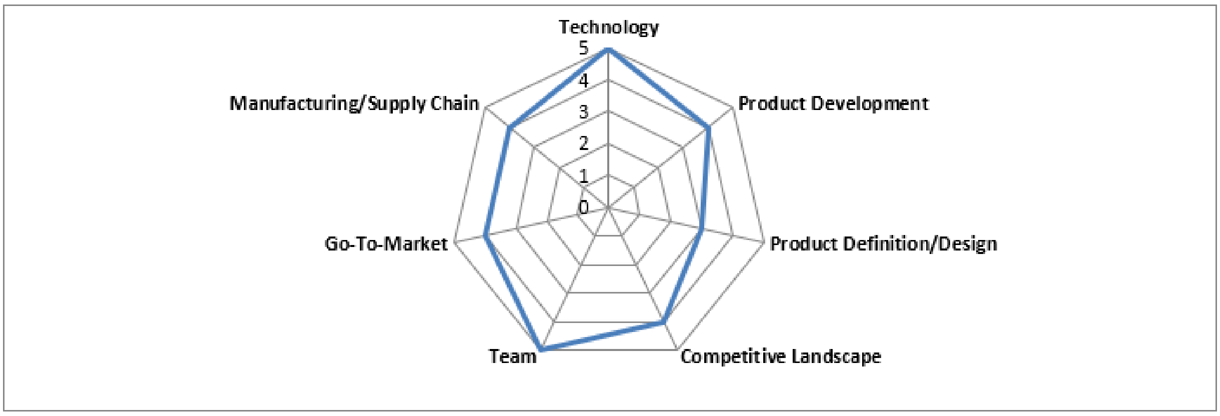

Figure 9: IOTA TRL Results

The IOTA platform reaches a TRL score of 8. Its main limiting factors are product definition/design and competitive landscape. The product has also yet to see successful implementation in full scale, commercial systems or products.

4.3. Ethereum – Smartcontracts

Technology: Grade 5
The concept has been used for several applications and demonstrates desired functionality and performance in its intended areas of interest. Laboratory scale integrated product/system demonstrates performance in the intended applications

Product development: Grade 4
The platform has operated for several years as a large permisionless network and been used for a wide variety of products and projects. However, the Product/system is not in its final form and has not yet operated under full range of operating conditions and environments in full-scale systems.

Product definition/design: Grade 4
Comprehensive development has been completed, with the platform boasting several tools for developing, testing and implementation of smartcontracts. Grade 5 is not achieved however, as the platform is still finalizing its tools and functions for commercial use, and customer optimization.

Competitive Language: Grade 5

Ethereum has been focused on smartcontract applications since the start. The platform has grown to the largest and arguably most well-known platform for blockchain 2.0 applications. The platform seems intent on continuing their focus and seems to have a sound understanding of target functionality and applications. Later add-ons such as BESU however, suggests the platform is still expanding on its competitive advantages.

Team: Grade 4
There is little information relating to the specifics of the Ethereum team. The presence of EEA greatly contributes to the team with outside advisors. The collaboration consists of several large industry partners, from several industries. However, due to the limited information on the Ethereum core team and scale/specifics of collaboration, grade 4 is selected.

Go-To-Market: Grade 5
The platform has seen much use in a variety of applications and concepts, with a seemingly high degree of interest in the platform, across multiple industries. The platform is the largest of its kind, and widespread deployment of product/system to customers and/or users has been achieved. The platform is also sold to/collaborating with other platforms such as Hyperledger, to offer smartcontract functionality.

Final Score:

Technology Readiness Level	**9**
Commercialization Readiness Level	**5**

Category	Answer
Technology	Laboratory scale integrated product/system demonstrates performance in the intended application(s)
Product Development	Product/system is in final form and has been operated under the full range of operating conditions and environments
Product Definition/Design	Comprehensive customer value proposition model has been developed, including a detailed understanding of product/system design specifications, required certifications, and trade-offs
Competitive Landscape	Full and complete understanding of the competitive landscape, target application(s), competitive products/systems, and market has been achieved
Team	Balanced team with technical and business development/commercialization experience running the company with assistance from outside advisors/mentors
Go-To-Market	Partnerships have been formed with key stakeholders across the value chain (e.g. suppliers, partners, service providers, and customers)
Manufacturing/Supply Chain	Full scale manufacturing and widespread deployment of product/system to customers and/or users has been achieved

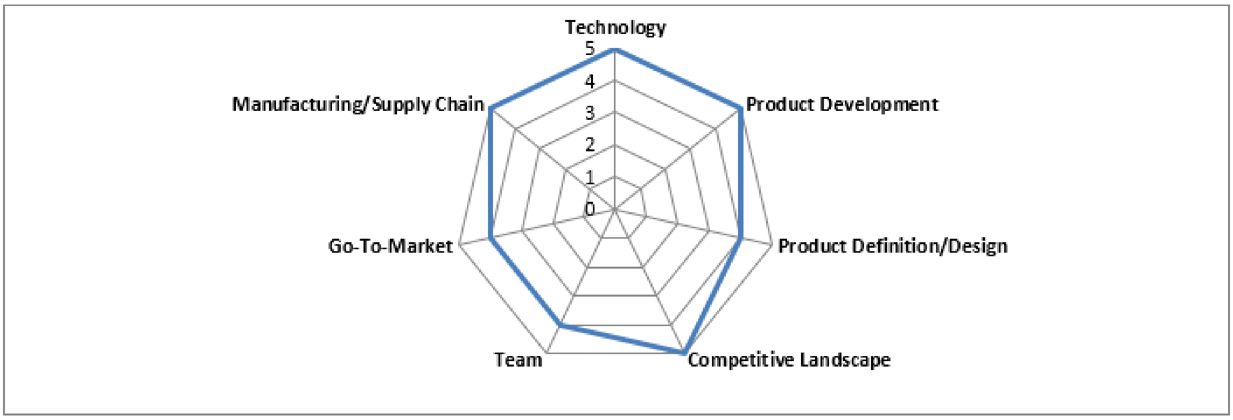

Figure 10: Ethereum TRL Results

The platform receives TRL 9. The platform is highly developed and boasts a high technological maturity. Its drawbacks are related to product definition/design, limited full-scale products and little available information on the core development team.

4.4. Hyperledger – Supply Chains

Technology: Grade 4
The system has been utilized and used in smaller to medium sized tests. The platform has however not seen use in a full-scale supply chain and does not receive the highest grade.

Product development: Grade 4
Actual product/system has been proven to work in its near-final form under a representative set of expected conditions and environments.

Product definition/design: Grade 4
The project has yet to complete final design optimization, and does not have detailed customer product requirements for customers outside the initial collaboration. Collaborators are constantly developing and improving the platform, to better align with consortium members` interests.

Competitive Language: Grade 4
Although the project is clearly geared towards supply chain management, recent implementations of other functions suggest a slight lack in choice of target applications and market. The large consortium contributes to an extensive amount of possibly unique features.

Team: Grade 5
Contributing corporations include IBM, Airbus and Daimler. The project has extensive technical and interdisciplinary support, from several participating organizations.

Go-To-Market: Grade 4
Key partnerships have been formed with relevant collaborators across large parts of the value chain. There are however no official purchase-orders or planned full-scale implementations, leading to a slightly lower grade of 4.

Manufacturing/supply chain: Grade 4
The project has been sold and applied to some degree by project contributors but has not reached full scale deployment in large international supply chains or shipping systems. Initial customers from the consortium, have however utilized the platform in pilot projects.

Final score

Technology Readiness Level 8

Commercialization Readiness Level 8

Category	Answer
Technology	Laboratory scale integrated product/system demonstrates performance in the intended application(s)
Product Development	Actual product/system has been proven to work in its near-final form under a representative set of expected conditions and environments
Product Definition/Design	Comprehensive customer value proposition model has been developed, including a detailed understanding of product/system design specifications, required certifications, and trade-offs
Competitive Landscape	Competitive analysis to illustrate unique features and advantages of the product/system compared to competitive products/systems has been completed
Team	Balanced team with all capabilities onboard (e.g. sales, marketing, customer service, operations, etc.) running the company with assistance from outside advisors/mentors
Go-To-Market	Partnerships have been formed with key stakeholders across the value chain (e.g. suppliers, partners, service providers, and customers)
Manufacturing/Supply Chain	Products/systems have been pilot manufactured and sold to initial customers

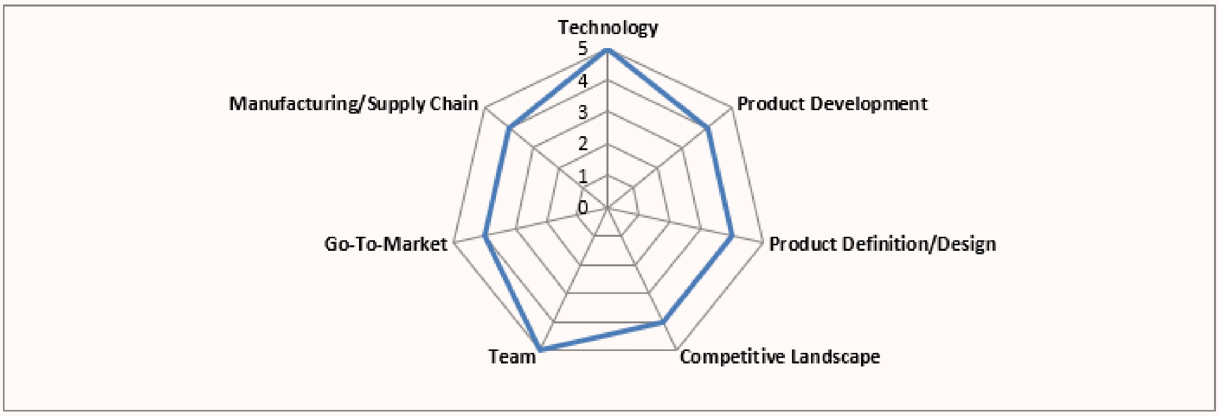

Figure 11: Hyperledger Fabric TRL Results

The project reaches a TRL of 8. Limiting factors are focused around the specific functionality of the final platform, and the inability to incorporate the system into full scale supply-chains.

4.5. LO3 Energy - Grid Engineering

Technology*:* Grade 5
The implementation of blockchain for power grids are well underway. Blockchain based concepts from LO3 have been tested even outside laboratory conditions. The technology has been tested at scale and demonstrates performance in the intended application.

Product development: Grade 4
The initial product has worked well during pilot testing, with a second pilot on its way in Vermont. These systems are however pilots with n=200 customers. The product has not been used under full range of operating conditions in larger systems.

Product definition/design: Grade 5
Customer needs have been identified and incorporated. The potentially final design optimization is being tested in Vermont and NY, with required permission and certificates received in order to connect the system to the local power grid.

Competitive Landscape: Grade 4

There is a clear strategy from LO3 to focus on microgrids, and thus not having to contend with the grid-monopolies of larger power-companies. Due to the rapid arrival of a second commercial product, LO3 seems eager to capitalize on recently discovered areas of interest. Companies working on Grid-applications are constantly emerging, and thus it might be hard to clearly map competition.

Team: Grade 5
The team consists of both economists, engineers and others, relevant to develop and deliver the final product.

Go-To-Market: Grade 5
LO3 Energy has formed partnerships with key stakeholders such as GMP, to facilitate the implementation of initial installations such as the Vermont pilot.

Manufacturing/supply chain: Grade 4
Initial pilot-facilities and smaller deployments have been manufactured and implemented. Widespread deployment of product to customers and/or users, have not been achieved with only a few current implementations in Vermont and NY.

Final score:

Technology Readiness Level	**9**
Commercialization Readiness Level	**8**

Category	Answer
Technology	Laboratory scale integrated product/system demonstrates performance in the intended application(s)
Product Development	Product/system is in final form and has been operated under the full range of operating conditions and environments
Product Definition/Design	Comprehensive customer value proposition model has been developed, including a detailed understanding of product/system design specifications, required certifications, and trade-offs
Competitive Landscape	Competitive analysis to illustrate unique features and advantages of the product/system compared to competitive products/systems has been completed
Team	Balanced team with all capabilities onboard (e.g. sales, marketing, customer service, operations, etc.) running the company with assistance from outside advisors/mentors
Go-To-Market	Supply agreements with suppliers and partners are in place and initial purchase orders from customers have been received
Manufacturing/Supply Chain	Products/systems have been pilot manufactured and sold to initial customers

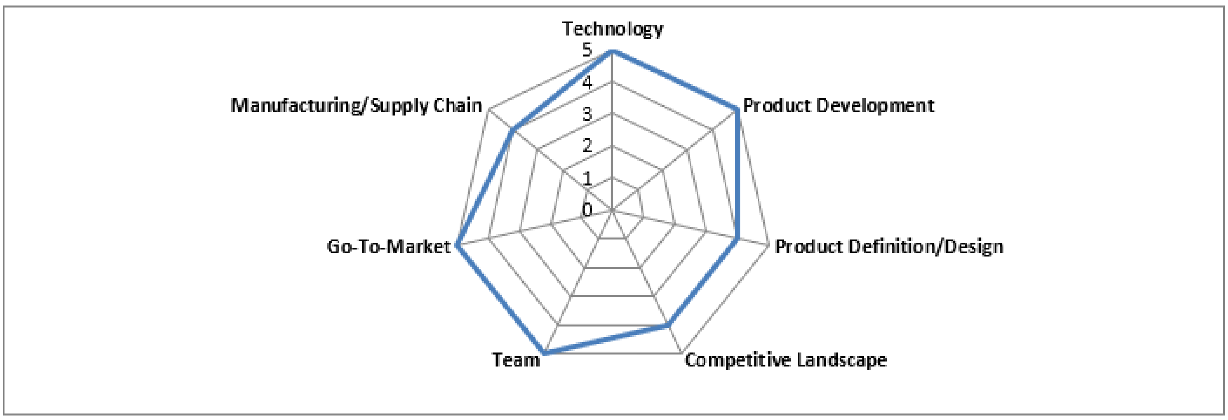

Figure 12: LO3 Energy TRL Results

LO3 receives a TRL of 9. Hardly surprising since the company has already deployed several commercially available products. Although the company is still developing pilots, the technological maturity seems highly sufficient.

4.6. Genesis of Things – Distributed Manufacturing

Technology: Grade 3
There is no record of any testing outside initial proof of concept. Technical feasibility has been established through participating organizations and the AM cufflinks as proof of concept.

Product development: Grade 2
Pilot scale product/system has been tested in intended applications, but no further tests have been conducted.

Product definition/design: Grade 2
Although system attributes and requirements may be defined, there is little evidence showing the Genesis of Things projects, has been scaled to a functioning pilot outside testing-conditions. Design-information is highly limited.

Competitive Language: Grade 2
There is no record of any comprehensive market research, outside the initial group of contributors and partners.

Team: Grade 4
The project is owned by Innogy, who has large resources in a variety of fields available to the project. Relevant contributors provide valuable input and resources in their respective field.

Go-To-Market: Grade 3
Initial partners and their needs have been identified. Market and customer/partner needs have been defined, and initial relationships have been developed with key stakeholders across the value chain.

Manufacturing/supply chain: Grade 2
Relationships have been established, working together for form the requirements of the platform. The manufacturing process however has not been initiated.

Final score

Technology Readiness Level 3

Commercialization Readiness Level 2

Category	Answer
Technology	Preliminary testing of technology components has begun, and technical feasibility has been established in a laboratory environment
Product Development	Pilot scale product/system has been tested in the intended application(s)
Product Definition/Design	Mapping product/system attributes against customer needs has highlighted a clear value proposition
Competitive Landscape	Primary market research to prove the product/system commercial feasibility has been completed and basic understanding of competitive products/systems has been demonstrated
Team	Balanced team with technical and business development/commercialization experience running the company with assistance from outside advisors/mentors
Go-To-Market	Market and customer/partner needs and how those translate to product requirements have been defined, and initial relationships have been developed with key stakeholders across the
Manufacturing/Supply Chain	Manufacturing process qualifications (e.g. QC/QA) have been defined and are in progress

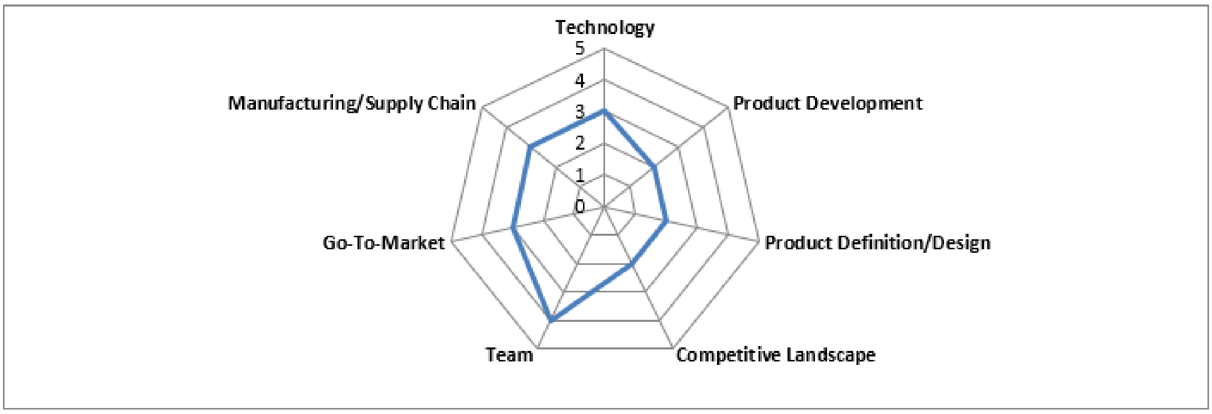

Figure 13: Genesis of Things TRL Results

Genesis of Things receives a TRL of 3. Its main drawbacks are insufficient product development, design and competitive landscape, with limited information on the specific workings and functionality of the planned final product.

5. Conclusion

Blockchain technology is still very much an emerging technology, evident by the extreme demand for qualified blockchain engineers, few commercially available products, few commercially successful areas of implementation and reoccurring issues with scaling, supporting architecture and lack of legal frameworks across the reviewed concepts and platforms. Some successful implementations are however present. Examples include IOTA, LO3 and Ethereum, with TRL`s of 8 and 9 indicating a high level of technological maturity in the selected area. Genesis of Things however, received a TRL score of 3, indicating that the technological maturity of the concept is still very low, and not yet ready for commercialization in full-scale manufacturing industry. The low score of Genesis of Things is also a result of lacking information and limited examples of successful pilot tests. Aspects that are not direct consequences of immature blockchain technology.

Platforms such as Hyperledger, Ethereum and IOTA significantly eases implementation by providing an established blockchain network, with the addition of developer tools for testing and implementation. However, platforms are still susceptible to many of the reoccurring issues of blockchains. Mainly no legal frameworks, lack of supporting architecture, and lack of engineering skill. Industry-unique challenges and requirements may also drastically increase the difficulty of implementation. Hurdles such as user privacy, and technological issues such as bugs, are some of the issues making implementation more difficult, despite having an established platform, and required supporting architecture and/or engineering skill.

Every application of blockchain 2.0 and 3.0 has a high level of uniqueness, and thus the functionality and features of the blockchain require adaptation and customization to fit its intended use. As Blockchain 3.0 may refer to an extremely extensive and varied amount of use-cases, creating turn-key solutions is arguably impossible with current blockchain technology. It might still be possible to create solutions and tools for easy IoT implementation and Supply chain monitoring as Hyperledger and IOTA are attempting. Largely due to the high degree of similarity in the issues and requirements of larger supply chain management systems. The most successful concepts reviewed in this thesis, all applied functionality from a variety of blockchain technologies. Including IoT, Smartcontracts and Blockchain 1.0. Smartcontracts are considered vital to reach required functionality and is a reoccurring feature in all projects/platforms with a TRL score of ≥ 8.

Blockchain 2.0 is more strictly defined than 3.0 but is still in need of customization to be efficient in its intended use, as a result of the huge amount of potential use cases. Frameworks such as ER^{EC} which delivers a more systematic approach to smartcontract modelling, might reduce the difficulty of developing smartcontracts. As blockchain 2.0 platforms have evolved, traditional contract strategy can be implemented to some degree when developing smartcontracts. The base theory of explicit contracting elements is just as relevant for smartcontracts, due to the high level of customizability provided by the presence of Blockchain 2.0 platforms such as Ethereum.

A smartcontract is only as good as its maker. For the contract to be viable, it must be entirely explicit, and have access to appropriate metrics. This severely limits their area of application to strictly explicit contracts. Given needed supporting technologies within automation and IT, Smartcontracts could help revolutionize automation of both physical and computerized tasks in large systems. Once combined with efficient IoT systems, smartcontracts become even more viable. Largely since additional, trustworthy metrics, allows for more automation and more efficient controlling, without the need for human labour or intervention in large supply chains, power grids and other relevant systems.

Smartcontracts are a vital part and an arguable requirement, for reaching full functionality and optimized implementation of blockchain based systems, across all reviewed concepts and industries. The ability to create simple logics, that use the immutable, trustworthy information from the blockchain to perform actions in a system or non-blockchain system, is extremely disruptive and highly versatile. The projects with the highest TRL (Hyperledger, Ethereum, LO3) have all implemented smartcontracts and relevant tools for smartcontract development and implementation. Without this functionality, the blockchain has no way of doing little more than perform transactions, and record information.

Despite the technical challenges associated with the current state of blockchain technology, the potential benefits of successful implementation in the reviewed industries is very large. The core functionalities of any blockchain could significantly alter and improve all reviewed industries. Increasing security, functionality, reduce overall costs of reporting and automate standardized payments or actions. In addition to strict improvements, the disruptive nature of blockchain technology gives rise to a large amount of potentially new business-models and opportunities such as peer-to-peer grid services and distributed manufacturing with no added trust tax.

The main observed benefits from successful implementation of current blockchain technology in the areas of interest (based on literary research and reviewed concepts) can be summarized as:

1. **Transparency**
   Distributed networks with consensus algorithms, allow for full transparency for all users. Drastically reducing the risks of concurrent transactions and fraud.
2. **No trust-tax**
   Nodal confirmation allows the network itself to create trust and validate transactions. This removes the need for a third party such as a bank or clearinghouse, which may in turn provide lover costs, even in larger transactions.

3. **Auditable trail**
   As information is automatically stored on the public ledger, information is kept safe. Creating an easily accessible and trustworthy auditable trial.
4. **Increased efficiency and productivity though smartcontracts**
   If implemented, smartcontracts are a safe and highly versatile way of automating cyclic, reoccurring or singular actions within a system. Platforms such as Ethereum has allowed users to create their own individually tailored smartcontracts.
5. **Decentralized architecture**
   As information is stored on all nodes of the network, data is stored safely and is always accessible, with no single point failure. In the event of a catastrophic failure within the system, the information is kept safe on each individual node of the network.
6. **Immutable data**
   The nodal confirmation associated with blockchain networks, make altering information on the chain impossible. This in turn creates a high level of trust.
7. **Security**
   As the network reaches a certain size, blockchain networks provide excellent security for its users. Hacking and malicious software is present but is generally observed during the infancy of a blockchain.
8. **Ability to safely handle payments and sensitive information.**
   Blockchains are well suited to record large amounts of transactions and information, with perfect accuracy and trust. Particularly for applications requiring complete accuracy (Time, amount, participants, etc) and auditability of previous transactions. This also applies to large amounts of sensor-data from IoT devices.
9. **Highly applicable for financial applications.**
   Blockchains adhere to the ACID principles and provide built-in concurrency-control, as a direct result of the technology.

The main weaknesses and implementation-hurdles of current blockchain technology observed across the reviewed concepts and areas of implementation, can be summarized as:

1. **Availability and support**
   Although applicable platforms are being developed, there is still a lack of industry-specific solutions, standards and frameworks.
2. **Change Management**
   Once a change is made to the blockchain, it can be extensive work to alter and add functionality to the blockchain. I have come across several examples such as Bitcoin-NG, where changes made to the blockchain caused extensive financial losses.
3. **Integration with older IT-systems**
   If all nodes of the network are not running on the same version of the Blockchain, it greatly increases the risk of forking within the chain.
4. **Low capacity and processing speed**
   The problem is observed with large permisionless blockchains. The large public ledger, coupled with energy-demanding proof of work algorithms, may cause long lead-times and low capacity due to limiting amount of processing power.
5. **Ownership challenge**
   In the event of a fork or loss of private key, it is usually impossible to prove ownership of a block in the blockchain or access one’s account or system.
6. **Limited engineering skill.**
   There is little available research, and a high demand for engineers with tangible hard skills in blockchain based systems.
7. **Scalability**
   Once the public ledger becomes too large, there are large issues regarding latency, capacity and processing speed that only worsens once the network grows.
8. **Lack of legislative frameworks.**
   The decentralized and pseudonymous nature of blockchain networks, give rise to legal issues regarding liability, ownership and intellectual property.

9. **Lack of supporting architecture and hardware.**
   Many platforms (such as Hyperledger and IOTA) struggle with the availability of supporting architecture. IoT devices for one, generally have too limited processing power to function as nodes.

The most frequently occurring issues faced by current blockchain implementation efforts are a lack of legislative frameworks, lack of engineering skill, scaling issues, lack of supporting hardware and architecture, with scaling-issues also being a reoccurring issue in larger systems such as regional powergrids. All of which except scaling, are not a result of immature or insufficient blockchain technology, rather its disruptive nature and unprepared industry.

There seems to be a distinct lack of reoccurring purely technical issues in the current state of blockchain technology, with several concepts reaching commercial or pilot-level success. Qualitative information also suggests that current blockchain technology is sufficiently mature to see successful commercial implementation, in grid engineering, supply chain management, IoT, various applications of smartcontracts and distributed manufacturing. The technology is however not mature enough for use in full-scale power grids and full-scale, international supply chains. Largely due to issues with scaling and lacking supporting architecture/hardware resulting in large initial costs.

5.2. Areas of Implementation

Below follows a discussion and conclusion regarding implementation of blockchain-technology in the chosen areas of interest. The section provides a more in-depth conclusion regarding the specific challenges and potential benefits of implementing blockchain technology. Project management will be discussed in section 5.2.3, as there is no commercial concept for PM to analyse.

5.2.3. Internet of Things

Implementing Blockchain-technology to IoT-systems is highly applicable and seems a viable application for the current state of blockchain. Blockchain implementation would reduce and even remove several of the major drawbacks associated with current IoT systems. Mainly:

1. Improve security of installed IoT devices through immutable records and encryption
2. Remove single-point failure and improve resilience, as data is stored on the ledger and not in a local database.
3. Allow for real time data-collection and monitoring, with the addition of immutable, efficient backlogs and historical data gathered from devices.
4. Complete trust in stored data and easily accessible backlogs
5. Reduced cost as a result of less systems maintenance and human labour when implementing smartcontract functionality.

Successful implementation of blockchain based IoT systems, would also greatly increase the viability and simplicity in designing systems for several of the other areas of implementation reviewed in this thesis. Mainly grid engineering and supply chain management. IoT functionality would also provide additional metrics and functionality to smartcontracts, further increasing the amount of potential use-cases for both IoT and smartcontracts.

The scaling problem should not be as significant, unless there is a distinct need to store large amounts of historical data from several extensive IoT systems on the blockchain. This may however be solved or mitigated through storage optimization or other relevant blockchain redesigns. The occurrence of issues such as Forking or implementation bugs, might prove more challenging. These technical issues are largely mitigated however, through the use of a privately permissioned network, with the main trade-off being a lowered level of security than in open networks.

The availability of platforms such as IOTA greatly increases user-friendliness and availability. The concept is well established and has received much industry support from a variety of businesses. If supporting IT-systems, technical skill and hardware is available, there is no reason why successful implementation is not possible for a variety of scenarios.

The IOTA platform received a TRL of 8, indicating a high level of technological maturity. Although the TRL is based solely on the IOTA platform, it indicates a high level of maturity for blockchain technology geared towards IoT implementation. As the platform continues to develop and improve, it lowers the bar for implementation. Based on the TRL analysis, I believe there is a sound technical foundation available for those looking to implement the current state of blockchain for IoT systems and applications.

To increase the viability of blockchain for IoT purposes, smart meters and hardware must be developed for blockchains. Currently available hardware is either not designed for blockchain or lacks the required processing power to function satisfactory as nodes. To achieve the necessary functionality in industries such as grid engineering and mechanical systems, the hardware must be sufficiently powerful to both store data, and process data as nodes.

The distinct lack of standards and existing frameworks for IoT systems, also contribute to increased difficulty in developing blockchain for IoT. If projects such as IoT-A and ASPIRE are successful, it would allow for more efficient development of blockchain based IoT systems, as developers no longer have the same need to redesign and develop system and architecture from scratch. This is however an issue for all IoT development efforts, and not a unique challenge to current blockchain implementation efforts.

5.2.4. Supply Chain Management

Supply chain management is a blockchain goldmine, and potentially the most promising area of implementation reviewed in this thesis. There are extensive upsides to successful implementation, solving or mitigating many of the current issues and troubles of large supply chains and shipping systems. For instance, in the case of the listeria-example from section 2.8, a blockchain would allow the manufacturer to accurately and instantly track an individual product throughout its entire shipping process. This in turn would allow for much easier and efficient identification of the diseased source, leading to reduced damage and overall cost. Blockchain show clear advantages in source-tracking and origin-guarantees for food-items, luxury goods and raw materials.

The most notable upsides to implementing blockchain-based supply chain systems include:

1. Increased security and transparency though immutable historical data. Allowing for trustworthy and secure tracing of a products origin.
2. Lower risk associated with defective or fraudulent goods through trustworthy and correct shipping records.
3. Real-time updates and immutable shipping-records during international transit, that are not susceptible to loss of connectivity and single point failure
4. Reduced paperwork burden and increased cost-efficiency when automating payments and paperwork through smartcontracts.
5. Operate and facilitate secure IoT functionality

Hyperledger fabric received a TRL score of 8. Showing that the technology and coinciding platform is seemingly ready for commercial implementation. Although the score represents the current industry leader in supply chain systems, the availability of a proper platform, may greatly aid implementation for smaller companies. The project has several large backers (Airbus, IBM, Intel), with several successful pilot-tests, and clear incentives from current issues in supply chain management. Blockchain technology seems a viable technology for supply chains in its current state.

The great scourge of successful implementation is currently a severe lack of compatible IT-systems, and subsequently large investment-costs for initial implementation. Undertaking implementation efforts is very expensive, due to the extensive tasks of upgrading supporting architecture, and developing a system that is efficient and usable for all sections of the supply chain.

International goods go through several checkpoints during shipping. For a blockchain-based system to work optimally, all these checkpoints in the supply chain must run on compatible IT-systems, and the same version of the selected blockchain to avoid issues such as forking. For businesses that control the entire supply-chain of their product, there are very few hindrances to achieving successful implementation.

Corporations seem reluctant to make the first move to adopting blockchain based systems, as the full advantage of such a system, is only available once all parts of the supply chain makes the transition to a blockchain based platform. That includes retailers, distributors, wholesalers, carriers, suppliers etc. 60% of organizations asked in the reviewed Capgemini study from section 2.8.4, state that their main hurdle for blockchain implementation, is that their IT-systems are not compatible with partner-organizations` IT-systems [98].

It seems highly likely that we will see more successful implementations of blockchain in supply-chain management over the coming years. Before this can happen however, 4 key challenges need to be addressed:

1. **Scalability**
   When shipping merchandise or collecting metrics, the sheer volume of transactions may lead to an oversized ledger on a permisionless network. Creating separate networks and private platforms may however greatly reduce the overall size of the ledger at the expense of security.
2. **IT systems**
   Many sub-contractors and vendors use different IT-systems. Implementing a blockchain-platform may then be highly challenging, and in order to obtain the full advantages of a blockchain system for IoT or supply-chains, all major nodes in the chain must be connected.
3. **Legal Frameworks**
   There is a distinct lack of legal frameworks to address issues such as privacy policies and regulatory challenges in regard to international shipping.
4. **Hardware**
   IoT devices and subsequent hardware to facilitate automated reporting and payments with smartcontracts should be developed.

Blockchain technology seems technically viable for use in shipping systems and supply chain management. There is a clear use-case for smartcontracts to perform automated payments and reduce the extensive, explicit paperwork associated with international shipping. Issues such as origin-tracking and peer-to-peer, trustless trading of luxury items or raw materials, are all highly viable use-cases for current blockchain technology.

5.2.5. Distributed Manufacturing

Distributed manufacturing is not yet viable for full scale implementation of current blockchain technology. Blockchain does however appear to provide the required functionality and technical maturity for a commercial distributed manufacturing platform or service. A successful implementation would greatly improve the manufacturing industry by facilitating cheaper, safe and more efficient production. The concept is also particularly well suited for AM applications.

The most commonly occurring issues and hurdles to implementing blockchain in distributed manufacturing systems can be summarized as:

1. **Scaling problems**
   For the system to reach a network-size that facilitates the required security, storing part-files would lead to an extensive and incredibly large public ledger. Downloading and accessing files would in such cases be fraught with latency and low transaction-speeds.
2. **Risk of Selfish Mining**
   If one entity were to achieve n>50% of total network size, it could prove disastrous for the rest of the network. Such an entity would be able to not only steal and produce parts for free, but also keep users from accessing parts or making their own purchases on the platform.
3. **Copyright Law and Enforcement**
   Parts often require some degree of customization to fit their intended use. If this alteration is not done by the original designer, one may claim ownership of the changed part as it now “has a different geometry and specifications than the original”. Drawing the line between what is considered a new part, and how designers are able to make alterations, is crucial for a commercial platform.

4. **Machine Connectivity.**
   In order to protect the intellectual property of designers, files should be transferred directly to production machines and initiated through smartcontracts. If the machine does not have internet connectivity, a manual transfer is required. Once the file has left the secure blockchain, there is nothing stopping a party from making additional copies without designer/owner consent.
5. **Interconnectivity**
   Several distributed manufacturing models emphasize the need for interoperability between open and closed networks, as well as other relevant IT systems. It might be highly challenging to provide the necessary level of interoperability, without sacrificing transparency and security of the final blockchain platform.

Although companies such as Innogy are believing in the concept of blockchain-enabled distributed manufacturing, there are few concrete examples in real life manufacturing systems, largely due to the low maturity of current distributed manufacturing systems. Although Genesis of Things have been seemingly successful in their initial tests, they are focusing heavily on AM. This might be one of the limiting factors of the concept, as AM (A highly disruptive technology in itself) is only just reaching a commercially viable standard.

The Genesis of Things project received a TRL score of 3, the lowest of the reviewed concepts. The concept requires increased functionality, more relevant partners, pilot-testing outside the initial contributors and a more focused market approach to become commercially available. Although these factors are not a direct result of blockchain technology itself, it shows that the concept still has a way to go before being fully equipped to implement current blockchain technologies. Blockchain technology seems however applicable, if the scaling-problem is mitigated. The scaling-problem is an instance of immature or insufficient blockchain technology, with other factors such as legal and AM adding to the difficulty of establishing an efficient blockchain based manufacturing system.

The Genesis of Things concept has shown promise, attracting much attention in the manufacturing industry. Blockchain solves many of the long-standing issues associated with distributed manufacturing. Mainly trust tax, transparency, traceability and immutability of designs (given appropriate machine connectivity). Despite this, interest seems smaller than that of other blockchain 3.0 applications. This may be due to a limited number of platforms that are open to manufacturers and designers, as most projects (including Genesis of Things) are at an early stage, with only a selected number of manufacturers allowed to test and influence the platform.

The incentive to continue working on blockchain based systems for distributed manufacturing, is clear. From the list of requirements for effective distributed manufacturing presented in section 2.7, blockchain could be a highly valuable tool in several of the listed requirements. Mainly:

1. **Distributed organization:** By implementing a blockchain based system, manufacturers and other relevant organizations, can safely and transparently trade and collaborate on data and resources. The transparency and safety of blockchains reduce the risk of moral hazards and opportunistic behaviour, as information is publicly available.

2. **Interoperability**: Smartcontracts can be used to automate and send commands to various IT-systems. This way, while the main system runs on blockchain, it can still cooperate with non-blockchain based subsystems of lower level manufacturers and suppliers.

3. **Cooperation:** Blockchain based systems allow full transparency, trust and fault-proof, real time updates regarding production at distributed manufacturing sites. Allowing for more efficient reporting and safe, auditable backlogs.

4. **Fault tolerance**: In the event of a failure or crash, no data placed on the blockchain will ever be deleted, damaged or corrupted. Recovering data or saving data after a crash, is incredibly easy as the blockchain facilitates this function automatically.

Although the distributed manufacturing concept received a low TRL of 3, blockchain seems sufficiently mature. Limited information on testing, product design and contributing partners, and current maturity of distributed manufacturing systems contribute to the low TRL score. Blockchain based manufacturing systems are particularly well suited for AM (due to connectivity and limited human labour requirements), and it is reasonable to believe that as AM increases in popularity and quality, blockchain will be a more applicable technology to further the distributed manufacturing concept.

5.2.6. Grid Engineering

The current state of blockchain technology, is not suitable for full scale, large regional or national power-systems. The technology is however mature enough, to see successful implementation in smaller systems such as microgrids and peer-to-peer services. Smaller applications such as microgrids (as used by LO3 Energy), does not have the same number of users or transactions recorded in the public ledger as a full-scale regional power grid. This allows for a significant reduction in the scaling-problem associated with large blockchains. Such microgrids are also not susceptible to the same associated risk in the event of failure, as large regional power systems.

In order for the technology to be applicable for full scale power-grids, there are 4 main hurdles:

1. **The scaling problem must be solved.**
   Any public blockchain implemented in the grid, would have to handle an immense load of transactions at any given time. As per now, there seems like no blockchain-platform is able to effectively deal with scaling and provide the required levels of low latency and transaction-speed.

2. **Supporting technologies needs to be created.**
   To achieve successful implementation, IoT devices and IT-systems that support the relevant blockchain platform is required. If power companies were to create these tools themselves, it would likely slow down implementation, as it increases both cost and complexity of the project.

3. **Legal aspects must be explored and mitigated.**
   Questions regarding liability, selfish mining and taxation for prosumers must be decided. A clear legal framework would greatly improve the simplicity of designing a blockchain-based system for full scale grid-implementation.

4. **Forking cannot be allowed to occur.**
   In the event of a fork, prosumers may be cheated for or gain additional value. This could offset not only the final price paid by the prosumer, but also lead to increased costs for the provider.

Available frameworks for developing IoT-systems would also greatly contribute, as it facilitates automation through smartcontracts, and reduces the overall cost of developing an efficient blockchain for full scale electric grid applications. In order for concepts such as peer-to-peer grid services and vehicle to grid to become a reality, smartcontracts are vital. Without the functionality, there would be a large amount of labour associated with auditing, controlling and approving transactions and pay-outs. These tasks are entirely explicit and should thus be automated through smartcontracts to reduce overall cost of maintaining the system.

The LO3 Energy microgrid project received a TRL score of 9, showing a high level of technological maturity. The concept proved to work in its intended scale, and the arrival of a second commercial product is announced. Although microgrids are not susceptible to the same level of technical challenges as a full-scale power grid, it shows a clear potential for blockchain based systems and the emerging business opportunities. Including peer-to-peer electricity trading and flexible power-services.

There is a clear incentive for power companies to work towards blockchain based smart grids, as it aids in reducing the cost felt by peaks and thus reduce KILE-cost, through more optimal power-distribution and timed consumption of energy. In addition to LO3, there is a multitude of concepts and projects, currently developing blockchain-based systems for power grids. There is a clear industry interest, and blockchain seems to be a preferred tool to facilitate flexible power-services, peer-to-peer trading and other emerging grid functionalities.

There are clear incentives to implement blockchain based systems in powergrids. If we see an improvement in the supporting technology, as well as overall blockchain design (in regard to the scaling problem for full scale systems), blockchain technology could greatly benefit the current state of power grids. Peer-to-peer solutions increases the solar panel efficiency by 2%, and blockchains allow for more transparent and efficient trading of green energy. All of which are powerful incentives, that may play a large role in future power grids.

5.2.7. Smartcontracts

Smartcontracts are the backbone of effective blockchain-based systems. The most successful Blockchain 3.0 implementations reviewed in this thesis, utilizes smartcontracts, or supports the use or development of smartcontracts. The technology allows users to automate tasks and streamline processes or payments. Platforms such as Ethereum has come a long way in facilitating and enabling customization, implementation and testing of unique smartcontracts. Without such a platform, the availability of the technology would be significantly reduced, and require an increased amount of engineering skill in order to be utilized effectively.

The Ethereum platform received a TRL score of 9. The platform has a wide range of tools and applications, designed to simplify the process of smartcontract creation. The platform has been used for a variety of smaller concepts and has focused on smartcontract development and implementation since its launch. Although every smartcontract implementation is different and unique, the presence of the Ethereum platform should greatly reduce the difficulty of implementing smartcontracts. The platform also provides an established network, that allows for high level of security and trust when developing and executing smartcontracts on the platform, not present in smaller or permissioned networks.

Smartcontracts have been part of successful implementation of blockchain technology in pilot shipping-systems such as Hyperledger fabric and Norway in a Box. Current applications of the technology also include automating digital transactions and transfers, thus greatly easing the operational burden associated with international accounts and assets for banks such as UBS, through the implementation of UTC.

The current most significant drawbacks to smartcontract implementation is a lack of technical skill and legislative issues. There is an immense need for blockchain engineers. Although platforms such as Ethereum significantly ease the process of smartcontract modelling, technical skill is still very much required. There are also many actions in which signatures are replaced by nodal confirmation, which may cause issues in terms of liability, should something go wrong. The Ethereum platform has also had instances where some contracts have been prioritized over others, due to an increased monetary incentive for miners to focus on larger contracts.

In some areas, such as supply chain management, smartcontracts may be hard to implement on a public platform such as Ethereum. The nature of blockchain technology, forces the owner of a contract to provide access to all metrics required for the completion of the contract. If one were to ship classified or high-profile cargo, legal aspects may require IoT data to be kept confidential, something not possible on an open blockchain 2.0 platform. Hyperledger has addressed this by relying on a private network, and incorporating smartcontracts through the BESU project. Nevertheless, engineers must develop efficient monitoring systems, that coincides with the rules of the business and use-case.

It is highly challenging to implement Blockchain 2.0 in large unique contracts. As most engineering contracts have implicit elements, Blockchain 2.0 seems unsuited for this application. Care should be taken regarding monetarily large investments with high risks. Blockchain 2.0 has an extensive history of implementation-issues and technical bugs, that may cause massive damage and inflated risk. Any implementation of smartcontracts should go through an initial testing-face, to make sure no such technical or implementation exploits are present.

Successful implementation could greatly improve automation, which is made even more powerful when combined with appropriate secondary technology such as IoT devices and relevant IT systems. If the IT-systems and IoT-devices are geared towards smartcontracts, the information available to the programme increases. The more information available to the contract, the more areas of application arise.
Although the issues with security and scalability are the same for Blockchain 2.0, many applications may not be as susceptible to these hurdles. Private or smaller systems may not require the transfer of large files with high frequency between multiple users of the network or be required to store large amounts of historical data. For cyclic contracts however, the scaling problem might pose challenges as the contract is used over a longer timeframe.

If a smartcontract was modelled on a permissioned network for a specific system or project, there are few significant drawbacks or challenges to implement the current state of Blockchain 2.0 technology, other than lacking technical skill and legislation. Its only real limitation on a permissioned network is the level of supporting architecture needed, and technical skill regarding development and implementation.

While most contracts are implicit and hard to define explicitly, many of the tasks and operations in projects and systems can easily be written as an explicit contract, provided enough metrics to confirm fulfilment of the contract. Examples include:

1. **Scheduling maintenance and repairs for offshore installations and grid-stations**
   Grid-repair is often a standardized task. Currently, grid operators must first be notified of a fault in the grid. Once notification is received, a supervisor sends out a crew to repair. The crew must then assess and determine the best course of action, such as turning of trafo-stations or applying redundancies where available. Smartcontracts would allow for automatic shut-offs and redundancy-switching in the event of failure. Saving time and power, whilst also reducing the risk of fires.
2. **Regulating power-output to individual end-users through blockchain-based utility switching.**
   By specifying operating-times, business-hours and current use of electrical energy, grid-companies can vary and even shut off power during peak hours, to strategic nodes in the grid. Saving large sums on reduced KILE-cost and overall power consumption. This would not only automate the process and reduce the costs for the grid service provider, but also reduce costs for the end-user. The information gathered though automatic switching of power-supply stored in the blockchain, could also prove an extremely valuable dataset when developing AI`s for Grid use.
3. **Automating payment for standard services such as parking**
   When the service is standardized, and use is regular, a smartcontract is highly applicable. The contract has access to your location, and knows you are in a car on your way to work through an IoT devices such as a smartphone. The contract has pre-set conditions detailing work schedule and preferred parking garage. Once you reach the garage, the contract meets all its prerequisites of timing, and geographical location. As all boxes are checked, the contract authorizes an automatic purchase of parking entry. Once you leave the garage after work, the contract is invalid as you are no longer on the specified geographical location. Once this is registered, the contract cancels continued payment for parking.

The concepts listed above is a simple way of highlighting the usefulness of smartcontracts. They are extremely versatile, and several explicit contracting elements and tasks can be automated with blockchain powered smartcontracts, provided the required supporting architecture is present.

The majority of large, project contracts are implicit. As a result, they are impossible to automate through smartcontracts, as we have no tangible conditions to activate the contract. Smartcontracts are not smart, and thus not able to evaluate or gauge information on its own. Although most contracts have some degree of explicit conditions, these would have to be identified and worked into code. This labour-intensive task would have to be repeated and changed for every contract. Not a practical or cost-efficient solution.

There is reason to believe an increase off successful Blockchain 2.0 implementations will occur over the coming years. The technology is more developed than many Blockchain 3.0 applications, with much interest from large industry partners. The customizable nature, and potential to improve existing blockchain-based systems through automation, makes the technology applicable for a wide range of future and present applications.

The current state of smartcontracts are technically viable and highly disruptive, with an enormous range of potential use-cases. Blockchain 2.0 seems a mature technology, evident by the high frequency of projects, platforms and commercial products, utilizing the technology. The technology allows users to create trustworthy, transparent computerized logics, that use transparent, trustworthy information from the blockchain to perform actions on or outside the relevant blockchain. Thus, not only providing automation, but also becoming a bridge between IT-systems and the blockchain.

5.2.7.4. Using Traditional Contracting Theory for Developing Smartcontracts

Despite implicit elements making smartcontracts unsuited for some applications, the occurrence of explicit contracting elements may still create use-cases for traditional contracting theory when formulating smartcontracts. In cases such as distributed manufacturing and purchase-orders, formulating an explicit contract should be a viable option. When that is the case, a smartcontract based on traditional contracting theory (as presented in section 2.5.3) could help structure and formulate the contract. Bridging the gap in required technical skill.

The ER^{EC} contracting framework presented in section 2.5 can be used as a foundation, with additions from classic contracts. Target price, cost plus and reimbursables can all easily be added to code on platforms such as Ethereum. This allows engineers and PM`s with even basic coding experience, to formulate, create and utilize smartcontracts for explicit elements of larger contracts or purchases. If subsequent support for monitoring and enforcement are present, implementing a smartcontract is made considerably easier by high functioning platforms such as Ethereum.

Due to the highly unique nature of most contracts, areas of application and the current state of available blockchain technology, it is highly difficult to create a turnkey solution to fit a variety of possible applications. Concepts such as distributed manufacturing may however be susceptible for the formulation of standard contracts to be used on the platform.

5.2.3. Project Management

There seems to be few incentives to incorporate and create blockchain-based systems, purely for PM. Although some increases in PM efficiency can be obtained through carry-over effects form other blockchain based systems, there are few if any, areas of specific implementation that would benefit a PM in a significant or cost-efficient way, given the current state of blockchain and available platforms/features.

The basic perks of current blockchain-systems, does little to directly impact either of the top factors for project success, listed in section 2.4.4. As a result, it is reasonable to conclude that implementing blockchain-systems for PM, would not lead to a significant increase in the probability of success, relative to the cost of developing a blockchain for PM. There are also no areas on the same list, that directly coincide with the functions and features of currently available blockchain-based systems reviewed.

From the list of "top 10 reasons why projects fail", presented in section 2.4.5, there are no areas in which blockchain-based systems would directly result in removing or significantly reducing the added risk of failure to the project. Although "lack of user input" might see some improvement through blockchain-based systems, this seems an unnecessarily complicated way of collecting user inputs. By using blockchain we add to the complexity of data collection, in a place where standard SQL databases offer appropriate functionality. When none of the featured upsides of blockchain is required, it is highly redundant to undertake such an effort.

Despite current blockchain technology not being suitable as a tailored PM tool (largely due to high development costs), there is reason to believe that successful implementation in relevant systems and areas, could aid in improving the probability of success for projects. More efficient supply chain management, access to reliable IoT data and improved efficiency for manufacturing parts, will in many cases help improve the PM`s chances of a successful project. These are however secondary or even tertiary effects, not a direct result of blockchain-based systems for PM.

5.3. Current Most Vital Blockchain Functionality

A singular form of blockchain technology is largely insufficient to utilize its current potential. Whilst a singular approach may work for Blockchain 1.0 where the sole purpose is the transfer of monetary funds, Blockchain 2.0 and 3.0 give rise to challenges and opportunities that often require a wider array of features and functionality to achieve full commercial potential, a positive ROI and superior features and incentives when compared to traditional SQL databases. Specifically, within supply chain management and grid engineering, where implementation might incur large costs associated with upgrading IT-systems of various suppliers. All projects analysed with a TRL ≥ 8, support smartcontracts and/or IoT functionality, in addition to traditional blockchain 1.0 features.

A prime example of synergy amongst concepts is supply-chain management. Whilst tracking a unit by barcode or manual entry is a usable alternative for some applications, it fails to justify the large investment-costs associated with implementation of full-scale systems. By implementing smartcontracts, larger parts of the supply chain can be automated and secured, with no single point failure and distrust. By reducing the burden of paperwork and automate standard payments, labour-cost might be reduced considerably.

Grid-applications also benefit heavily from multiple blockchain functionality. LO3 Energy started with the goal of keeping a secure, immutable record of transactions or transfer of units of energy in microgrids. Essential for correct billing and control when building a flexible grid-service to minimize KILE-cost and expenses for both consumers and operators. LO3 have later implemented smartcontracts and more suitable IoT-functionality, to achieve the necessary functionality for commercial implementation. Such features are important to facilitate effective peer-to-peer trading between consumers and prosumers. Without it, tracking and monitoring consumption/production is highly labour intensive, and requires an extensive amount of billing.

Based on the review of selected concepts/platforms, current applications of blockchain would benefit from a wider range of functionality and features, than strict Blockchain 1.0 and 2.0. Smartcontracts are perhaps the most applicable, as it allows for automation and interaction between the blockchain, and external systems. Without smartcontracts, the blockchain has no ability to act upon the information available on the blockchain. Whilst IoT-functionality and the possibility of fiscal transactions are welcome additions for many applications, they are not as vital as smartcontracts for the reviewed areas of implementation. Largely due to IoT and Blockchain 1.0, will not live out their true potential without the presence of smartcontracts to provide automation. IoT would only allow for increased data-collection and improved metrics, while expensive manual action would still be required to make simple alterations to the system or other, based on the available metrics from IoT devices.

From the projects and platforms reviewed in this thesis, the following functionality can be observed across concepts and platforms:

	Technology/functionality		
Projects/Platforms/Technology	IoT	Blockchain 2.0	Blockchain 1.0
Ethereum			
Hyperledger			
IOTA			
Utility Settlement Coin			
Norway in a box			
LO3 Energy			
Genesis of Things			

Table 6: Crossover functionality

- Red: Not supported through either development tools or functionality in final product

- Orange: Supported to a minor degree but requires additional development
- Green: Prioritized functionality, easily accessible in the commercial product or as a developer tool on the relevant platform.

Blockchain 1.0 is reoccurring in all reviewed concepts except for Norway in a box. By allowing smartcontracts to perform payments based on IoT data stored in the blockchain, a wide range of applications and functionality is achieved. The combination is directly responsible for the largest potential cost-reductions in areas such as Grid engineering and supply chain management.

Ethereum offers basic tools for IoT implementation. So does IOTA and UTC for smartcontracts. Although the technology is possible to implement on the Ethereum platform, there are limited tailored development tools available. To implement full range of functionality, additional software development must be performed. The table also shows how the 4 most successful projects from the TRL analysis (IOTA, Hyperledger, Ethereum and LO3) have implemented full technical functionality (Blockchain 1.0, Smartcontracts and IoT).

With the current state of blockchain technology, providing a full range of functionality is often vital to justify the associated large costs associated with development and implementation. Development costs are high, engineering skill is low, and frameworks/standards are not yet developed, utilizing the technology fully to increase the efficiency of the system, could in some cases be a requirement to reach a positive ROI. The full potential of blockchain technology is reached once smartcontracts have been appropriately combined with Blockchain 1.0 and supporting functionality such as IoT-Hardware or other relevant systems.

5.4. Is There Ever a Need for Blockchain?

Blockchain features such as highly resilient decentralization and concurrency control is currently available through tried and tested SQL database technology. Despite the possibility of a database, there are several key features that could make blockchain-based systems the preferred choice. The main features not found in SQL databases are easily accessible high levels of security, immutability, no single point failure, complete transparency and trust amongst peers. Larger database systems with geographically spread out servers, are not geared towards a high number of individual users from various geographical locations. Such systems are highly susceptible to loss of communication, issues in maintaining ACID principles and susceptibility to cyber-attacks.

For non-financial applications not requiring high levels of security, immutability and transparency, blockchain-based systems seem sub-optimal. Traditional database-technology such as SQL, can provide sufficient storage and optimization of data, provided designers take the necessary time to develop the database according to specifications and theory.

Of applications presented in this thesis, distributed manufacturing and supply chain management could achieve necessary functionality through traditional database technology. Despite databases being a viable choice, blockchain can (once implemented) supply a higher degree of security and reliability, than current database systems. By applying blockchain to these areas however, one may open up to new business opportunities not available through traditional databases, and reduce costs associated with menial tasks.

There are examples of situations in which the complete trust and transparency found in blockchain-based systems are worth the associated added cost. In the reviewed example from Norway in a Box, Chinese consumers are willing to absorb additional cost to receive the complete trust and immutability only found in blockchain-based system.

New business-opportunities such as microgrids, Peer-to-peer services and automation through Blockchain 2.0, are features not easily available to SQL-based systems. For financial applications as trading of financial assets between individuals with no trust, blockchain-based systems are irreplaceable. There is no currently available technology, that can compete with the trust and transparency of blockchain-networks in financial applications. The addition of smartcontracts provide blockchain-based systems with functionality and possibility far beyond that of a traditional database. Specifically, within automation, resilience and security.

5.5. Requirements for Successful Implementation

Reviewed concepts received TRL scores ranging from 3 → 9, and few incentives to create PM-specific blockchain tools, showing clear differences in the viability of current blockchain technology for the reviewed areas of interest. Based on the most successfully reviewed projects, and the available features of current platforms and blockchain technology, the most applicable areas of implementation have the following characteristics:

1. Businesses or projects with a need for secure and immutable records, that span across multiple users and nationalities.
2. Applications with a large volume of transactions of varying size and timing amongst a very large number of individual users.
3. Industries in need of increased transparency and security in supply chains
   Particularly in regard to authenticity and the need for specific shipping conditions
4. Areas with large-scale IoT implementation, or other technology with a large amount of potentially classified data, with the need for immutability and security.
5. Peer-to-peer services where trust is needed, but difficult to guarantee or establish, without suffering from a third-party trust tax.
6. Areas with limited legal implications and complexity
7. Projects or areas with a high number of menial explicit tasks, paperwork or payments.

Based on the acquired TRL score, and subsequent analysis of the most common reoccurring issues, the following properties make a company or industry particularly well equipped to reach successful implementation of current blockchain technology:

1. Engineering skill in blockchain development and relevant systems
2. Industry partners with similar cost-contributing issues or clear market-demand for decentralized systems.
3. Legal framework that facilitates the intended use of the technology
4. A solid understanding of critical success-factors and requirements for the system
5. An established blockchain-platform suited for the unique core use of the business or market
6. A definitive need for immutability and security, as well as removal of single-point failure in existing systems
7. Large number of explicit tasks and paperwork
8. Ability and budget to undergo large development projects

If a business or project exhibits the requirements above, it has the capabilities of successfully implementing a blockchain-based system in its current technological maturity, and should be able to overcome the potential drawbacks to early implementation. Using an existing, established platform such as IOTA and Ethereum, also removes much of the risks and concerns, normally associated with implementation.

5.6. What is Holding Blockchain Back?

During the research, few commercially successful projects were available for analysis. Although the thesis contains examples of several successful commercial concepts such as LO3 energy and Norway in a box, there are very few commercial products available, compared to what one might expect based on the current excitement that surrounds blockchain technology.

Based on the data collected from reviewed concepts and areas of implementation, the most frequently reoccurring issues are:

		Area of implementation				
Issues and concerns	IoT	Distributed Manufacturing	Supply chain Management	Grid Engineering	Smartcontracts	**Frequency**
Large initial costs	0	0	1	1	0	0.4
Legal aspects	1	1	1	1	1	1
Engineering skill	1	1	1	1	1	1
Lack of Supporting Hardware	1	1	1	1	0	0.8
Scaling	1	1	0	1	0	0.6
Forking	1	0	0	0	1	0.6
Technical frameworks/Industry standards	1	1	0	1	0	0.6
Selfish Mining	0	1	0	0	0	0.2
Need to delete user data	0	0	0	1	0	0.2
Supporting architecture	1	1	1	1	0	0.8

Table 7: Reoccurring Issues

1: The issue is present and listed as a major concern or issue with current blockchain technology
0: The issue is not classified as a major issue in implementing current blockchain technology
Frequency: The mean frequency for each issue or concern.

From the table we see that the most frequently occurring issues in the reviewed areas of implementation are:

1. Legal Aspects
2. Lack of Engineering Skill
3. Supporting Architecture
4. Supporting Hardware

The 4 listed issues are reoccurring in at least 80% of all reviewed concepts and platforms. Legal aspects and lack of engineering skill are reoccurring in all reviewed concepts. The table indicates that while blockchains might have reached a sufficient technological maturity for several commercial use-cases, secondary technologies, lack of engineering skill and legal aspects are making implementation difficult. There is reason to believe that once legal frameworks have been developed, along with appropriate supporting hardware (particularly IoT devices) and engineering skill, blockchain implementation will be simplified and a more viable alternative in the reviewed areas of implementation.

6. Considerations

Throughout this thesis I have chosen to not heavily focus on system architecture, cryptography or the specific data science behind blockchain development and technology. The technical specifics of mining and consensus algorithms have also not been prioritized. This due to my technical background not being in computer-science or cryptography. The paper has aimed to explore and qualitatively evaluate the current state of blockchain technology, along with some of the most promising areas of implementation. Not theoretical challenges of creating and developing a blockchain or next generation blockchains.

It became apparent early on in my research, that leaning solely on journal articles and books would not allow for sufficient data collection. There are extensive amounts of information available in blogs, online news outlets and social media, which are often far more updated or recent, than available journal articles. The “Eat, Drink, Innovate” 2019 presentation on Norway in a box was also very helpful, to learn more about the current workings of the Norway in a box project and product.

I have observed that blockchain engineers and entrepreneurs frequently write blogs about their work or publish articles and opinions on sites such as CoinDesk or Cointelegraph, two of the larger blockchain-focused news-sites. These articles often contain information based on opinion and not peer reviewed fact or quantifiable research. I have done my best to omit such information from the thesis. The articles do, however, quite often relate updated information on ongoing projects, and the current development of technology in the industry. Information gathered from these sources have largely not been included, unless the information is backed by a reputable source such as journal or whitepaper.

Similar articles and explanations were also found on the homepage for several of the established cryptocurrencies and blockchain-platforms mentioned. Such as Ethereum, IOTA and Hyperledger. These articles (though not peer-reviewed) have been vital in researching specific projects and platforms. I have deemed them reputable, as they are written by the developers and published on the platforms own home page. Except from this, I have relied on peer-reviewed journal-articles, books and published whitepapers for technical details and explanations.

When using the NYSERDA TRL algorithm, Commercial Readiness Level (CRL) is also calculated. This level has not been addressed or considered, as the CRL framework assesses various indicators which influence the commercial and market conditions beyond technology maturity [143]. As this thesis investigates technological maturity of blockchain, CRL was omitted from the conclusion.

7. Further Work

Further study on this topic would benefit from increased focus on smartcontract implementation and hardware. Although the topic receives much focus in this study, specific enforcement and monitoring tools are not explored, and specific hardware is only lightly mentioned. In order to reap the benefits of smartcontracts, such mechanisms must be in place. Although the thesis also contains simple examples on how smartcontracts function, a more in-depth case-study or proof of concept would be welcoming. By formulating an entire smartcontract on a suitable platform, more of the underlying challenges of smartcontract development would become clear.

There are several consensus protocols not covered in this thesis. Although PoW, PoS and PBFT are mentioned, other alternatives might provide solutions or improvements to some of the commonly listed problems with scaling and selfish mining. Scaling is perhaps the most major technological fault in current blockchain technology. To better understand this issue, studying how scaling affects a current platform and subsequent consensus model, would be highly beneficial.

Although much research on scaling blockchain exists, much is conducted on the bitcoin network. To better understand when scaling becomes an issue, work should be conducted on the Hyperledger or IOTA platform, as these are highly applicable to areas in which scaling might be a major, reoccurring concern for several use-cases of current blockchain technology.

Any work that investigates the current state of legal frameworks for blockchain, would be beneficial. Legal concerns are reoccurring across all reviewed concepts, and frequently listed as a major concern or challenge in reviewed journal articles and whitepapers. As I have no legal education or experience, this topic has been left largely un-explored throughout the thesis.

Lastly, a more in-depth study of some reviewed areas of implementation and concepts. This thesis covers the main aspects, attempting to create a well-rounded image of the current state of blockchain. As a result, some of the potentially important technical and non-technical industry-details might be under-explored. Specifically:

Grid engineering:

- Specifically, which areas of a grid can be automated through smartcontracts
- Are permissioned networks applicable for grid-services, despite having lower levels of security
- Is there a way to comply with GDPR-rules, and delete customer information from the blockchain?

Supply chain Management:

- An in-depth review of the potential cost-reduction, that might be achieved with successful implementation of blockchain.
- A review of the supporting architecture in harbours and shipping checkpoints, to verify the possibility of making automated payments through smartcontracts.
- The work required and associated cost, to upgrade legacy systems and supporting architecture to accommodate blockchain for shipping.

IoT:

- Current available hardware
- Specific hardware requirements
- Investigating the max capacity of current systems, to determine when scaling becomes a major issue.

Although PM was chosen as an area of focus, there were no available PM projects to undergo the TRL algorithm. The topic has received less focus than others, largely due to highly limited information in journals and scientific publications. To create a more in-depth review of blockchain technology for PM, a case study of a specific project(s), would be appropriate. This would allow for a more in-depth identification of the most prevalent issues and hurdles, as well as possible advantages for PM`s when implementing current blockchain-systems.

8. Appendix

Screenshots of the NYSERDA TRL algorithm, used in section 4:

NEW YORK STATE OF OPPORTUNITY. | NYSERDA

Technology & Commercialization Readiness Level Calculator

Instructions

This Excel Workbook has been developed by NYSERDA to help emerging and growing companies determine the level of technical and commercial maturity of their products/innovations through the use of a customized and integrated Technology Readiness Level (TRL) and Commercialization Readiness Level (CRL) Calculator. This TRL/CRL Calculator is based on the systems developed by NASA, DOE, and ARPA-E, and has been designed specifically for ventures in the clean energy industry.

For each category, select the button next to the description that best fits the status of your product/innovation. This calculator will determine the appropriate TRL and CRL levels based on your answers. Once all categories have been completed, click the "See Results" button to view your TRL and CRL scores and answers.

PLEASE NOTE: This TRL/CRL Calculator is provided for informational purposes only, with the understanding that NYSERDA is not rendering any professional opinion or advice. You should consult with a professional advisor before taking any action based on the content of this calculator.

Profile	
Company/Organization Name:	LO3
Proposal Title:	
Product/Innovation Description:	Grid engineering

Technology		
○	1	Project work is beyond basic research and technology concept has been defined
○	2	Applied research has begun and practical application(s) have been identified
○	3	Preliminary testing of technology components has begun, and technical feasibility has been established in a laboratory environment
○	4	Initial testing of integrated product/system has been completed in a laboratory environment
○	5	Laboratory scale integrated product/system demonstrates performance in the intended application(s)

Answer	**No Answer**

		Product Development
○	**1**	Initial product/market fit has been defined
○	**2**	Pilot scale product/system has been tested in the intended application(s)
○	**3**	Demonstration of a full scale product/system prototype has been completed in the intended application(s)
○	**4**	Actual product/system has been proven to work in its near-final form under a representative set of expected conditions and environments
○	**5**	Product/system is in final form and has been operated under the full range of operating conditions and environments

Answer	**No Answer**

		Product Definition/Design
○	**1**	One or more initial product hypotheses have been defined
○	**2**	Mapping product/system attributes against customer needs has highlighted a clear value proposition
○	**3**	The product/system has been scaled from laboratory to pilot scale and issues that may affect achieving full scale have been identified
○	**4**	Comprehensive customer value proposition model has been developed, including a detailed understanding of product/system design specifications, required certifications, and trade-offs
○	**5**	Product/system final design optimization has been completed, required certifications have been obtained, and product/system has incorporated detailed customer and product requirements

Answer	**No Answer**

Competitive Landscape		
	1	Secondary market research has been performed and basic knowledge of potential applications and competitive landscape have been identified
	2	Primary market research to prove the product/system commercial feasibility has been completed and basic understanding of competitive products/systems has been demonstrated
	3	Comprehensive market research to prove the product/system commercial feasibility has been completed and intermediate understanding of competitive products/systems has been demonstrated
	4	Competitive analysis to illustrate unique features and advantages of the product/system compared to competitive products/systems has been completed
	5	Full and complete understanding of the competitive landscape, target application(s), competitive products/systems, and market has been achieved

Answer	No Answer

Team		
	1	No team or company in place (single individual, no legal entity)
	2	Solely technical or non-technical founder(s) running the company with no outside assistance
	3	Solely technical or non-technical founder(s) running the company with assistance from outside advisors/mentors and/or incubator/accelerator
	4	Balanced team with technical and business development/commercialization experience running the company with assistance from outside advisors/mentors
	5	Balanced team with all capabilities onboard (e.g. sales, marketing, customer service, operations, etc.) running the company with assistance from outside advisors/mentors

Answer	No Answer

Go-To-Market		
	1	Initial business model and value proposition have been defined
	2	Customers/partners have been interviewed to understand their pain points/needs, and business model and value proposition have been refined based on customer/partner feedback
	3	Market and customer/partner needs and how those translate to product requirements have been defined, and initial relationships have been developed with key stakeholders across the value chain
	4	Partnerships have been formed with key stakeholders across the value chain (e.g. suppliers, partners, service providers, and customers)
	5	Supply agreements with suppliers and partners are in place and initial purchase orders from customers have been received

Answer	No Answer

Manufacturing/Supply Chain		
	1	Potential suppliers, partners, and customers have been identified and mapped in an initial value chain analysis
	2	Relationships have been established with potential suppliers, partners, service providers, and customers and they have provided input on product and manufacturability requirements
	3	Manufacturing process qualifications (e.g. QC/QA) have been defined and are in progress
	4	Products/systems have been pilot manufactured and sold to initial customers
	5	Full scale manufacturing and widespread deployment of product/system to customers and/or users has been achieved

Answer	No Answer

Reset Answers *See Results*

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