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Blockchain: New technology adoption

A guide for decision makers based on financial and nonfinancial valuation

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Abstract:

The opportunities opened by the development of blockchain technology have been stirring intensive discussions in both corporate and governmental circles over the last 18 months. Given the vast amount of information published on different blogs and websites, in research papers and in books, it should be fairly easy for decision makers to grasp the situation. However, more information does not seem to improve clarity. Confusion dominates if one looks beyond the technology's main characteristics and attempts to grasp how those broadly described and widely advertised applications can be implemented in an organization. This research aims to support decision makers in conducting an objective and detailed analysis of a blockchain project in their organization by offering a step by step framework and demonstrating how to best utilize it. To provide multiple perspectives over the benefits and risks of the project, the evaluation of nonfinancial criteria such as technology, strategy and organizational learning is combined with a discounted cash flow valuation. The research examines a blockchain application in the supply chain area by building multiple scenarios and argues that nonfinancial aspects have the potential to be more influential than financial valuation when determining the best course of action for a new technology project.

Keywords: Blockchain, Decision making, Discounted cash flow, Innovation, New technology evaluation

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Table of Contents

1. Introduction

The novelty of blockchain technology and its potential to radically transform the systems that support the functioning of our economies and organizations have captured the imagination of the entire World, as suggested by the search interest in the topic “blockchain” provided by Google Trends (2017). The worldwide interest in April 2017 is 7.75 times higher compared to April 2015 and twice as high compared to April 2016.

Briefly, blockchain is a distributed database that helps multiple partners in an interaction to build trust between each other without the need for a central intermediary. This is achieved by sharing data and by jointly agreeing on its validity. It delivers most value in processes where two or more external stakeholders are directly exchanging data that cannot be trusted without further checks and confirmations, as presented by Mougayar (2016) and Tapscott (2016).

In contrast, the current informational landscape is fragmented, secretive and opaque as stakeholders collect and analyze process information in their own systems. In some cases, information is exchanged one to one between systems, but in most situations, the reconciliation of information between systems is a time intensive manual process that increases transaction costs between organizations. This is the result of companies adapting information technology to their unique processes and operating models, which makes collaboration difficult due to the lack of a common working standard. Moreover, legal contracts are usually structured with two distinct parties in mind, accentuating the separation of information within a process where more than two parties interact.

Blockchain offers the opportunity for groups of external stakeholders to jointly develop a common data and process standard, which improves transparency, reduces fraud risks and transaction costs, and maintains trust between all participants. This collaboration requirement complicates the adoption process as the interests of multiple organizations have to be aligned – for example, companies that are competitors must overcome their rivalries to build and operate a mutually advantageous blockchain solution.

The multi-faceted nature of blockchain technology coupled with its dynamic open source development creates an extremely exciting research topic, from multiple perspectives – economic, technical, legal. Furthermore, a financial viewpoint over would enrich existing discussions regarding blockchain adoption in an organization, as they are mostly centered on evaluating nonfinancial aspects such as technology and strategic fit.

As organizations that are open to innovation have been intensively studying the technology for the last 12 to 18 months, the author expects that interest in blockchain will increase in the next 12 to 18 months as institutions that are on average slower to respond to technology trends will follow the high expectations currently voiced in the community. In parallel, the management of companies that are already familiar with the technology will need to identify blockchain applications, evaluate if these projects can deliver value to the organization and decide on their adoption or rejection.

The research aims to offer decision makers, a tool to support an objective evaluation of blockchain projects by taking into consideration, both financial and non-financial criteria, while eliminating the impact of unrealistic expectations. Moreover, the paper hopes to fill a gap in the academic research of new technologies by providing a guide to perform the financial evaluation of a blockchain project.

Given that blockchain is new technology, the first section of the second chapter discusses if blockchain is a disruptive technology or not, helpful for determining the resource allocation necessary. In addition, two frameworks are introduced that help decision makers estimate the level of investment required for building a community of external stakeholders around their project and assess the technical novelty of their project. The conclusion of the first chapter is clear – all organizations are recommended to learn about blockchain. Section two maintains the new technology perspective and examines which financial valuation method is optimal for assessing a blockchain project, while also pointing out how project risks should be incorporated in the financial evaluation.

Chapter three offers a more in depth description of blockchain technology, aiming to familiarize readers with the two main architectures and with practical information regarding government initiatives and supply chain applications, both necessary topics for understanding the case study application presented in chapter five.

The framework for blockchain project evaluation is developed and presented in chapter four and demonstrated in chapter five. The paper focuses on the financial valuation, while details regarding nonfinancial valuation are included in the appendix sections alongside further research information. Chapter six concludes the discussion.

2. Understanding new technologies

To measure the value adding capabilities of blockchain it is important to consider how novel technologies fit in the strategy of an organization. In parallel, the most appropriate financial methods that support objective decision making must be identified.

From a strategic perspective, practitioners have developed a wide selection of concepts to assist them in incorporating new technologies in various organizations (section 2.1). In contrast to the flexibility of strategic approaches, section 2.2 advises users that although different financial valuation methods exist, they should carefully consider the capabilities of the valuation method selected and the underlying assumptions.

2.1. Technology adoption

Technology adoption is an important aspect for every company to consider and constantly review, as new improvement ideas can appear every day. However, only a few can be developed into feasible applications and even fewer can create value. Blockchain falls in the same category as multiple applications are envisioned but only a select few can deliver value, as the technology cannot always be applied to the operating model of an organization or does not meet process requirements. Blockchain adoption can be seen as a strategic move that can help a company establish a better competitive position by increasing revenues and by reducing its cost base, while minimizing its operational risks.

According to Christensen (1997), companies that focus on extending the performance of conventional technologies and choose to be followers in the development of new ones, can remain strong and competitive. However, this is the not the case for disruptive technologies, where organizations that make the first move have the advantage, as the market and technology are not known and organizations must learn how to maximize their value before competitors start learning and experimenting.

Some sustaining technologies can be discontinuous or radical in behavior, while others can be incremental in nature. Whatever their manifestation is, they all bring improvements to established products or services along performance metrics valued by mainstream customers.

Disruptive technologies lead to a loss of performance in the short term compared to established technologies, but generally bring to market a new and different benefits. Customers immediately value some of these new features, such as lower cost, reduced dimensions or increased convenience, and start switching from the old technology to the new.

Iansiti and Lakhani (2017) argue that blockchain is a "foundational" technology, as it has the potential to create new foundations for our socio-economic system. It is not a disruptive solution as it does not attack current competitors by delivering a low-cost solution to established business models, nor can it change business models in the short term, especially if it is implemented as a pure infrastructure component and not as a technology that allows customers a new way of interacting with the organization or with other customers and organizations.

Blockchain has many different barriers to overcome: technical, governance, organizational and societal. To understand its possible evolution, Iansiti and Lakhani (2017) build their thesis around the main assumption that blockchain is similar to the TCP/IP protocol, a technology that has enabled our internet society, but which has been 45 years in the making.

To identify which applications will gain traction first and how the technology will manage to reach critical mass, the authors propose an adoption matrix. It is built around two dimensions that have historically influenced foundational technologies: novelty (how new a technology is to the world) and complexity (the number and diversity of participants that need to work together to obtain value from the technology's adoption).

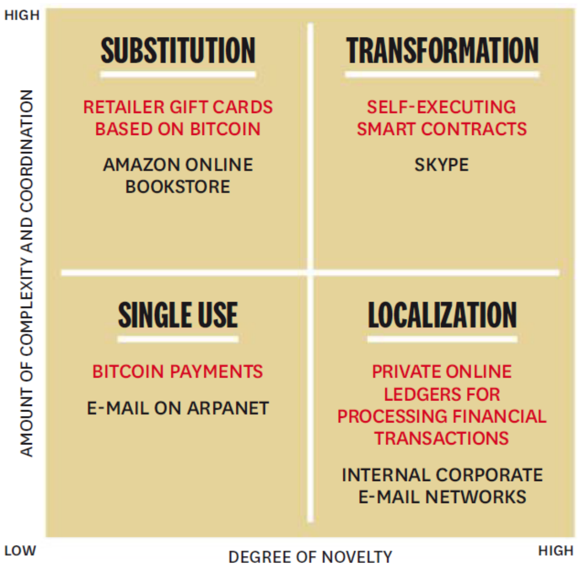

Figure 2.1: Framework – "How Foundational Technologies Take Hold"
The matrix helps identify which blockchain applications have the potential to be adopted today (bottom row) and which should be considered in the future (upper row).

For each of the four quadrants a set of guidelines can be inferred: the level of collaboration and consensus needed, the legislative and regulatory efforts required, and the processes and infrastructure that must be established to facilitate the application's adoption. The authors present blockchain innovations in red and internet applications in black.

"Single use", the first quadrant, is dedicated to applications that create better, less costly and highly focused solutions which can deliver value even to a small user base (the network effect required is low).

Ranking quite high in novelty but requiring a low number of users to generate immediate value, applications in the "Localization" quadrant are also good candidates for adoption. Private blockchain applications that serve a specific set of purposes are expected to be the covered here, as the coordination requirements between stakeholders are relatively modest, while the technology is still in early stages compared to public blockchains.

Building on top of existing single use applications, innovations placed in the "Substitution" quadrant involve multiple stakeholders and satisfy public (more open) applications. Thus, network effects are crucial for driving scale. High barriers for adoption are expected as multiple partners are involved and government regulation might not be in place.

All innovations that have the potential of changing one or more of our core organizational or societal systems (e.g.: economic, political, social) should be placed in the "Transformation" quadrant. These applications require major change at both individual and societal levels, and agreement on standards and processes are paramount. A smart contract is one such transformative application, as our society is built on legal contracts. Replacing human "wet" law with "dry" computer code will certainly not be a facile task, nor will it happen without resistance, but we have the basic ingredients for such a transformation today: an expanding array of data sources that capture an increasing amount of aspects from our daily lives. And blockchain is a secure and decentralized tool that can help store the data.

Given the importance that blockchain can play in the future economy, organizations have to start to educate the workforce about the topic and to conceptually develop applications across the four quadrants. Starting small to develop a level of know-how and a blockchain infrastructure is the first step, but the level and the timing of the investment should be dependent upon the context of the organization and of the industry.

Similar long term confidence for blockchain as a technology that will permeate the global economy is expressed by Swan (2015), Mougayar (2016) and Tapscott (2016). Blockchain can create new players, new services, new value flows and will end up creating a global crypto economy. However, in the short term, a possible crash can occur, due to recent hyping of the technology. Large capital inflows into start-ups and heightened expectations for the technology, risk to expose major differences between the blockchain's long term potential and the current developments. Mougayar (2016) considers that a possible crash might slow down the evolution over the next three to five years, as it happened for the internet after the dot-com crash in the year 2000.

For an innovation to become mainstream, timing is as important as the technology itself, an idea reinforced by Adner and Kapoor (2016). They advocate for extending the decision maker's perspective from thinking about new technology versus old technology to examining the entire ecosystem that is necessary for the new technology to become mainstream versus the developments of the old technology's ecosystem.

Few new technologies are compatible to the ecosystem (e.g: processes, infrastructure, user mindset) of old technologies and can perform a smooth substitution. One such example is the light saving bulb. Being equipped with the same socket as conventional bulbs, the new bulbs can use the old infrastructure and thus can easily replace the old, conventional and non-economical light bulbs. However, for most new technologies a whole new ecosystem must emerge to support the innovation, creating the importance of thinking in terms of old versus new ecosystem.

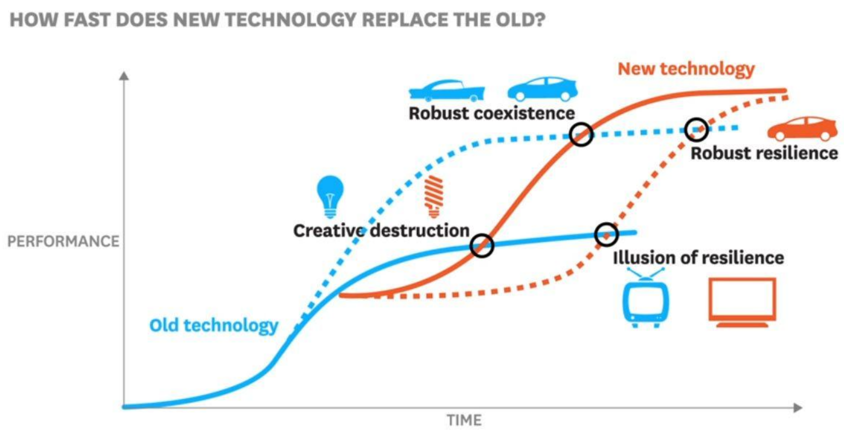

Figure 2.2: "How fast does a new technology replace the old?"
Using "S" curves of innovation, four competitive scenarios can be depicted by examining how a new technology might evolve in comparison to the dynamic of an existing technology

The four main competitive situations are presented in figure 2.2 with the help of innovation S-curves, a method discussed in detail by Brown (1992) and Christensen (1997).

“Creative destruction” occurs when the old technology has no future improvement opportunities and its performance is surpassed by the new technology. This is the moment when innovators should invest to reach wide market adoption, while incumbents should retreat into niche markets where the old technology still has advantages.

The development of an innovation will not produce the expected market impact if the supporting ecosystem is not developed, leading to a juncture named “Illusion of resilience”. Innovators should invest at full-speed in their solution and perfect it with early adopters and with receptive customers. Incumbents should continue to develop their ecosystem and technology as the coexistence of the technologies will persist, and in parallel should search for profitable niche markets.

If the current technology or ecosystem has improvement opportunities, the performance threshold for the new technology will rise, thus the adoption of the new technology will be delayed as competition will be high. The situation, “Robust coexistence”, favors consumers, but it is an important signal for innovators to shift resources from the development of the technology to the development of the ecosystem. Incumbents should only make sustaining investments in their current solution and should plan for a future decline in market share.

The slowest form of substitution, “Robust resilience”, happens when the new technology’s ecosystem cannot keep up with innovation, while the old technology continues to improve, putting pressure on the performance benchmarks that the new technology must exceed. Innovators must work to remove the constraints in their ecosystems, while continuing to improve their technology, a situation that requires significant resources and a long-term plan. Incumbents should invest aggressively in upgrading their offerings to raise their performance in the face of their new challengers.

One path that leads to change, focuses on the exhaustion of the old technology, by going from the robust resilience state, to robust coexistence and then to creative destruction, where substitution will occur. For an innovator, this requires focus on aligning the new technology ecosystem to the requirements without much emphasis on performance. The other path, focuses on competing against an improving incumbent technology, by going from creative destruction, to illusion of resilience and then to creative destruction, where substitution will occur. For an innovator, this requires a simultaneous elevation of technology performance and ecosystem development.

Swanson (2015), Franco (2015), Evans et al (2016), Adner and Kapoor (2016) view blockchain as a foundational non-disruptive technology, therefore it should not be pursued by organizations as the next “hot” thing that can provide a productivity boost or that can unlock a whole new business model. Depending on the industry dynamics and on the company context, organizations might be better off taking the follower position to observe how peers are using the technology and what their results are. Given the fact that current relational database technology and its supporting ecosystem are stable and have been constantly improving, making a large investment in blockchain with the sole aim of being a technology leader is unlikely to payoff. However, learning about blockchain through small scale experimentation is a must and should be combined with active collaboration with potential external partners.

Both frameworks presented in this section approach technological innovation from a strategic point of view, guiding decision makers in determining the optimal timing for adoption and providing insights into areas that require resource allocation. In contrast, the following section offers an overview of theoretical models for performing financial valuation of new technologies and advises on how decisions can be improved by analyzing the project from a financial perspective.

2.2. Financial valuation of new technologies

Traditional techniques such as return on investment and net present value are often used by practitioners to assess the value of investment in information technology projects. This section presents an overview of valuation methods and presents potential upsides and downsides in evaluating IT and new technology projects.

Blockchain is a new IT solution that is well suited to transform and enhance an organization’s information infrastructure. Such projects have long implementation cycles, pass through multiple development stages, thus can be analyzed as decisions that generate long-term results. Due to the long development timeline and innovative features, management must make sure that value of the project is correctly and objectively reflected by selecting the appropriate valuation methods and techniques.

One important decision that can affect the quality of the financial valuation is selecting the right method. According to Damodaran (2006), the four main approaches to valuation are discounted cash flows (DCF), liquidation and accounting, relative and real options analysis.

DCF is an appropriate valuation method if users do not treat it as a black box, observed Hodder and Riggs (1985). The inputs and the assumptions made should be carefully considered, based on a solid understanding of the impact that the analyzed project creates. DCF techniques can assist managers as a powerful tool for objectively comparing cash flows at different points in time, an important element for all investment projects.

$$\text{NPV[standard]} = \sum_{t=1}^{n} \frac{\overline{\text{CF}}_t}{(1+k)^t} - \bar{I}_t \qquad \text{(equation 3.1)}$$

$$\text{Estimated NPV [scenarios]} = \sum_{i=1}^{m} CF[scenario\, i] * \Pr_i \qquad \text{(equation 3.2)}$$

$$CF\ \text{[scenario i]} = \left[\sum_{t=1}^{n(i)} \frac{CF_t^i}{(1+k)^t} - I_t^i \right] \qquad \text{(equation 3.3)}$$

Notations: CF_t = cash flow in year t; I_t = investment in year t; k = discount rate; Pr_i = the probability of scenario "i" occurring

On the other hand, the difficulty in using DCF techniques for new technology investments lies in projecting future cash flows. Moreover, managers tend to misuse and misinterpret DCF valuations of long term projects that appear to involve high risk. In addition, DCF presents certain flaws that must be carefully considered by its users. Firstly, a constant discount rate is normally assumed, and thus, the time varying risk profile of new technologies is not considered. Secondly, DCF methods fail to capture the value of future decision flexibility, extracting the upsides while eliminating the downsides. Both flaws can be addressed by using the real options analysis. Finally, the net present value (NPV) approach has limitations when it comes to risky projects, although it is widely used in practice. Inflating the discount rate to reflect the project risk is not advisable as it penalizes long term risky projects and should only be used when project risks are increasing uniformly over time.

In addition to estimating the benefits and the costs for each scenario, it is important to think about the possible project uncertainties, steering our conversation towards the concept of risk. According to the Safe Activities for Enhancement (SAFE) method discussed by Meli (1998), risk is defined as the expected value of the damage caused to the project by a combination of uncertain conditions. In a subsequent paper focused on risk estimation for software projects, Meli (1999) asserted that poorly formulated project objectives and inadequate allocation of resources for the planned activities frequently showed up as the main causes of project failure and time/cost overruns. Kitchenham and Linkman (1997) indicated measurement error, model error, assumption error and scope error as sources of uncertainty that project analysts have to be aware of when designing a valuation model.

In the case of blockchain projects, Hogan (2017) advises that vendor risk is the most important aspect to take into consideration when it comes to implementing a permissioned architecture as many solutions are developed by start-ups and small companies, which might not have the financial and technical capability to deliver a longer term and broad scope project. From a financial perspective, if an analyst attempts to create estimates for the costs and benefits of a project, the lack of information is problematic, as blockchain is not yet a mainstream technology (few commercial applications have been implemented).

To understand the effects that different risks have on the project's value, Damodaran (2002) suggested splitting risks into four main types: 1) continuous market risk that is difficult to hedge against; 2) discontinuous market risk that can have large economic consequences but has a small probability of occurring; 3) market risk that is dependent upon a specific occurrence; 4) firm specific risk.

Davies et al (2012) proposed an improved solution to inflating the discount rate to reflect project risk – creating multiple scenarios, assigning probabilities and using the expected value as the project estimated value. At least two scenarios should be created, one reflecting the base assumptions and the other reflecting the worst-case situation. Such an approach provides decision makers with more information, encourages project members to identify strategies for mitigating project risks and considers a broader range of outcomes for the project.

When it comes to selecting the DCF valuation method most suitable, Arshad (2012) advised to use NPV, as it is superior to IRR. The author performed a literature review that included 40 books published between 2002 and 2012, and found that 52.5% of authors are in favor of NPV, compared to 10% in favor of IRR and 37.5% with a situation specific solution. His view is strengthened by Pogue (2010), who argued that NPV is superior to IRR as it is consistent with the shareholder wealth maximization objective.

New technology investments without managerial flexibility do not exist. Steffens and Douglas (2007) pointed out that a regular DCF calculation would significantly underestimate the value of the project, even if different scenarios are considered and the corresponding

NPVs are weighted with probabilities. Decision flexibility is a source of project value, especially in IT infrastructure, and as a result, projects in the area are undervalued by using NPV methods, as discussed by Kumar (2004).

The value of a business can also be estimated by summing up the value of all individual assets owned. This approach might be theoretically correct, as Varmaz Armin et al (2008) argued, but a business is an ongoing entity which has assets that it already owns (assets in place) and assets that it expects to invest in (growth assets).

For a business, a blockchain project would be a growth asset that is purchased with the aim of producing savings or reducing risks, but it could also provide a positive impact in developing new business models. As the technology's value generating capabilities are not well known, the value of a blockchain project on the balance sheet of a company might not be equal to its real business value, and therefore, the liquidation and accounting valuation method cannot provide a correct picture when evaluating such a project.

Another method for estimating the value of a business or a project is relative valuation, which is built on the assumption that the market gets the pricing of assets correct on average, while it may be wrong in how it prices individual assets. Damodaran (2002) argued that while it might be easy to compare assets that are similar based on price, the situation gets more complicated if assets display different characteristics. From a user perspective, relative valuation implies abandoning the intrinsic asset value and trusting that the market correctly evaluates the asset. Such valuation involves the usage of several financial measures (e.g.: enterprise value, stock price, revenue) which can be combined to form standardized and easy to compare indicators (e.g: multiples of earnings, firm value over revenue).

The inability to find relevant peers or comparable technologies for comparison is a topic also discussed by Steffens and Douglas (2007). Similar companies that are researching or implementing new technologies might not disclose financial information, while market information on deals or economic impact is missing as the technology is not generating substantial income streams. Moreover, there is a low probability of finding publicly listed companies or disclosure amounts for deals that are focused on the technology of interest. Therefore, suitable market data is most probably not available. An additional problem can stem from the small initial economic value of a new technology and its unseen growth potential over a medium to long time horizon, both of which depend on the speed of adoption.

The interdependencies between the technologies that make up an IT portfolio can be estimated using real options, thus improving the prioritization of IT investments, found Bardhan et al. (2004). An IT infrastructure project might have a negative NPV, but it can also offer future options to build value adding applications on top of it. If the flexibility is not considered, then managers will not be able to accurately assess the project's strategic business value.

Most investment projects can be started at a later stage in the future, when more information will be available or when financing will be more attractive. Moreover, some investments can lead the way to other subsequent investments, thus reinforcing the optionality perspective. All investment decisions should be treated as option pricing problems, if the investment opportunity does not instantly disappear if not immediately undertaken, argued Ross (1995).

Firms face constant uncertainty as their future growth depends up to a certain extent on the opportunities they already invested in. It is no surprise that real option analysis has captured the fascination of both managers and researchers, who consider its framework as a good fit for assessing a firm's challenges since it links current decisions with uncertain future states, reported McGrath (1997) and Kogut & Kulatilaka (2001). By purchasing a real option, management makes a small investment to postpone a larger investment while the uncertainty factors persist. At or before the expiration period of the option, management can choose to either undertake the big investment or to cancel the project, based on the signals received. Dixit and Pindyck (1994) classified investments that are suitable for real options analysis based on the following criteria: sequential, irreversible and made under conditions of uncertainty.

The boundaries of real option valuation are examined by Adner and Levinthal (2004), who pointed out that the method should be applied only to a limited type of investment decisions, those that display a unique technical set-up (technical properties are set) and a fixed target market (the product or service that will be created is decided and not subject to further modifications). Real options are not recommended to be used in other investment situations as the method would not produce the expected results in terms of decision making effectiveness. For areas where flexible technical solutions are employed and/or the target market is flexible, a path dependent investment strategy is recommended, where small investments in learning and searching are the preferred way to reduce uncertainty.

Real option thinking should be used when considering investments in risky technologies or ventures, as it is important to capture all possible benefits while minimizing the impact of threats. However, real option valuation is inferior to decision tree analysis in the context of new technologies, argued Steffens and Douglas (2007). Firstly, real options capture market risks in a sophisticated approach, but fail to capture firm-specific risks. The high levels of risk for a new technology stem from firm-risk, thus the real option valuation is not suitable. For example, Gartner et al. (1999) identified seven factors which distinguished surviving and non-surviving firms, of which all but one were firm specific. Secondly, a valuation using real options starts with the valuation of the underlying asset in the absence of a real option, with the project or venture cash flows being analyzed using the DCF method. However, the discount rate cannot be established for a hypothetical project or firm, because the real option is an integral part of the project/ firm, making it difficult to use real option analysis to value a start-up based on the development of a new technology.

To conclude, taking into account that the objective of the paper is to deliver an evaluation framework for blockchain technology that can serve decision makers, the financial valuation methods identified as optimal are DCF (NPV) and decision tree analysis. Given the fact that both real options and relative valuation rely on external (market) data and that accounting valuation relies on financial information that already reflects firm value, they are not suitable for evaluating a new technology. Under development, highly customizable and with few proven applications in use, blockchain requires an evaluation focused on internal drivers, where its actual contribution to the project must be carefully examined.

To support the identification of value drivers, the next chapter offers a more detailed understanding of blockchain from a technology perspective. The two main architectures are presented in the following two sections, while specific applications are discussed in section number three.

3. Understanding blockchain

Two weeks after Lehman Brothers' bankruptcy filing, in October 2008, Nakamoto (2008) published[1] the paper "Bitcoin: A Peer-to-Peer Electronic Cash System", which introduced the plans for the Bitcoin digital currency system. The paper triggered the development of the open source cryptocurrency network and its following ascent into public opinion. As the usage and notoriety of Bitcoin expanded, companies across a variety of industries started to examine possible applications of cryptocurrency and of its underlying technologies, as discussed and theorized by Swan (2015), Mougayar (2016), Tapscott (2016). One technology that has been receiving significant attention is blockchain – a distributed storage technology that is designed to build trust between transacting parties without the need for a central intermediary.

Before diving into the details of blockchain, let's first explore the concept of trust. Merriam Webster (2017) dictionary defines trust as: "assured reliance on the character, ability, strength, or truth of someone or something". A cross-disciplinary study on trust was performed by Rousseau et al (1998) and uncovered that although it is a complex phenomenon, the two necessary conditions, risk and interdependence, are also inherent factors to business transactions. Trust is a foundational element for doing business and for our economy, but as the adoption of digital tools is increasing, maintaining trust is becoming more expensive, time-consuming, and in many cases inefficient, Piscini et al (2016) note. By analyzing four business cases and the literature, Woolthuis et al. (2005) argued that between trust and legal contracts a complicated connection exists, as trust can both complement and substitute contracts. However, trust is required in the first place to build a relationship and ultimately, trust leads to more successful partnering. From a supply chain point of view, Handfield and Bechtel (2002) found that improvements can be made in the relationship between buyers and sellers if assets and information are shared.

Blockchain helps in building a trust network between partners that previously did not trust each other by establishing if transactions reflect reality (validate the truth) and by storing the information in a shared and transparent ledger (all partners control the same data). As described by Franco (2015), Mougayar (2016) and Tapscott (2016), from a technological point of view, blockchain is a database that is replicated in real-time across all computers in a

[1] Note: The name Satoshi Nakamoto is used by the person or group of people who designed Bitcoin and created its original reference implementation, Bitcoin Core (formerly known as Bitcoin-Qt). As a part of the implementation, they also devised the first blockchain distributed database. In the process they were the first to solve the double spending problem for digital currency. However, their real identity remains unknown.
Source: The Economist, 2015, Who is Satoshi Nakamoto?, November 2nd

network, storing shared data that all partners agree on (consensus). Every participant can modify or delete the data on the database he or she controls, but from a system-wide perspective, the modification will be implemented only if the majority of participants in the network verify that the change is correct and accept it. Therefore, the data stored on a blockchain cannot be modified or deleted (immutable) and is trusted by all participants that have access to it.

Furthermore, blockchain can help users have full control over the data they generate by choosing if and when to share it with other individuals or organizations, as discussed by Moody's (2016), Mougayar (2016) and Tapscott (2016). Such a feature is useful in situations where private information is valuable such as medical records storage, as presented by Azaria and Ekblaw (2016).

As Bitcoin allows users to openly join the network and to send value directly to other users, its blockchain is designed to provide complete transparency and traceability over validated transactions (auditability), discussed in depth by Bitfury (2016). However, the open feature does not match a firm's operational environment which is defined by confidential and trusted one to one contracts which can be enforced by law – a firm requires a closed blockchain, as discussed by Accenture (2015), Swanson (2015), Moody's (2016), Mougayar (2016), Iansiti and Lakhani (2017). Therefore, the blockchain community (made up of IT programmers and enthusiasts, companies, non-profit organizations and government institutions) has taken the core blockchain idea, distributed, immutable database, and shaped it according to the needs provided by different organizations, present Mainelli and Smith (2015) and Mougayar (2016). A list of blockchain projects is curated by the community on GitHub.

Evans et al (2016) presents the original Bitcoin stacked architecture - upper level functions depend on lower level functions, but the reverse does not hold (figure 3.1). The lower functions represent the infrastructure, which is designed to be reliable, secure and scalable, while the upper functions are highly customizable, offering the opportunities for open innovation in the case of a public ecosystem or for strategic innovation in the case of a private ecosystem.

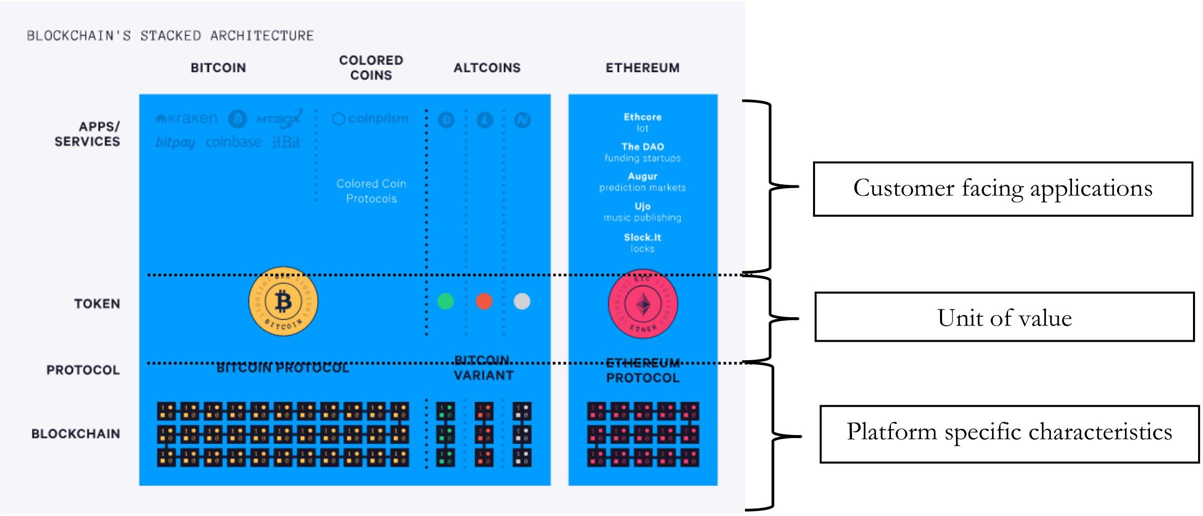

Figure 3.1: Cryptocurrency's stacked architecture

A cryptocurrency system has a technical set-up similar to any cloud based application. The base layer holds the blockchain that stores transaction data. This data is controlled and processed by a set of rules specific to each cryptocurrency network (e.g.: Bitcoin protocol). At the center of each cryptocurrency system is the actual monetary unit itself, called token, which allows users to send value to network participants. On top of all components described, applications can be built to facilitate different operations (e.g.: buying or selling cryptocurrency units, storage of cryptocurrency, payment processing for business users such as retailers).

To this end, blockchain is presented as a distributed database used in a single function, recording cryptocurrency transactions. As this research aims to provide a general framework for evaluating blockchain projects, the specifications must be expanded to encompass a wider variety of possible applications. Theorists and practitioners, Pilkington (2015), Cachin (2016), Mattila (2016), Mattila et al. (2016), Mougayar (2016), Peters and Panayi (2016), Tapscott (2016), argue that a blockchain's architectural set up can be classified into two main categories, as presented in the following two sections.

3.1. Permissionless architecture

An permissionless (or unpermissioned) blockchain is an open and decentralized ledger which records the transfer of value between all participants and allows any user to create transactions without requesting access from the network operator. Every transaction is first validated then included in a block. Each block is cryptographically chained to the previous block, resulting in a permanent, immutable and verifiable record of "truth" that everyone can see and agree on, as discussed by Franco (2015). This feature is useful when no central entity is available or wanted to verify the validity and correctness of a transaction, and can be leveraged to replace central entities and middlemen with a peer to peer system.

Moreover, unpermissioned blockchains are “censorship resistant”, a key feature for the libertarian ideals of cryptocurrency systems. The Bitcoin community is striving for a monetary system where all users have an unknown identity which ensures financial freedom through the registration of all transactions on the blockchain, hence value can be transferred regardless of authoritarian interests. This feature also has negative side effects, such as creating difficulties for governments and regulatory bodies to prevent money laundering, black market developments and other illicit activities, as argued by the Federal Bureau of Investigations (2012).

An unpermissioned blockchain is a public ecosystem, where any member can interact with it and can add innovations on top of the open source code. To validate the transactions, a proof-of-work consensus mechanism is used and transactions occur between public peers, notes Franco (2015). The cost of running such a system is currently low for participants but predicted to increase as miners expand electric energy by solving the transaction blocks and are compensated with bitcoins (the amount will constantly decrease in the future) and through transaction fees (the amount will increase in the future, raising the cost for users). According to Swanson (2015), the energy cost and the environmental cost of running a proof-of-work validation mechanism for Bitcoin will rise as long as the value of bitcoin will rise. The value derived from creating a block will increase and competition to capture this value will diminish the margin between the value derived from creating one block (number of bitcoin units earned multiplied with the market value of bitcoin) and the cost of creating a block (e.g.: energy expanded for validating transactions, depreciation of assets used). If costs are greater than the earning from block creation, transaction fees will cover the difference.

Being an open source projects where everyone is free to contribute, the permissionless blockchain architecture suffers from divergences and from the different perspectives that each community member holds, as researched by Robles and González-Barahona (2012), and Jameson (2016). This phenomenon has led to different forks, changes of important source code that affected how the system operates, that in a few cases caused loss of economic value for some or for all members. In the case of a fork, some members of a system community will continue to use the code in its old format, while other members will use the new code. Through forks, different systems and cryptocurrency solutions have been created, a positive aspect when it comes to innovation, but a significant drawback when it comes to trust between developers in the community and system support continuity.

To conclude, an open blockchain architecture is best suited for applications that target a wide pool of customers which today are using a third party to transact or to connect with each other. It helps to maintain the trust between participants without requiring them to set up legal contracts before transacting, as discussed by Mougayar (2016) and Tapscott (2016). Yet, not all areas in the economy are suitable for such an implementation. Third party providers that offer additional value besides intermediating transactions cannot be easily replaced by a simple network made up of connections. Similarly, in situations where it is difficult to validate the real-time status of a real asset registered on the blockchain, the benefits of using the technology are limited as trust cannot be guaranteed. A more detailed comparison between the advantages and disadvantages of permissionless architecture is presented in Appendix 3.

3.2. Permissioned architecture

A permissioned blockchain technology is far more appealing to enterprise users as it allows control over the access rights of a predefined list of users, which can be established based on existing contractual agreements, as researched by Cachin (2017) and Yermack (2017). Certain paper-based processes can be replaced with vastly improved digitalized processes, especially in areas where collaboration between multiple external stakeholders is required. In a study published by Barclays,

Simon (2015) argues that the main issue which limits adoption into practice is "consensus", using algorithms and computer processing to establish an agreement between all network participants. Swanson (2015) considers that blockchain's consensus contrasts with today, where every bank, government department and law firm has its own paper copy of the truth. Blockchain aims to replace these individual independent records held by each organization with a single shared digital record of data. Beside cost and time savings, the risk of theft and forgery is reduced to literally zero. This can happen without the use of cryptocurrency monetary units as permissioned blockchains are designed to store actual financial and non-financial process data such as asset transactions. However, as Swanson (2015) points out, it is important to ensure that the situation recorded on the blockchain can be enforced in real life, otherwise blockchain cannot add any value compared to current systems.

A permissioned blockchain is recommended in a private ecosystem, as explained by Swanson (2015), Kakavand et al (2016), Berke (2017), because only a closed group of individuals and/or organizations can participate, which already have known and verified identities. Therefore, transactions can be validated by known partners, compared to a public system where transactions are validated by unknown miners. The consensus mechanism chosen by the participating organizations can be adjusted to be more relaxed compared to the proof-of-work mechanism used in a public blockchain. This eliminates much of the cost associated with validating transactions, allowing the network of partners on private blockchain to run their transactions at an increased speed and with minimal costs. The cost of running such a system can vary from case to case and can be covered by the participating organizations in a shared manner. A closed architecture would also eliminate the limit on the number of transactions processed per second and the dependency on consensus established between a large number of unknown decentralized partners.

In conclusion, a permissioned blockchain is the optimal architecture for organizations that aim to improve their existing processes with multiple external partners. Information flows can be restricted based on contractual agreements to protect confidentiality agreements and the competitive position of all partners. Therefore, validation of information becomes a more important component as consensus is only established between parties that have access to shared data or to interrelated data. As research by Accenture (2015) shows, private blockchains have to produce benefits that other centralized technologies cannot already deliver to stand a chance for implementation in an existing IT landscape. A more detailed comparison between the advantages and disadvantages of permissioned architecture is presented in Appendix 4.

3.3. Practical blockchain applications and ideas

This section supports the case study presented in chapter five by discussing how blockchain can be used in supply chain operations and how government authorities plan to issue regulations on the technology. As of April 2017, no government authority has issued strong guidance in favor or against the use of blockchain in a certain industry.

3.3.1. Government authorities

Atzori (2015) asserts the capability of blockchain to transform the traditional centralized government systems into modern decentralized platforms and explores the possible risks. The fact that blockchain can enforce changes on governments is supported by the results of a survey performed by The Economist Intelligence Unit on 200 government leaders in 16 countries and published by Institute for Business Value (IBM, 2017). It estimates that most blockchain investments are expected to arise in the following three areas: asset management, identity management and regulatory compliance. On the other hand, regulatory constraints and immaturity of technology are seen as the biggest threats to government adoption. Although the interest in blockchain seems elevated, with 14% of respondents planning to build a working application in 2017, the adoption will be dependent on individual agencies.

For instance, the Government of Sweden has been testing a blockchain tool to register real estate transactions, as reported by Reuters (2016), while the Monetary Authority of Singapore (2016) has developed a plan to develop a blockchain infrastructure for financial transactions, both aiming to improve transparency and reduce costs. Blockchain driven projects on an even larger scale are under evaluation, such as issuing e-currency (digital version of fiat currency) on a blockchain infrastructure, an idea explored by the central banks of Sweden, UK, Russia, Canada, Australia, China as reported by Financial Times (2016). In April 2017 the European Commission (2017) proposed the establishment of a blockchain working group for the next two years that aims to discuss and develop possible applications.

As cryptocurrency systems enabled peer to peer transfer of value without the need for a central intermediary, as presented by Nakamoto (2008) and Franco (2015), blockchain has received the largest amount of attention from financial institutions. Therefore, financial regulators both in the US and in Europe have investigated the technology, but have not yet issued strong regulations, preferring to take a hands-off approach until the technology matures and comes into wider use, as discussed by Kakavand et al (2016) and by Yeoh (2017). However, starting with the financial industry and then extending to other fields, regulators are expected to start shifting from expecting organizations to comply with regulation, to actively requesting an irrefutable proof of compliance. Blockchain is viewed by Reuters (2015) and Carney (2017) as one of the technologies that is driving this movement, as it can help organizations demonstrate compliance to government authorities by ensuring data integrity and immutability, and by offering a secure way to share sensitive data to regulators.

From a joint, supply chain and government perspective, the government of Dubai has offered support for a blockchain supply chain application that involves the digitization of transactions and simplifying trade finance processes, as reported by Reuters (2017).

3.3.2. Supply chain

Blockchain can be enhanced by capturing data from sensors on the movement of physical goods, then using it to automatically execute digital contracts and agreements, creating a completely digital supply chain, propose by Casey and Wong (2017). The benefits of product traceability and process automation can extend to multiple industries as demonstrated by different applications prototyped.

Provenance (2015) built an ecosystem of producers, shops and consumers that can track the journey of a product from source to the shop on blockchain; thus, a consumer can check the origin of a product before purchasing. On the same principle of providing transparency of a product throughout its lifecycle, Everledger created and operates commercially a blockchain based application which immutably stores 40 different characteristics of a diamond, with the aim of improving the transparency of diamond sales, reducing fake insurance claims and helping to verify the authenticity of a diamond.

Casey and Wong (2017) report two main challenges that can impact the development of blockchain in supply chain. Firstly, the governance of a blockchain application is complicated by the fact that multiple stakeholders with different interests need to be involved in its development. Secondly, a global supply chain is required to respect a complex set of different national regulations, maritime law and commercial codes, governing the ownership and possession of goods during transport and in each jurisdiction. The multinational scope of a supply chain process and the level of cooperation required with the diverse set of stakeholders indicate that a long and complex period of change is required to transform today's mostly paper based process to a fully digital one based on blockchain.

In summary, blockchain is an emerging technology that has the potential to improve processes in a variety of industries, but which has not yet received strong regulatory recommendations. Given that government authorities seem to be open to learning and experimenting, it is safe to assume that future regulation will take into account the best outcomes for both markets and for the industry players. However, uncertainty still remains regarding the precise form and guidance of future policy in each country. It is safe to assume that the first areas that will experience stronger regulatory pressures will be those where blockchain delivers an entirely new way of doing business, not just a process improvement by replacing old ways of working with a blockchain system.

The next chapter introduces the framework proposed for evaluating blockchain projects.

4. Proposed framework for blockchain project evaluation

This chapter presents the framework suggested for evaluating blockchain projects. It has been designed to be widely applicable in a variety of industries and applications.

The framework aims to prepare users for an informed and objective decision on whether the blockchain project should be rejected or accepted. The use of a decision-making framework is endorsed by the Ministry of Economics, Trade and Industry of Japan (2017), which considers misunderstanding and unreasonable expectations as the two main factors that lead to the unwillingness to introduce the technology. The proposed framework is structured into three parts, eliminating in the first stage the projects that are least likely to succeed, thus helping users focus on projects that display potential benefits. From the experience of the writer, most of the analyzed blockchain projects have been rejected as other technologies have been identified as more suitable for delivering the desired results.

Part one is designed to be all encompassing, starting on purpose with specific questions based on blockchain features, as it is important to identify early on if blockchain is the optimal technical solution for the project, as presented in similar frameworks developed by Trilogy Associates (2008), Greenspan (2015) and Cooke et al (2015). The theoretical concepts used in developing the first part of the framework are enclosed in chapter three and in the second appendix section. It is important to mention that the questions should not be viewed in a rigid manner, especially in a question by question evaluation – do not reject a case immediately when a certain answer is negative.

Part two is designed to evaluate if the proposed project delivers financial benefits to the organization and is an integral part of the blockchain framework, influencing the ultimate decision outcome. It is important to note that the financial valuation is dependent upon how the user has described the project and on how blockchain is viewed from a technical point of view, as adapted from the research of Damodaran (2002). For example, a project can be purely focused on using blockchain technology for a single process or for a process function. Another project might consider blockchain as a component in a wider technical set up that involves several technologies with the aim of delivering functionality to a larger process or to an entire organizational function. Therefore, it is up to the analyst to identify in the financial evaluation which are the components that deliver value in a complex situation. It is advisable to break down a project into functioning components to make it easier to identify benefit and cost drivers.

The framework builds on the financial theory discussed in section 2.2. DCF is proposed as the preferred valuation method (equations 3.1, 3.2, 3.3), as it is a flexible and objective method to determine future cash flows, which clearly lays out investment resources needed and requires the identification of value drivers, Hodder and Riggs (1985) and Pogue (2010).

Decision tree analysis can be coupled with DCF valuation to capture the added value of managerial flexibility, which is important to consider if the investment in a new technology allows decision makers the flexibility to make additional investments, as discussed by Kumar (2004) and Steffens and Douglas (2007). For example, a project can be seen as the first move in a multi stage road map leading to an extended functionality.

The working assumptions for the blockchain application must be clearly identified and laid out, in accordance to the implementation plan. If the project is a first in the organization and no existing applications or processes fulfill the identified task, the evaluator has to set a rough set of assumptions based upon the function performed in the organization by the envisioned technology. Cash flows, initial investment and discount rate are the main items required to compute an NPV analysis. For blockchain, this phase might pose additional hurdles as it is mostly an untested technology in real-life. One way would be to draw rough assumptions by thinking about similar technologies that satisfy the same basic operational requirements, such as TCP/IP as proposed by Iansiti and Lakhani (2017), and then refining the assumptions by incorporating blockchain's unique specifications. If the organization already has a process and technology in place that can be improved by using blockchain, the assumptions should clearly capture the changes generated by implementing blockchain, as discussed by Tipping (1995).

When it comes to the execution of the financial valuation, the framework's general approach towards blockchain allows users the flexibility to adapt to the specifics of the project analyzed. The best valuation practices must of course be respected to provide optimal results, as outlined by Khan (1999), Damodaran (2002), Westland (2003) and Brealey et al. (2011).

Developing several possible scenarios is highly advisable, as endorsed by Damodaran (2009), however users must take into consideration the following: 1) which are the factors the scenarios will be built around; 2) determining the number of scenarios to be analyzed; 3) assigning probabilities to each scenario given the available information.

Part three, the final decision regarding the project adoption, should weigh the non-financial benefits and drawbacks uncovered in part one with the financial evaluation results from part two. If the framework identifies a project as beneficial from both a technical and financial point of view, the project can be accepted. The next step towards adoption is to identify IT providers that can support in running a proof of concept, a small-scale test that will help decision makers understand if the project can deliver the expected results in the envisioned organizational setting. The research does not cover the actual implementation of a successful project; however, multiple approaches exist for validating an idea and transforming it into a working solution, discussed in-depth by Poppendieck (2003), Rise (2011), Sutherland (2014).

In the situation that results from part one recommend adoption, while results from part two show no indication of economic value to the organization, it is recommended to consider if non-financial benefits such as safety, lower operational risks, organizational learning, compliance to regulation or better collaboration with stakeholders should be prioritized. If the project is forecasted to deliver negative financial results that cannot be offset by non-financial benefits, break it down into components to observe the major cost drivers and what other areas can deliver benefits but have not been initially considered. If no additional information is uncovered, reject the project.

Both the academic and the common business literature contain examples of new technologies that were either vastly underestimated or overestimated, causing loss of market share or even company bankruptcy, described at length by Christensen (1997) and Munir (2012). The evaluation framework developed in this paper aims to help managers take informed decisions that lead to the optimal applicability of blockchain, either as a standalone technology or in combination with other technologies.

The proposed framework is enclosed in the following two pages. The next chapter presents a case study that captures the usability of the framework in an organizational setting. As the paper has a finance focus, the second part of the framework (the financial valuation) is presented in more detail. Both part one and part three are briefly discussed, with additional details enclosed in the appendix sections 5, 6, 7 and 8.

PROJECT NAME:
SUBMITTER:
DATE:
INTRODUCTION. SHORT DESCRIPTION
1) Describe the envisioned and complete blockchain project in 10 to 20 rows
2) Design a rough process flow
3) Are changes in the organization or in the industry driving the need for adopting blockchain technology?
4) What are the main changes that blockchain enforces?
5) What are the main benefits of implementing blockchain technology?
6) What are the main expected implementation hurdles?
PART 1. TECHNOLOGICAL AND STRATEGIC EVALUATION
SECTION A. BLOCKCHAIN FIT
Q_A1. Does the project require storage of data? (Yes – 1p / No – 0p)
Q_A2. What is the size of data that needs to be stored in one transaction? (Small, under 1MB – 1p / Large, over 1 MB – 0p)
Q_A3. Is the process defined in the project 100% deterministic? / Can you prove that the status of an asset reflects reality? (Yes – 1p / No – 0p) [Related to Q_B1]
Q_A4. Is there a need for multiple database writers? (Yes – 1p / No – 0p)
Q_A5. Does Roche trust the data provided by partners or do partners trust data shared by Roche? (Yes – 1p / No – 0p)
Q_A6. Is there a need to remove the intermediary or existing interfaces between systems? (Yes – 1p / No – 0p)
Q_A7. Do transactions or information flows depend upon each other? (Yes – 1p / No – 0p)
SECTION B. DIFFERENTIATE BETWEEN A STRONG AND A WEAK CASE
Q_B1. Can you enforce the status of the asset as registered on the blockchain to reality? (Yes – 1p / No – 0p) [Related to Q_A3]
Q_B2. Would the partners included in the network have any motivation to collaborate between themselves? (Yes, stakeholders can develop connections between themselves – 1p / No, Roche is the main contact point for all stakeholders – 0p)
Q_B3. Can the project deliver value even if not all process stakeholders become network partners (the ecosystem is not crucial for success)? (Yes – 1p / No – 0p)
Q_B4. Can the blockchain project be developed without government support or oversight? (Yes – 1p / No – 0p)
SECTION C. INDUSTRY INVOLVEMENT
Q_C1. Does the project require industry collaboration to assure project success? (Yes / No)
Q_C2. Could the project be improved if industry partners collaborate? (Yes / No)
SECTION D. DIFFERENTIATE BETWEEN A PERMISSIONED AND A PERMISIONLESS CASE

Q_D1. Does the project require restricted access to data based on contractual/ disclosure agreements? (Yes - permissioned / No – permissionless)
Q_D2. Does the project require a complete identity check of all partners on the network? (Yes - permissioned / No – permissionless)
SECTION E. BLOCKCHAIN AND SUPPORTING TECHNOLOGIES
Q_E1. Does the project require a combination between blockchain and additional technologies? (Yes/ No)
SECTION F. BLOCKCHAIN TECHNOLOGY FOCUS:
Q_F1. Are there existing applications that are not built upon blockchain but satisfy all requirements?
Q_F2. Does blockchain stand out as unique or are there many additional solutions for the project?
Q_F3. Are there similar applications on the market using blockchain?
Q_F4. What is the stage of development for blockchain? (e.g. prototype, proof of concept, in development, market ready application, application in use)
Q_F5. Is blockchain a complex or simple technical solution to implement?
Q_F6. How does blockchain's performance stand out against the other technologies?
Q_F7. What is the track record of blockchain?
Q_F8. Are there providers of applications based upon blockchain available for the specific project?
Q_F9. Should the blockchain solution be developed in-house or licensed from a third party?
INTERMEDIARY DECISION POINT – IS THE PROJECT COMPATIBLE WITH BLOCKCHAIN TECHNOLOGY? (Yes – continue to Part 2 / No – jump to Part 3)
PART 2. FINANCIAL EVALUATION
Recommended valuation method: NPV (DCF) – recommended use of multiple scenarios
Additional valuation method: Decision tree (based on NPV)
Valuation period: 3 years or more
What are the estimated investments necessary?
What are the estimated benefits?
What are the estimated costs?
What is the estimated discount rate?
Overall, what is the NPV of the project?
Does the blockchain project generate value in comparison to the current situation?
What are the main development scenarios?
Additional sources of value not captured by the financial valuation? – e.g.: managerial flexibility, organizational learning, trust, credibility, innovation.
PART 3. DECISION AND IMPLEMENTATION COMMENTS

5. Case study: Tank asset tracking

This chapter builds upon the theoretical concepts presented in chapters two and three, and provides a step by step evaluation of a real world blockchain project utilizing the assessment framework suggested in chapter four. In addition to the analysis, the chapter aims to offer an objective range of commentary regarding blockchain adoption decision by employing multiple perspectives that are simple to use in practice.

5.1. Case study[2] introduction

The case study described is based on the tank asset tracking project and all information presented in the paper is disclosed from the project's intranet page with permission or collected through discussions with colleagues responsible for the project.

Tank tracking is a worldwide undertaking within Roche, which delivers tracking and planning for the movement of metal tanks that are used in transporting raw chemicals and finished product substance between 25 manufacturing sites on 3 continents. Currently, there are 2500 metal tanks in use, worth more than USD 330 million, which are critical for global manufacturing operations, both for internal manufacturing within Roche and for manufacturing performed by 3rd party entities, contract manufacturing operations (CMO). A tank lifecycle schema is enclosed in appendix 5. The content carried by each tank is worth on average USD 1 million, and falls under health regulations as the entire manufacturing chain for the pharmaceutical industry is highly regulated to assure product quality.

Tank tracking is a 100% internal IT driven process that combines information from supply chain and manufacturing areas. All collected data is owned and controlled by Roche. Four enterprise resource planning (ERP) systems record the movement of transported content from a Roche site to another Roche site or to a CMO site. The tank asset tracking project built an application that offers reports based on data held in these ERP systems and on information from other sources (email, phone calls, paper reports). Information on the movement of tanks is based upon confirmations and receipts, which are either paper or electronic documents issued by different stakeholders when tanks undergo a certain process such as when they enter or leave a certain location. These documents are stored on the ERP systems as evidence for the transactions recorded, the movement of assets. By using the IT reporting application, the team can deliver reports to authorities and can support internal decision making.

[2] The case study is based on a blockchain project evaluated by the writer in April 2017 as part of an internship program at F. Hoffmann-La Roche AG.

Having an accurate overview over the location of each tank is important from both a business and a regulatory perspective:

1) business perspective – active management and improved planning increases tank utilization rates by reducing time spent at different sites or in transit;
2) business perspective – monitor the transit of product to ensure manufacturing flow and production quality;
3) regulatory perspective – prove compliance to regulatory bodies by providing reports and information upon request on the number of tanks stored at a certain location and on other required criteria;
4) regulatory perspective – apply for transit or storage permit to different government authorities ahead of time to avoid potential delays that can affect manufacturing runs.

From an accounting perspective, the project is a cost generator and does not produce revenues for the organization. However, the project generates internal operational efficiencies such as lower cost and improved management information, and ensures compliance with regulations.

The tank asset tracking project can be further improved by taking advantage of new technology developments. The improvement objectives are:

1) traceability – use of digital platform to report tank location and to demonstrate tank traceability to government agencies;

2) timeliness – offer a real-time location overview of all tanks across the World;

3) digitization – transform the exchange of information with active process stakeholders from paper based to 100% digital.

The following two sections discuss if blockchain is the appropriate technology for delivering the above-mentioned improvements to the project, by providing a technology, strategy and financial evaluation based on the framework introduced in chapter four. A final section concludes the chapter, offering a recommendation to either accept or reject the use of blockchain technology in the tank asset tracking project.

5.2. Technology evaluation

An overview of the technology set-up proposed for the tank tracking project is provided in the beginning of the section. Thereafter, the technical evaluation is presented.

The tank asset tracking project involves three main active process stakeholder groups: Roche (the owner and user of the tank fleet), CMO (users of tank fleet) and logistics provider (transporters of tanks between production sites). One additional main process stakeholder group is government authority, which plays a passive role, using tank location reports specific for each jurisdiction to ensure compliance to regulation. As defined in the paper, a stakeholder has an active role in the process if it physically manipulates the tank.

Described in chapter three, blockchain is an emerging technology that helps build trust between stakeholders through sharing of data, validating it and having all involved parties agree that the data correctly reflects the reality. Moreover, blockchain offers a single data and work standard for a process that is jointly created and adopted by stakeholders, making collaboration easier by enhancing the digital exchange of information.

Blockchain plays a central role in the technical set-up of the tank tracking project, as it ensures data integrity by receiving all tank location information, validating it and storing it in an immutable manner that complies with the reporting needs of government authorities. Tank location data is received from Internet of Things (IoT) sensors that transmit the real-time location of each tank and from logistics providers. The data is validated at certain points in time by active stakeholders when tanks undergo processes they control. In addition, validation occurs continuously by comparing actual sensor data against the tank movement plan and by automatically detecting when a tank has reached a preassigned location. Additional details on the technical set-up are presented in appendix 6. However, it is important to mention that a permissioned (closed) blockchain architecture has been selected, as the project has a limited number of already known stakeholders and deals with confidential process data. This is characteristic influences all project details specified further.

The complete answers for the first part of the blockchain evaluation framework are enclosed in appendix 7. They are focused on the technical aspects of blockchain adoption, a topic that is not within the paper’s scope. To summarize, the analysis indicates that blockchain technology fits the requirements of the project and is recommended to continue the evaluation from a financial perspective to identify if it can deliver value to the organization. However, the fit is not perfect, thus some areas are recommended to be investigated in more detail. The strategic fit complements the technical discussion and is presented in the following section.

5.3. Strategic evaluation

Given the information presented in sections 3.3, 5.1 and in the appendix section 7, tank asset tracking can be viewed as a niche supply chain application, for several reasons. Firstly, the items shipped and their dedicated supply chain systems are completely separated from the organization's main supply chain operation. Secondly, in comparison to the main supply chain area, the tank operation is small, both in terms of yearly number of shipments and in terms of stakeholder groups involved. Thirdly, government regulation is specific to this operational area, making government compliance simpler from an informational point of view, but tougher to implement major project wide changes. All three points combined make the case for an increased likelihood of implementing a blockchain solution in a shorter time frame than otherwise conceivable for the main supply chain process.

Considering the theories focused on strategic adoption of new technologies exposed in section 2.1, the adoption matrix (figure 2.1) points out that the project fits the localization quadrant best, indicating that blockchain adoption is feasible in the near future. The connection between blockchain and IoT sensors requires new technical solutions, while from a coordination perspective, the project involves a low number of known stakeholders. Based on figure 2.2, blockchain best fits the robust resilience quadrant, suggesting a long transition period from conventional database technology to blockchain. Current database technology and their specific data processes have seen constant improvements in reliability, quality and in extracting more data from a greater number of sources, while blockchain technology lacks a strong ecosystem for most envisioned applications, as discussed by Yli-Huumo et al (2016) and by Iansiti and Lakhani (2017). However, it must be pointed out that blockchain is not designed to replace conventional databases as they are currently used, mostly in internal processes, but to offer a new way to collaborate and coordinate with external stakeholders while maintaining a high level of trust in the process.

The core blockchain technology exists, improvements can be made by each group of partners based on their application's requirements. Yet, to achieve the desired results, each organization must focus on strengthening the ecosystem around the solution by collaborating closely and openly. Furthermore, the adoption of blockchain will not happen in a stable and known operating environment as the subsequent discussion point demonstrates.

5.4. Project risks

As outlined in the framework (appendix 7) in response to the introductory question number six (R_6), the following project risks have been considered in the evaluation.

Firstly, government authorities in multiple jurisdictions are expected to increase the level of compliance required, generating the need to use a blockchain for tank location reporting. However, the point in time when these new regulations will come into existence is not known. Today, regulation regarding tank movement and storage is different from country to country, and there is no regulatory movement planned to bridge the differences across the jurisdictions. Building a blockchain that can serve a tank tracking reporting purpose is similar to creating an international standard, a difficult endeavor as discussed by Higgins and Hallström (2007). If authorities will not require an increased level of compliance compared to today, then blockchain would not be a necessary technical component as the active stakeholders trust each other given the legal contracts that are already in place and the historical collaboration. Thus, in a non-blockchain solution, location data can be captured in Roche's ERP system, with the location reporting to governments performed as today. If the data stored on the blockchain will be required, then today's process can be replaced by a web portal that can hold personalized reports and can allow authorities to have access to the data shared on the blockchain network.

Secondly, blockchain technology is still in its early stages, as discussed in chapter three, thus possible setbacks can affect the implementation effort, causing time and cost overruns. This can be partially mitigated by project management decisions, by choosing the right IT provider and by other actions the organization can take as outlined by Meli (1998) and Meli (1999), but cannot be fully mitigated, as for example, a weakness ("bug") in the open source developed software can affect the entire solution, as pointed out by Franco (2015), Evans et al (2016).

Thirdly, building a blockchain-based application requires organizations to change their thinking, from a purely internal to an external collaborative focus, as the key step for building a blockchain network is developing the ecosystem with stakeholders, a topic widely discussed by Swanson (2015), Mougayar (2016), Swan (2016), Tapscott (2016), Iansiti and Lakhani

(2017). Therefore, disagreements between stakeholders while building or implementing the project can cause time and cost overruns. Mitigating such risks does not only require internal project management decisions, but collaboration on common goals and actions, and trust that partners are making the right decisions for the overall project.

In conclusion, building the tank asset tracking project based on blockchain, requires a joint development of the solution and creating a network where all active process stakeholders are collaborating openly. The sensors provide real-time tank location data and send it to blockchain, which creates a trusted proof of location by providing a platform where all process stakeholders can agree on the data. Moreover, for the project to be successful, government authorities must be engaged in discussions regarding the benefits of using blockchain for tank location reporting compared to the current process. Despite the possible stumbling blocks, the project is technologically feasible and can support the achievement of the project objectives outlined in section 5.1. In addition, the implementation benefits extend beyond the project's objectives to the entire company, as organizational learning regarding blockchain and IoT sensors can be enhanced if the project is adopted.

The following section presents the financial valuation of the project and illustrates how the second part of the framework enhances decision making.

5.5. Financial evaluation

This section focuses on the financial valuation of blockchain, a key technical component for the tank tracking IT landscape. The analysis is built according to the recommendations for performing the financial valuation of a blockchain project that are provided in chapter four and takes into consideration the theoretical concepts presented in section 2.2.

5.5.1. Evaluation scenarios

The blockchain technical set-up for the tank asset tracking project is described in section 5.2 and in more detail in the appendix sections 6 and 7. To recap, IoT sensors send real-time tank tracking data to the blockchain where it is shared with the active process stakeholders, then validated by them, creating complete agreement over the location of every tank, thus satisfying the timeliness and traceability objectives. The real-time and validated location data is reported to government authorities via an online portal, where it can be further investigated. In this scenario, named blockchain baseline, all stakeholders have access to the location of the assigned tanks via the blockchain platform, which can fulfill additional requirements such as exchanging digital information, enabling the digitization of the tank tracking process. Thus, all project improvement objectives are accomplished.

The worst-case scenario considered is named blockchain delayed. Based on blockchain baseline, it captures the uncertainties related to technology development and coordination issues that can arise during implementation, causing project delays and cost overruns, as presented in section 5.4.

Based on information received from colleagues responsible for tank asset tracking and for project management, blockchain is not viewed as technology that could cause significant implementation time and cost overruns compared to IT projects already delivered. Moreover, the organization has experience in selecting IT providers and in running IT projects with external stakeholders. The following probabilities were estimated for the worst-case scenario, based on historical averages for IT projects completed in the organization:

- probability of a project delay occurring during the implementation phase: 30%
- average length of delay: 50% more than the original development time allocated;
- average size of cost overrun: 50% increase in yearly operating costs for blockchain technology compared to the baseline scenario

The two scenarios described view blockchain as a key technical component, following the assumption that government authorities move towards more stringent compliance standards that require data integrity that can be achieved by a blockchain solution. The scenarios combined generate an estimated project valuation, as suggested by Davies et al (2012), a better solution for integrating project risk than calculating a project risk premium and adjusting the discount rate.

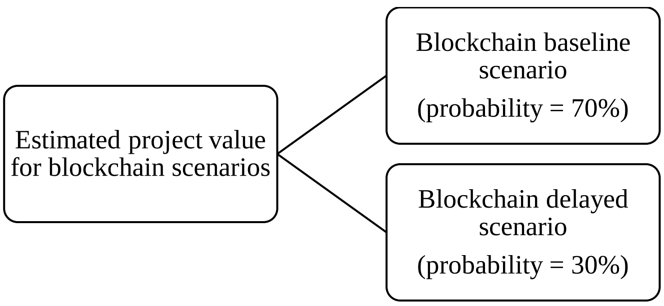

Figure 5.1: Approach 1 – Map of estimated blockchain scenarios (including probabilities)

This first valuation approach assumes that the blockchain implementation decision is made in January 2018, with the project timeline extending from 2019 to 2023.

Period	Jan 2018	Jan 2019	Jan 2020	Jan 2021	Jan 2022	Jan 2023
Time	T=0	T=1	T=2	T=3	T=4	T=5
Delayed	No (blockchain baseline scenario)					
Decision	start project					
Invest	investment					
Activities	roll-out	roll-out	completed	completed	completed	completed
Delayed	Yes (blockchain delayed scenario)					
Decision	decision					
Invest	investment					
Activities	DELAY	roll-out	roll-out	completed	completed	completed

Table 5.1: Estimated project timeline for the first valuation approach

However, one of the project risks described in section 5.1, deals exactly with the opposite situation, uncertainty related to when and if authorities will adopt the new compliance standards. To reflect this risk, a scenario named enhanced simplified, is built to capitalize on the usage of IoT location sensors and on logistic providers sending real-time location data to Roche's ERPs, satisfying the project's timeliness improvement objective. Roche has full control and oversight over the location of all tanks. The location data is processed by Roche and tank location reports for each jurisdiction are sent electronically or on paper to authorities. This process is compliant with today's regulations, but will have to be changed if more stringent compliance targets will be required as it is not transparent. As the current process is internal and all the data is owned and controlled by Roche, it can attract the suspicion of authorities over possible unlawful manipulation of tank location data even if the company acts in a compliant manner.

Blockchain can help Roche prove its regulatory compliance to authorities in a transparent manner, as discussed in the blockchain baseline and blockchain delayed scenarios. However, if it is not required, the company can use existing technologies to develop a fully digital exchange of information with process stakeholders, as discussed by Hao et al. (2015). Closer collaboration and exchange of information between all stakeholders can deliver the same advantages as using a blockchain platform if the stakeholders are trusted. In the case of the tank operation, the active stakeholders are trusted, as contracts are in place and all stakeholders are evaluated by Roche before the business relationship begins. The inclusion of a cloud collaboration platform alongside location sensors in the evaluation scenario enhanced assures that the traceability and the digitization improvement objectives are achieved, necessary to maintain the valuation comparable with the blockchain scenarios, as recommended by Damodaran (2002).

Roche and its external stakeholders use the cloud platform to exchange process documentation and real-time tank location data, as they would use a blockchain. However, the tank location data stored on the conventional cloud platform is not validated by the external stakeholders and can be modified through malicious actions, thus not attaining the level of trust and data integrity provided by blockchain technology.

This second valuation approach assumes that no blockchain solution is required at the initial decision point in January 2018, with both the enhanced and enhanced simplified scenarios being implemented from 2019 to 2023.

Period	Jan 2018	Jan 2019	Jan 2020	Jan 2021	Jan 2022	Jan 2023
Time	T=0	T=1	T=2	T=3	T=4	T=5
Decision	start project					
Invest	investment					
Activities	roll-out	roll-out	completed	completed	completed	completed

Table 5.2: Estimated project timeline for the second valuation approach

A comparison between the components included in each scenario is presented in the following table.

<table>
<tr><th>Criteria/ Scenarios</th><th>Current</th><th>Enhanced simplified</th><th>Enhanced</th><th>Blockchain baseline</th><th>Blockchain delayed</th></tr>
<tr><td>Valuation approach</td><td>Current</td><td colspan="2">Number 2</td><td colspan="2">Number 1</td></tr>
<tr><td>Blockchain</td><td>No</td><td colspan="2">No</td><td colspan="2">Yes</td></tr>
<tr><td>IoT location sensors</td><td>No</td><td colspan="4">Yes</td></tr>
<tr><td>Project delays expected</td><td>No</td><td colspan="3">No</td><td>Yes</td></tr>
<tr><td>Traceability objective</td><td colspan="2">Not achieved</td><td>Achieved (cloud platform)</td><td colspan="2">Achieved (blockchain)</td></tr>
<tr><td>Timeliness objective</td><td>Not achieved</td><td colspan="4">Achieved (IoT location sensors)</td></tr>
<tr><td>Digitization objective</td><td colspan="2">Not achieved</td><td>Achieved (cloud platform)</td><td colspan="2">Achieved (blockchain)</td></tr>
<tr><td>Location data</td><td colspan="3">Owned and controlled by Roche</td><td colspan="2">Shared and validated by all active stakeholders</td></tr>
<tr><td>Reporting to authorities</td><td colspan="2">On paper or electronically, not real time</td><td colspan="3">Digital, real-time</td></tr>
<tr><td>Reported data to authorities</td><td colspan="3">Untrusted</td><td colspan="2">Trusted</td></tr>
</table>

Table 5.3 – A comparison between the evaluation scenarios considered

5.5.2. The valuation model

The valuation model is designed to capture the incremental cash flows that stem from the adoption of the project. As described in section 5.1, a tank tracking application is currently in operation, thus it is considered as the starting point for the valuation (named current scenario).

The current project costs that can be eliminated or reduced through the improvement project are related to: 1) cost of fines issued by government authorities for deviations between reported location and actual tank location, caused by delays in reporting; 2) cost of unusable content shipped, caused by delays in determining tank location and its stage in the process or by delays in processing documentation with external stakeholders; 3) operational costs generated by transactions and information exchange with external stakeholders; 4) costs of fleet renewal generated by the need to retire used tanks and purchase new ones. Therefore, the above-mentioned costs are viewed as incremental benefits (positive cash flows).

On the cost side, the improvement project generates incremental expenses related to: 1) IoT sensor services; 2) information storage; 3) IT infrastructure; 4) license fees for the blockchain or for the cloud collaboration tool; 5) depreciation. It is assumed that the IoT sensor cost represents a one-time investment and is linearly depreciated over 2 years. The valuation model is enclosed in appendix 9.

One item that has proved difficult to estimate during the evaluation has been the actual cost of deploying blockchain technology in a project: how a blockchain solution can be priced, how much it would cost users to implement it and how it should be evaluated. Public information is scarcely available on the websites of blockchain providers, technology consultants or on discussion forums dedicated to blockchain topics. What is more, such discussions are inexistent in academic research. Therefore, decision makers have to either rely on sales brochures and personalized quotes provided by representatives of companies that offer blockchain services or to engage internal IT staff into building a solution in-house based on the open source code available, thus being able to directly evaluate blockchain costs.

The two main reasons why this informational scarcity exists are technological novelty and flexibility. Blockchain is a new technology and few providers have commercial solutions on offer. In addition, applications can be built in a variety of ways, as they require adaptability to diverse processes, data flows and process stakeholders. Therefore, the final solution is custom built for each specific project and for each network of organizations, making it difficult to establish a complete price without drafting detailed IT requirements.

It is assumed that the tank asset tracking uses a blockchain solution developed by a selected third party IT provider. Therefore, determining the cost of the blockchain is an important component to the financial evaluation. Malviya (2016) recommends using cloud computing as a reference for establishing the cost for permissioned blockchain systems, as both technologies are developed, administered and provided by IT companies, and can be priced using a combination of time, storage, data transfer and computing speed requirements. Therefore, blockchain is a resource provided as a service to satisfy the project’s requirements. To provide such services, IT providers leverage vast quantities of computing power that help companies maintain flexibility in allocating IT resources, as discussed by Armbrust et al (2009) and Marston et al (2011). Multiple payment schemes for cloud infrastructure exist, as presented in pricing calculators provided platforms such as Microsoft Azure (2017) and by IBM Bluemix (2017). A fixed yearly fee has been chosen in this paper to maintain simplicity.

IBM (2017) is the only provider of blockchain as service identified which publicly mentions prices for an enterprise ready solution: USD 120,000 per year for a network consisting of 4 peers. The development kit is free, a fact also mentioned by Microsoft. In the research, it is assumed that the license fee increases linearly with the number of peers included in the network, and that no blockchain fees are charged during the roll-out phase of the project.

As the limitations of the current IT solution are known and the improvement objectives are designed to eliminate them, the outcomes of implementing a new technology in the project landscape can be determined with an above average level of certainty. For example, it is known what benefits real time location data and improved collaboration with stakeholders can create, while costs can be assumed with a fair amount of accuracy based on market prices.

5.5.3. Determining the discount rate

When it comes to determining the appropriate discount rate for the project, it is useful to consider the types of risks that stem from the implementation of blockchain technology in the context of tank asset tracking, as Damodaran (2002) advises. As examined in section 5.4, the risks inherent to a blockchain implementation in tank asset tracking can be estimated by building different scenarios. Moreover, all risks mentioned in relation to the blockchain project are firm specific, as they appear and can be mitigated by the firm’s actions.

In addition, financial information is scarce when a technology is emerging as firms do not disclose data as discussed by Steffens and Douglas (2007), making it difficult to calculate a weighted average cost of capital (WACC) specific for the project (based on the CAPM method) as proposed by Kruger et all (2015). Moreover, as the organization is equipped for running such a project, implementing blockchain does not have an above average risk profile.

After taking all arguments into consideration, using the Roche WACC for discounting the project cash flows is the solution considered for the evaluation. Furthermore, it is recommended to not include a risk premium on top of the discount rate. Note: The assumptions used in the valuation are included in appendix 8.

Decision tree analysis has not been utilized in the tank asset tracking evaluation due to a number of restrictions: 1) implementing the project in a step wise fashion would deliver lower benefits, thus it is recommended to build the required infrastructure as fast as possible; 2) tank tracking is a niche in the supply chain operations and its infrastructure cannot be scaled beyond the boundaries of the project; 3) implementing IoT sensors separately from the blockchain or from the cloud collaboration platform has been assessed in the enhanced simplified scenario. Therefore, the following subsection presents the valuation results estimated using the DCF (NPV) method. Note: The Net Present Value (NPV) and the Present Value (PV) are assumed to be calculated for January 2018, the decision point.

5.5.4. Financial valuation results and observations

When reviewing the valuation results, it can be observed that all improvement scenarios (2 to 6) are estimated to add value to the tank asset tracking project (column A), given the assumptions and the technical set-ups considered. From a financial perspective, all options can be considered suitable for adoption as the NPV is greater than zero, an important fact for a decision maker to recognize. However, an array of positive results does not help in determining the optimal solution, given the level of uncertainty inherent to each alternative and the differences between the technical solutions proposed.

Scenario	A. NPV (USD)	B. Value generated in addition to the IoT contribution (USD)	C. Value contribution of IoT sensors as % of Value generated by scenario (%)
1. Current	-175,034,307	-	-
2. Enhanced simplified (IoT sensors only)	47,351,512	-	100%
3. Enhanced (IoT + cloud collaboration platform)	70,942,357	23,590,845	67%
4. Blockchain baseline [prob. =70%]	69,317,994	21,966,482	68%
5. Blockchain delayed [prob. =30%]	8,691,341	-38,660,170	545%
6. Risk adjusted blockchain scenario	51,129,998	3,778,486	93%

Table 5.4 – Comparison of scenario valuation results

The most valuable alternative considers the adoption of IoT sensors coupled with a cloud based collaboration platform, delivering an estimated saving of USD 70.9 million. It is closely followed by the blockchain baseline scenario, which is projected to deliver an improvement of USD 69.3 million.

If only the IoT location sensors would be implemented and connected to the current infrastructure and processes (2), the set-up is estimated to save USD 47.3 million. This is by far the largest financial contribution of any component included in the technical solution (column C). The more complex solutions generate (column B) a maximum of USD 23.5 million in additional savings (enhanced scenario) and USD 22 million (blockchain baseline scenario). Therefore, a large part of the project value is directly dependent upon the implementation of the IoT component, signaling its improvement potential in the tank tracking operations. On the other hand, it can be observed that the blockchain delayed scenario destroys part of the value created by the IoT component, a reason why the 545% figure in column C is not completely relevant.

However, the real-time location data by itself does not satisfy all project improvement objectives, thus it cannot be considered as the optimal scenario for adoption. The probability weighted blockchain scenario (6) delivers an additional estimated benefit of USD 3.8 million by building a closer collaboration between Roche and its stakeholders, while creating a fully trusted reporting capability for authorities. On the other hand, the cloud collaboration platform (3) creates approximatively USD 19.8 million of additional savings on top of scenario (6), while delivering the same level of collaboration with stakeholders. Yet, it does not fulfill the trusted data requirement that might be potentially necessary in satisfying future tank location reporting regulations.

Financial model/ Scenarios	3.Enhanced (USD)	4. Blockchain baseline [prob. =70%] (USD)	5. Blockchain delayed [prob. =30%] (USD)
Initial investment	-625,000	-625,000	-625,000
PV of yearly benefits	173,604,541	173,604,541	131,841,924
PV of yearly costs	-103,639,006	-105,263,369	-124,040,534
PV of Net results	69,965,535	68,341,171	7,801,390
PV of Adjustments	976,822	976,822	889,952
NPV	70,942,357	69,317,994	8,691,341

Table 5.5 – Detailed valuation results – scenarios 3, 4 and 5 presented in parallel

It is important to point out that between the blockchain baseline scenario (4) and the enhanced scenario (3) there is a difference of approximatively USD 1.6 million, as observed in table 5.5. The initial investment requirement and the financial benefits are equal, but the blockchain solution is estimated to generate higher yearly fees compared to the conventional cloud solution, driving up yearly costs. Basically, this is the single difference from a financial point of view between the enhanced and the blockchain baseline scenarios. On the other hand, the blockchain delayed scenario (5) displays weaker financial performance due to the assumed cost overruns and due to project implementation delays, which reduce its potential to generate savings during the five-year project life time.

Financial model/ Scenarios	3.Enhanced (USD)	6. Risk adjusted blockchain scenario (USD)	Difference between blockchain and enhanced scenarios [(6)-(3)] (USD)
Initial investment	-625,000	-625,000	0
PV of yearly benefits	173,604,541	161,075,755	-12,528,785
PV of yearly costs	-103,639,006	-110,896,519	-7,257,513
PV of Net results	69,965,535	50,179,237	-19,786,298
PV of Adjustments	976,822	950,761	-26,061
NPV	70,942,357	51,129,998	-19,812,359

Table 5.6 – Detailed valuation results – comparison between scenario 3 and 6

Building upon the theoretical guidance provided in beginning of this section and in chapter four, the only two scenarios that take into account a broader range of uncertainties and deliver all project improvement scenarios are presented in table 5.6. These are the only potentially optimal scenarios that a decision maker should consider.

When the blockchain project risks are taken into account by considering the estimated delay probabilities as in scenario (6), one can argue that blockchain is not the optimal solution for improving the tank asset tracking project. The underperformance of USD 19.8 million compared to scenario (3) is driven mostly by the effects of project implementation delays (lower level of estimated savings translate into lower benefits and higher costs).

To conclude, blockchain, the technology of focus for the research, is estimated to create less value compared to an already existing cloud solution that delivers the same improvement objectives to its end users as it is expected to generate lower benefits and higher costs due to possible implementation delays.

5.5.5. Sensitivity analysis

The previous subsection proved that a significant amount of savings to all project scenarios is attributed to IoT location sensors. Their contribution is assumed to be relatively stable in comparison to the value generated by the blockchain component. The risk adjusted blockchain scenario is assumed to incur more risks, thus it is important to understand how sensitive the conclusion that blockchain creates value is to the volatility of certain key inputs. Steiger (2008) argued that although discounted cash flow analysis is a good tool to analyze assumptions and conditions, it is also vulnerable to changes in the underlying assumptions.

Firstly, it is important to point out that the analysis is only relevant for the risk adjusted blockchain scenario as it is the one involved in the final decision making process. Secondly, the value created by blockchain has to be determined. This can be done by subtracting the savings created by the IoT sensors (NPV of scenario number 2) from the value of the blockchain scenario (6), as presented in table 5.7.

Scenarios	NPV (USD)	Comments
2. Enhanced simplified (IoT sensors only)	47,351,512	Value created by IoT sensors in isolation
6. Risk adjusted blockchain scenario	51,129,998	Value created by IoT sensors in combination with the blockchain component
Value generated by blockchain [(6)-(2)]	3,778,486	Blockchain's value contribution

Table 5.7 – Determining the appropriate break even value for the sensitivity analysis

Based on the valuation model, the following drivers were chosen: 1) yearly cost of blockchain solution; 2) cost overrun for the blockchain solution; 3) probability for a delay to occur; 4) percentage change of tank fleet; 5) WACC. Except for WACC, the other parameters only impact the value delivered by the blockchain component. The critical threshold is determined by calculating the value of the parameter that reduces the blockchain's contribution to zero.

Valuation inputs	Expected value	Critical value	% change
Yearly cost of the blockchain solution (USD)	660,000	1,903,211	188%
Estimated cost overrun for the blockchain solution (%)	50%	946%	1791%
Probability of delayed scenario (%)	30.00%	36.23%	21%
Fleet reduction (%)	5.00%	4.05%	-19%
WACC (%)	9.00%	10.98%	22%

Table 5.8 – Results of the sensitivity analysis

As observed in table 5.8, blockchain's value adding capability can be mostly affected by: 1) a higher likelihood for a project delay; 2) a lower than expected fleet reduction effect; 3) a higher than expected WACC. On the other hand, and increase in license fees or larger than predicted cost overruns do not generate a significant impact, unless the volatility is high.

However, Brealey et al (2011) point out that sensitivity analysis can provide misleading results if two or more of the inputs are correlated. In addition, the probability of reaching the critical value cannot be estimated, making the results more difficult to grasp, especially in a highly uncertain domain such as new technology.

In conclusion, sensitivity analysis identified certain items that can cancel the blockchain's value adding contribution if their deviation exceeds plus or minus 20%. These must be carefully managed across the project lifetime to ensure that the project's exposure is limited. Even though it has been clearly outlined that blockchain is not the financially optimal solution, management is advised to look beyond the financial valuation before deciding to reject the technology, as the following subsection demonstrates.

5.5.6. Nonfinancial value drivers

The characteristic that sets blockchain apart from a conventional cloud platform solution is the creation of trust by providing process transparency and by involving stakeholders in establishing the accuracy of the tank location data. As discussed in section 3.3, governments have started to explore possible applications of blockchain technology from a compliance perspective. They are expected to switch their approach from checking if organizations respect regulations to getting organizations to actively demonstrate their compliance. It is uncertain when such changes will occur, which jurisdictions will be first affected and how the new blockchain oriented regulations will look like.

Yet, the value of trust that blockchain delivers has not been explicitly included in the financial evaluation, as no reasonable approach was identified. Instead, it is recommended for decision makers to maintain it as a factor that can influence the adoption outcome. Given the research findings of Piscini et al (2016), blockchain has the potential to produce more savings than estimated as maintaining trust is becoming costlier and more time consuming in an increasingly digitalized society. Such operational savings are included in the valuation and can be directly linked to the blockchain component, however the author considers that these actions do not fully reflect the value of trust.

One additional aspect that has not been captured in the financial evaluation is learning, an important topic as it is one of the ways through which organizations acquire new technologies, as discussed by Dodgson (1993). Learning has broad analytical value and has been identified as a driver of firm financial performance in studies performed by Ellinger et al (2002) and Prieto and Revilla (2006), but produces no direct cash flows that can influence the outcome of an NPV analysis. Therefore, decision makers should consider the impact of learning in addition to the financial outcome estimated by discounting cash flows.

Furthermore, organizational learning plays a significant role in managing risk through adaptive management, a science based approach for gathering new information about uncertain variables, as theorized by McDaniels and Gregory (2004). An investment decision can benefit an organization in multiple ways, such as improving objective setting, creating better implementation options and understanding the trade-offs between the alternatives, all aspects directly related to learning.

Yet, none of the arguments mentioned provides a context for expressing the potential of learning in financial terms. Reviewing the literature, most articles offer advice on how learning can be supported from a process or from a strategic (big picture) perspective, with few indications offered on how to measure the financial impact of learning. Garvin (1993) presents the advantages and disadvantages of using three methods, learning curves, experience curves and half-life curves. The methods measure the impact of learning by assessing the changes in performance of pre-selected target areas, then transforming the differences into a financial value. However, they are designed to follow-up on the results of a learning activity, not as an estimation mechanism.

Given the little guidance available, the writer proposes to start with understanding what the implementation of blockchain in the current project can deliver – minimizing future risks, as the organization will learn how to integrate the new technology in its IT systems and will learn to jointly develop the solution with a network made up of external process stakeholders. Therefore, the more blockchain projects an organization considers, the higher the value of the learning that can be generated by the analyzed project. The same logic applies for the IoT location sensors, raising the total expected value of learning that can be extracted from the analyzed project. As in the case of trust, organizational learning should be considered as a factor that can influence the adoption decision.

To conclude the valuation section, blockchain is estimated to offer a positive financial outcome to the tank asset tracking project while accomplishing all improvement objectives. Moreover, it is the only solution that helps Roche actively demonstrate its compliance with tank location regulation to government authorities, a feature that is expected to become necessary if stronger regulations will be enforced. However, when it comes to respecting current regulations and to delivering on the project's improvement objectives, a cloud platform can offer the same functionalities at a lower operating cost and with a lower risk exposure. One additional aspect that decision makers should take into consideration is the value of nonfinancial (soft) aspects such as trust and organizational learning, which have the potential generate additional benefits for the project and beyond.

5.6. Conclusion

Both the first and the second framework sections present blockchain as a viable solution for achieving the improvement objectives set for the tank asset tracking project. Viewed solely from this perspective, the technology is recommended to be adopted. Yet, the optimal solution that maximizes project value and reduces implementation risks given the current regulatory standards is the cloud collaboration platform. Note that for all scenarios, the largest value driver is the adoption of IoT sensors (see table 5.4).

Changes in regulation can be considered as a main driver of the blockchain implementation agenda, as the organization would need to deliver trusted data to authorities, requiring a blockchain based reporting solution. Therefore, initiating an active dialogue with regulators regarding future tank reporting rules and the use of new technologies should be viewed as a next step. From an organizational perspective, preparing today for an uncertain future does not make sense as blockchain can be implemented at a future date. However, given the fact that a blockchain project cannot be undertaken by one entity, inter organizational politics and coordination efforts will consume a considerable amount of time.

New technology assessments performed using a discounted cash flow method are affected by uncertainties related to the cash flow estimation. The research has tried to mitigate these issues by identifying the top risks and evaluating multiple scenarios. In addition, a sensitivity analysis exposed the components whose volatility can negatively affect the project’s value. However, a financial valuation typically overlooks many of the real-world complexities inherent to a new technology project. Therefore, the results represent a conservative estimate of the value of implementing blockchain technology.

In conclusion, a decision maker has to carefully weigh the financial and nonfinancial arguments. Overall, nonfinancial aspects such as technology capabilities, strategic fit, trust and organizational learning point towards adoption, while the financial evaluation indicates that blockchain is not the optimal component for the project as it estimated to generate USD 19.8 million less value than a comparable technology. Whether nonfinancial items can outweigh the added risk exposure and increased operational costs inherent to a new technology is an open discussion that hinges on the importance of trust in the target process and on the ambitions of a company in developing blockchain applications. If the analyzed project implies applying a blockchain in a process where there is no trust between the external stakeholders and potentially, no legal contracts, then the value of trust would be high. Similarly, learning would be more valuable for an organization that plans to develop multiple blockchain applications.

In the case of tank tracking, as the external stakeholders are known and connected through legal agreements, the value of additional trust that blockchain could deliver is low. On the other hand, it is difficult to estimate the value of trust that such a system would create in relation to government authorities, as regulation and expectations are different between jurisdictions. From the perspective of learning, blockchain has the potential to create value given the opportunities available in the organization and the necessity to create an area of expertise. Considering the arguments exposed, the risk adjusted financial benefits expected, the achievement of all improvement objectives, the author recommends the adoption of the blockchain project.

6. Conclusion

Numerous blog posts [Medium (2016), World Economic Forum (WEF) (2016)], books [Mougayar (2016), Swan (2016), Tapscott (2016)] and news articles [CNN (2015), VentureBeat (2015), Reuters (2017)] written in the last two to three years have been advocating for utilizing blockchain in various applications spread across multiple industries. Even if the list of works that should be cited can go on for multiple pages, the five main benefits mentioned by the majority of authors are: 1) establishing trust between parties that previously did not trust each other without using a central party; 2) lowering transaction costs and settlement duration, by removing the intermediary and allowing for direct connections between the members of a network (peer to peer); 3) establishing transparency between the members of a network by sharing data and having all users maintain control over their own copy of the database; 4) validating if the shared data reflects reality by getting the majority to agree on it; 5) leveraging the fact that each user has a copy of the database to block attempts to modify or delete the stored data.

Even if all the above-mentioned improvements can deliver benefits to private citizens, organizations and entire economies, the change process is expected to stretch over a significant period. Adner and Kapoor (2016) stress the importance of looking beyond technological improvement as a sole driver for successful blockchain adoption and encourage decision makers to consider the creation and expansion of an ecosystem of partners around the project. As blockchain is a tool designed for collaborating with external partners, not for internal use within an organization, it must be developed in agreement with the selected stakeholders because it will become a single operating standard affecting everyone involved.

As companies have been exploring the viability of blockchain projects, the differences between the original ideal of complete transparency and their operating requirements, focused on data protection, secrecy and agreements defined by legal contracts, were significant. This led to the development of closed blockchains, described by Swanson (2015), where multiple process stakeholders can exchange information without sharing it with the entire network. As discussed by Woolthuis et al. (2005), between trust and contract there is a complex relationship, as trust can both complement and substitute contracts. Therefore, the existence of legal agreements in an inter-organizational setting where all parties are known and have legal responsibilities and rights eliminates one major benefit of using blockchain, developing trust. In cases where trust and legal contracts already exist between partners, existing data sharing technologies (such as cloud based collaboration platforms) are recommended to be taken into consideration when evaluating a project.

Perhaps, the biggest contribution that blockchain has made is shifting the mindset of company leaders from an internal focus to viewing relationships with business partners as an area where improvements, cost savings and lower risks can be achieved by encouraging collaboration and information sharing.

The research aims to help decision makers in reaching an objective conclusion whether a blockchain project should be adopted, by developing and demonstrating an evaluation framework that takes into consideration both nonfinancial and financial aspects.

Although nonfinancial aspects have been assessed and presented, the financial valuation has been the focus point of the case study as it expands the existing blockchain research developed by academics and practitioners.

The paper aims to open further research in developing objective methods for evaluating blockchain projects and for identifying if the observed opportunities can already be achieved with existing technologies. Given the prevalence of open source blockchain projects, it would be helpful to understand under which circumstances would an organization maximize the value of a project, by developing the solution by itself or by purchasing a solution based on the same open source project.

A set of simplifications have been made in the case study, which can be improved: 1) customs authorities and insurance providers have not been included in the stakeholder landscape – their impact on the decision to adopt blockchain should be discussed; 2) building multiple scenarios using discounted cash flows has been the single valuation method employed – using Monte Carlo simulation can help estimate a wider range of uncertain inputs; 3) information regarding pricing of blockchain solutions, IoT sensors and cloud collaboration platforms should be requested from vendors based on a detailed technical description of the project; 4) the value of trust and learning requires a more detailed research.

To conclude, blockchain is a technology that can inspire decision makers to take radical actions towards capitalizing upon its promised opportunities. This paper advocates for: 1) the importance of performing an initial objective assessment for each envisioned project; 2) for connecting with external partners; and 3) for uncovering all potential value drivers, both financial and nonfinancial, that can contribute to the desired outcomes.

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Appendix

Appendix 1: Definitions of technical concepts

Blockchain[3] – The distributed, public ledger containing the history of all transactions on the Bitcoin Network which is stored locally on the computer hard drive of each user running a full version of the Bitcoin network software. The blockchain includes the full list of blocks (all confirmed transaction data) that have been created since the start of the Bitcoin Network. The blockchain is designed so that each block contains a cryptographic reference to the block that came before it, thereby linking each block into a verifiable and tamperproof chain.

Distributed ledger[3] – is a ledger of transactions replicated on multiple computers and servers linked to the internet or to a private network. Each transaction is signed uniquely by the user's private key. Transaction integrity and confirmation are enforced through cryptography, agreed through the consensus of network's nodes. It is utilized in practice to minimize the confusion between new applications and the original blockchain component of the Bitcoin network.

In the paper blockchain and distributed ledger are fully interchangeable terms.

Bitcoin[3] – With a capitalized "B", Bitcoin refers to: i) the Bitcoin Network, ii) the Source Code or software based on the Source Code, or iii) the general technology relating to Bitcoin.

bitcoin[3] – When a lowercase "b", bitcoin refers to a unit of account that may be transferred on the Bitcoin Network.

P2P or peer-to-peer[3] – Decentralized interactions that happen between at least two parties in a highly interconnected network. An alternative system to a 'hub-and-spoke' arrangement, in which all participants in a transaction deal with each other through a single mediation point.

Miners[3] – The users on the Bitcoin Network that run specific Bitcoin software through which they perform the validation, clearing and recording of transactions on the blockchain, all in exchange for a reward of newly created bitcoins.

Transaction[3] – A chunk of binary data that describes how bitcoins are moved from one owner to another. Transactions are stored on the blockchain. Every transaction (except for the first transaction in the system) has a reference to one or more previous transactions (inputs) and one or more rules on how to spend these bitcoins further (outputs).

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[3] Kaye Scholer LLP, 2016, An Introduction to Bitcoin and Blockchain Technology, February

Appendix 2: Connecting financial valuation with nonfinancial criteria

Financial valuation is strongly connected with the nonfinancial aspects of the project, thus the adoption decision should be based on a carefully considered mix of factors. Furthermore, the development of a structured framework which includes a combination of decision criteria is important to assure optimal decision making.

A multi staged framework which requires users to evaluate technology projects based upon a set of interrelated factors that can influence the lifetime value of the project is proposed by McGrath and MacMillan (2000). This approach reduces uncertainty and helps decision makers focus on the most important value drivers when they apply a real option valuation method. In addition, the authors stress the importance of building a mixed team of professionals for the project, as multiple perspectives will most likely increase the probability of developing a successful project.

The life span of the project is an important nonfinancial evaluation criterion, according to Wessel (2004), as for longer framed projects it is more difficult to estimate financials with certainty. Thus, it is important to view an investment as an option. For example, small investments in projects that have potential big upsides can deliver more value than larger investments in "conventional" projects. Venture capitalists invest small amounts in new businesses that are open to capture the biggest gains as they grow, compared to corporate decision makers, who invest in large projects than make sense from a business continuity perspective but have no disruptive potential. Measures such as ROI, IRR, DCF are important for every decision maker to consider. However, they are most suitable for evaluating incremental change projects not for taking advantage of disruptive opportunities. The following three questions can help decision makers better judge project proposals in large companies:

1) "What if it works?" - It is important to understand how much upside an option can offer before comparing it with other investment opportunities;

2) "What is required to leave the option open to upside?" - Investing a large amount up-front without knowing if the project is going to deliver in subsequent stages is one important trap to avoid. Small financial commitments and continuous learning is required;

3) "Do we have what it takes to follow this through?" - To take full advantage of the option at hand, an investment plan and the required capabilities need to be in place.

Dekleva (2005) enforced the point that quantitative metrics cannot fully describe the advantages and disadvantages of new technology projects. This view is also held by Harris and Casonato (2002), who suggest the following ten measures as primary decision factors: 1) better, faster product design; 2) better products; 3) new revenue through new products, customers and channels; 4) improved customer service; 5) increased employee effectiveness; 6) increased process effectiveness; 7) increased brand value and reputation; 8) creation of other intellectual assets; 9) connectedness; 10) asset utilization.

Some researchers consider that the justification for going ahead with a new technology investment project lies in the nature and the goals of the actual investment. For example, Ross and Beath (2002) split IT investment into four types: 1) process improvement (operational outcomes of existing business processes); 2) experiments (needed to develop capabilities and understand limitations of new technologies); 3) renewal (replace old technologies with newer, more powerful or more cost-effective ones); and 4) transformation (intentionally change a company's infrastructure in ways that not only enable but demand process change).

A similar categorization approach is followed by practitioners Rau and Bye (2003), who argued for the removal of decisional "guess-work". Four value dimensions (expense containment, process improvement, customer advantage, and talent leverage) are defined. Then each is divided of into three major subcomponents (capital and operating expense, people, and innovation). Accounting rules drive how capital and annual operating expenses are measured. The value of IT staff can be measured using (return on assets, return on capital expended, human capital return on investment, human capital value added, and human economic value added). Innovation is the subcomponent most difficult to measure as it is the least tangible. However, IT innovation can be connected to different business outcomes, thus a link can be established to observe improvements over time, before versus after adoption.

Based on a study carried out with US and Swedish IT contractors, Svavarsson (2004) advised that platform investment risks stem from the following four components: 1) user adoption risk (internal users are not willing to purchase new IT solutions); 2) interaction risk (a platform that allows interaction with external stakeholders is valuable only if the externals use it); 3) technology risk (technical factors related to system operation and delivery of promised functionality); and 4) vendor risk (the vendor should be financially and operationally stable enough to offer system support and future upgrades).

A multi layered approach to evaluating an IT project was recommended by Earl (1989) and by Meredith and Hill (1987). It covers a joint list of qualitative and quantitative measures made up of: 1) NPV based on costs and benefits; 2) list of intangible costs and benefits; 3) analysis of risks and uncertainties. In addition, Milis et al. (2009) argued that no investment should be pursued if it does not respect the company's strategy and business goals and enforced the multiple perspectives approach to valuation by suggesting a mixture of qualitative and quantitative measures.

Going one step further, a balanced score card that measures the most important indicators for a company, both financial and non-financial, can be structured based on four key questions: 1) how do customers see us? (customer perspective); 2) what must we excel at? (internal perspective); 3) can we continue to improve and create value? (innovation and learning perspective); and 4) how do we look to shareholders? (financial perspective). Kaplan and Norton (1992) suggested that each perspective has a set of goals and measures that must be defined, achieved and tracked, and it aims to help managers focus on critical business drivers.

To conclude, this appendix section presented additional tools and offered advice on assessing the nonfinancial aspects of a new technology investment project. Some of the techniques were included in the proposed framework while others were used directly into the comments presented in the main body of the research paper.

Appendix 3: Advantages and disadvantages of an open (permissionless) architecture

The following classification is based on the specifications of Bitcoin's blockchain.

Advantages	Disadvantages
Transparency – all transactions recorded in the system are immutable and auditable[5]	*Expertise* – difficult to integrate with existing technologies
Low costs for accessing the network – public blockchains generate network effects so administrators need to incentivize adoption	*Difficult to enforce know your customer procedures (e.g.: anti money-laundering)* – due to built-in anonymity of transactions[6] in public networks FBI (2012)
Security – public and private keys, cryptography, proof of work mechanism and decentralization make the system secure	*Lack of protection if transaction errors occur* – transactions cannot be reversed or modified so the information can be lost in case of error
Privacy – transactions are executed using the minimum amount of information necessary	*Irreversibility of transactions* – today's systems allow for transaction reversal
Data integrity – consensus over data ensures that there is one version of truth agreed by all	*Analytics* – data retrieval, inquiry, reporting or analytics tools are not fully developed
Fast transaction settlement – transactions are included in the block within minutes to hours, compared for days in the Swift system	*Difficult to integrate* – with modern data management tools and with existing sub-systems in an organization
Third party elimination – in today's system a central third party is needed to ensure trust between the various users	*Energy consumption* – worrying if proof of work scales up as it will require increasing amounts of electricity to create blocks
Smart contract functionality – based on paper contracts, electronic contracts can be written and can make rule based payments by analyzing the necessary data inputs	*Not flexible* – an open blockchain solution cannot be adjusted to suit a wide array of applications unless the community agrees
Community excitement – an ecosystem of start-ups has been formed around blockchain related applications, serving as an important driver for innovation and future adoption	*Small amount of transactions processed per second* – open architectures have a limited amount of transaction processing capability due to the limits of proof-of-work consensus
Investment and interest – 149 blockchain and bitcoin startups raised more than $1.2B from venture capital and corporate investors[7]	*Private key protection* – individual users are responsible for ensuring that their digital private keys are safe
Reduces central risk of failure – data is stored and processed in a distributed system, so there is no risk of a system wide stoppage if some of the members are hacked or experience technical issues	*Regulation and bureaucracy* – industries that are heavily regulated require permission to implement proof of concept projects to prove technology reliability; assets that are subject to various regulations complicate the picture;
Transparency and auditability – all transactions are available to all participants and all transactions can be audited	*Data ownership* – rules and regulation around data ownership are still under development[8]

Table 1: Comparison of advantages and disadvantages of a permissionless blockchain architecture

[5] Bitfury Group Limited, (Nov 14, 2016, On Blockchain Auditability – Whitepaper, version 1.0
[6] Möser, Malte, 2013, Anonymity of Bitcoin Transactions, University of Münster
[7] Moody's Investor Services, 2016, Credit Strategy – Blockchain Technology, Sector in-depth,
[8] The Law Library of Congress, 2014, Regulation of Bitcoin in Selected Jurisdictions, January

Appendix 4: Advantages and disadvantages of a closed (permissioned) architecture

The following classification reflects the most common set-up for a closed blockchain, as observed in the following blockchain projects:

1. Hyperledger Fabric (information retrieved from Github)

2. Sawtooth Lake (information retrieved from Github)

3. Project Bletchley (information retrieved from Github)

The three projects mentioned were proposed by different IT companies (Fabric – IBM, Sawtooth Lake – Intel, Bletchley – Microsoft) and the code was donated as open source to the blockchain community. Therefore, the development of the projects has been done in collaboration between enthusiasts and experts, involving both individuals and companies.

Advantages	Disadvantages
Flexibility – solutions can be designed with the primary project requirements in mind	*Expertise* – difficult to integrate with existing technologies
Transparency controls – transactions are immutable, auditable and available only to the approved stakeholders	*Analytics* – data retrieval, inquiry, reporting and analytics tools are not fully developed
Easy to enforce know your customer procedures (e.g.: anti money-laundering) – all parties on the network are known and screened before being accepted	*No high-speed access to data* – big data technology offers significantly higher analytics speed
Security – public and private keys, cryptography, consensus mechanism and decentralization make the system secure against hacking/ theft	*Cross country harmonization* – laws over data and contractual agreements differ between jurisdictions, creating an additional difficulty during implementation
Privacy – transactions between users are executed using the minimum amount of information necessary	*Asset control* – an asset registered on the blockchain has no value if it cannot be controlled in real-life
Data integrity – consensus validation of data by stakeholders ensures that there is one truth	*Difficult to integrate* – with modern data management tools and with existing systems
Fast transaction settlement – faster than a permissionless system as it does not use the time-consuming proof of work mechanism	*Smart contract functionality in early stages* – current smart contracts are not yet able to replicate complicated transactions
Third party elimination – in today's system a central third party is needed to ensure trust between the various users	*Private key protection* – users are responsible to maintain control over their digital private keys at all time
Smart contract functionality – based on paper contracts, electronic contracts can be written and can make rule based payments by analyzing the necessary data inputs	*Regulation and bureaucracy* – heavily regulated industries need to implement proof of concept tests to validate the technology; assets that are subject to various regulations complicate the picture;

Reduces central risk of failure – data is stored and processed in a distributed system, so there is no risk of a system wide stoppage if some of the members are hacked or experience technical issues	*Censorship* – given its nature as a permissioned system, the community members can technically prohibit other members from executing transactions
Investment and interest – 149 blockchain and bitcoin startups raised more than $1.2B from venture capital and corporate investors[9]	*Data ownership* – rules and regulation around data ownership are still in development
Community excitement – an ecosystem of start-ups has been formed around blockchain related applications, serving as an important driver for innovation and future adoption	
Energy friendly – as the need for a proof of work process is eliminated, a permissioned system consumes significantly less energy	
Asset digitalization – a digital asset can be created on the blockchain to represent a real-life asset	
Transaction reversibility – additional features have been created to allow for transaction reversibility in case of system errors	

Table 1: Comparison of advantages and disadvantages of a permissioned blockchain architecture

[9] Moody's Investor Services, 2016, Credit Strategy – Blockchain Technology, Sector in-depth

Appendix 5: Case study – additional information

The figure presents a full lifecycle of a tank, including the main processes, the stakeholders responsible for the process and the tank's status. The duration of a lifecycle is on average two years.

Location	1. Tank management center			In transit	2. Drug substance filling site			In transit
Process	Receive	Maintain and clean	Ship-to	National/ International shipping	Receive	Fill	Ship-to	National/ International shipping
Tank status	Empty	Empty	Empty	Empty	Empty	Filled	Filled	Filled
Responsible	Roche	Roche	Roche	Logistic provider	Roche or CMO	Roche or CMO	Roche or CMO	Logistic provider

3. Warehouse (optional step)			In transit	4. Drug product manufacturing site		
Receive	Store	Ship-to	National/ International shipping	Receive	Deplete	Ship-to
Filled	Filled	Filled	Filled	Filled	Empty	Empty
Roche or CMO	Roche or CMO	Roche or CMO	Logistic provider	Roche or CMO	Roche or CMO	Roche or CMO

Empty tank goes back to the tank management centre (cycle repeats itself)

Figure 1: Tank life cycle

Appendix 6: Case study – technical set-up

This appendix section expands the tank asset tracking project described in chapter 5 - section 1, and illustrates the technological set-up necessary for delivering improvements in the following three areas: timeliness, accuracy and traceability. The section was not included in the main body of the paper as it focuses on the proposed IT architecture of the project, but it is useful for understanding the outcome of the project evaluation.

The information regarding the project's current operational status was provided by colleagues responsible for the project and sourced from the dedicated intranet page.

To improve tracking timeliness, firstly, data from logistics providers is needed as they are responsible for the tanks in transit. The data exists already, as logistics providers monitor the goods they ship and can already provide reports through log-in portals for goods tracking.

Secondly, data from contract manufacturing operation (CMO) sites regarding tank position and status is needed in real time. Today, information regarding substance batches reaching a certain filling or production site is transmitted once all documentation is cleared and uploaded to the CMO enterprise resource planning (ERP) system. The CMO ERP systems communicate electronically with Roche's ERP systems. Due to the manual processing of documentation, real time data is difficult and expensive to obtain. What exactly happens with a tank in a site run by an external party is not known precisely. If the contractual partners are considered to be trusted, data provided by these entities can be incorporated in Roche's tracking system without the fear that the information in the system will diverge from reality. However, if the contractual partners are not considered as trusted, a third-party inspector, pictures or real time global positioning system (GPS) location data would be necessary to validate that the information reported is consistent with reality. The discussion regarding partner trustiness will be resumed later in the section. Appendix 5 holds the visual description of a tank lifecycle.

Thirdly, within a Roche site, today, the tanks can be tracked up to each individual site, as in the CMO case. Tanks are stored in special inside locations, depending on the status in the process or even outside if they are placed into empty storage. The tanks are not offered a pre-set location at any site and it requires manual work to identify where each tank is within a site before using it in the planned process. Sites have evaluated the idea of assigning special places and keeping tracking of the container identification number stored, but it has been considered a cumbersome solution requiring substantial manual work. Therefore, a solution would be to either install sensors in each Roche site to automatically capture the location and to trace the route of each tank from building to building, or to install GPS sensors on each tank.

As reported by colleagues responsible for the tank asset tracking, government authorities are expected to become more stringent when it comes to tank regulation and are expected to require more information regarding tank location. Today, paper and electronic documentation is used to report tank location depending on authority, making the reporting process resource intensive.

Described in more detail in chapter three, blockchain is a technology that helps build trust between transacting parties through sharing of information, validating that the information is true and having all involved parties agree that the information correctly reflects the reality. Therefore, if a process or a party produces information that is trusted by the other partners then blockchain would not deliver additional value to the project as conventional data storage and sharing technologies have better functional characteristics and performance, as debated by Swan (2015) and Drescher (2017).

As government agencies require documentation to validate the tank location data submitted by Roche, this translates into an untrusted data exchange, an area where blockchain can help by building trust between Roche and its government stakeholders.

Blockchain plays a central component in the project architecture, receiving all tank location information from different sources, validating it and storing it in an immutable manner that complies with the reporting needs of government authorities. In the described project, there are three active process stakeholder groups: Roche (the owner and user of the tank fleet), CMO organization (user of tank fleet) and logistics provider (transporter of tank fleet between sites). One additional process stakeholder group is government authority, which play a passive role, using tank location reports for their jurisdiction to check for compliance with regulation.

As trust is discussed in connection to government authorities, the relationship between Roche and CMOs should also be examined. Roche and CMOs collaborate based on multiple legal agreements. Moreover, before establishing the manufacturing relationship, Roche performs due diligence and audits to understand if the manufacturing standards of CMO organizations respect Roche's manufacturing standards. In addition, audits and inquiries are made regularly to check for manufacturing quality. Therefore, CMOs and the information provided by them should be considered trusted. When it comes to blockchain, there would be no need for it to connect only Roche and CMO organizations as the data exchanged is trusted and already communicated electronically using data exchanges. In fact, blockchain delivers value when the information from logistic providers and Roche is combined with CMO data, creating complete location traceability for a tank over its entire lifecycle, which can be reported with government authorities.

However, none of the topics discussed so far solve the information timeliness issue. One solution is to use sensors on the tank that monitor real-time location. Applying such sensors to the tanks will transform them from "dumb" unconnected devices into "smart" devices, connected to the internet, and now part of the Internet of Things (IoT). Presented by Karen et al. (2015), IoT is a network of connected devices, ranging from buildings, to industrial machinery to common household appliances. The sensors capture data, transmit it for analysis to a server, receive feedback from the server and thus, certain functions of the connected device can adapt to the surrounding environment by using information captured by the sensors. In the case of a tank, location data based on mobile network connection can be obtained even inside a building by using the SIM card which also provides the internet connection. Additional information on IoT devices and architectures are discussed by Gubbia and Buyyab (2013), Macagnano (2014), Karen et al. (2015), Lee (2015).

Using an active sensor implies that location data will be provided at constant time intervals if the sensors are connected to the internet. The implementation can be performed in multiple ways, but exploring this topic further is not within the scope of this research; it will be assumed that real-time location is necessary for assuring tank location traceability.

However, it is important to briefly discuss the drawbacks of active IoT sensors: 1) energy consumption – to ensure constant transmission of data over a two-year lifecycle a battery with enough storage capacity is required or connection to the power supply needs to be available; 2) SIM card dependence – a SIM card provides the sensor with a connection to the internet via mobile networks in multiple countries thus creating significant costs; in addition, SIM cards can be affected by compatibility issues between networks in different countries; 3) security – reliability of data correctness and the risk of hacking can impact the quality of the data transmitted from the sensor to the blockchain.

As described in the above paragraphs, outfitting tanks with an active sensor generates location data throughout a tank's life cycle, regardless of where a tank is positioned. However, logistic providers can offer location data during transport, an area where duplication is not an issue as there is no internet connection available if the tanks are on a ship in the middle of the ocean.

Writing data from IoT sensors to a blockchain is discussed by Karst and Brodar (2017), while a practical application has been demonstrated by Intel (2017), using the Sawtooth Lake blockchain implementation and tracking sensors, also in the supply chain area.

Blockchain can deliver additional benefits on top of storing tank location data. Roche together with CMO organizations and logistic providers can replace the paper documentation and one to one electronic exchanges of information that are used today for confirmation of tank location with tank location data provided by sensors. For example, if a sensor transmits that a tank is located at a CMO site (marked by a geofence, a virtual perimeter corresponding to a real-life location), the CMO organization can validate the sensor data by accepting it and posting to the blockchain an electronic receival document generated from its system. Thus, the sensor data is written to the blockchain and shared with only the stakeholders that are interested in the tank's location at that stage in the process, improving operational efficiency.

The recommended blockchain architecture is permissioned (closed) as all tank movement is done based on contractual agreements between all parties, thus all stakeholders are known and have a common ownership over the blockchain system (equal rights to write and validate data). Moreover, the movement of each individual tank is only important for Roche, as the fleet owner, therefore information for the individual location of each tank is only shared with the stakeholders that will handle that contact over its lifecycle. Government authorities will be able to access tank location data only for their jurisdiction using an online log in portal, where they can observe the location of tanks in real time or can investigate detailed historical data for all tanks that have been in their jurisdiction. As discussed with the project team, tank location can be viewed as a competitive issue, and should not be shared openly, thus an open blockchain architecture does not fit the project requirements.

In comparison to conventional database storage systems, blockchain is a new technology that has yet to be implemented on a wide scale, in applications other than the original cryptocurrency network transaction ledger. As described, blockchain serves as a distributed database, where all stakeholders involved in the tank life cycle own a synchronized copy of the database, where the movement of tanks is recorded. Given that the tank flow is a step wise process, going from maintenance to filling to depletion and back to maintenance, it is possible to establish an agreement on tank location by using the data shared and validated by all active stakeholders. Because of the consensus established between all partners involved, the location data is secured on the blockchain in an immutable way (cannot be changed or deleted without the majority of partners agreeing) and can provide a verified proof of location to government entities.

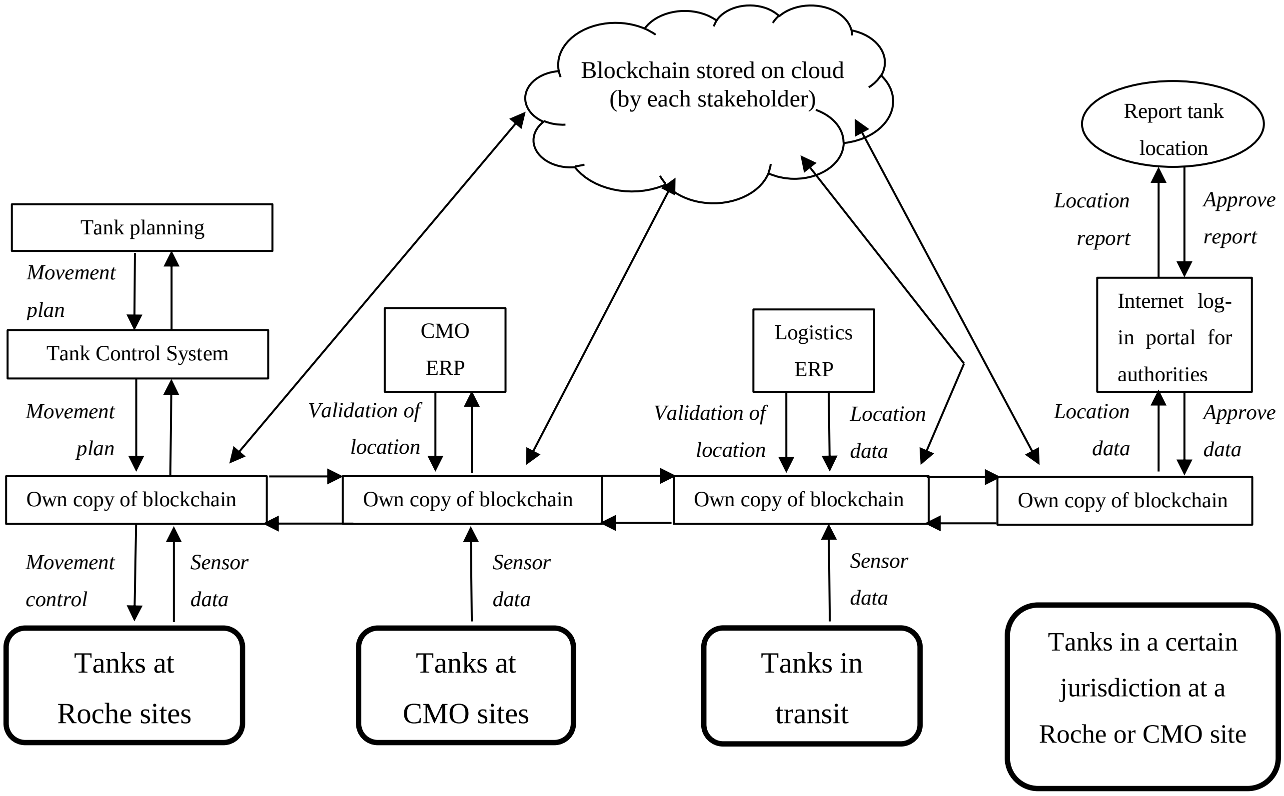

Figure 1: Technology set-up – active IoT sensors

The information flow proposed for the project, including blockchain, sensor data and the existing ERP systems is presented in figure 1. Blockchain connects the three active stakeholder groups which are responsible for the validation of tank location data provided by sensors (Roche, CMO and logistic providers) with the passive stakeholder, the government agency which require reports on tank located in their jurisdiction. All stakeholders control their own copy of the blockchain and store it separately with a chosen IT provider on a cloud storage platform or on their own IT infrastructure.

In conclusion, the tank asset tracking project evaluated in chapter five is based on the following technology set-up: 1) a blockchain distributed database collects real time location of tanks from active sensors (IoT) and tank location provided by logistics partners; 2) the tank location data is validated by the three active stakeholders Roche, CMOs and logistic providers on the blockchain; 3) government authorities can view the data stored on the blockchain as trusted as it was validated and agreed upon by multiple independent stakeholders.

Appendix 7: Technical and strategic evaluation – answers for part 1 of the framework

This appendix complements the second section of chapter five. The answers provided in the part one of the framework are based on information from the tank asset tracking project presented in section 5.1, appendix 5 and appendix 6. The framework has been introduced in chapter four.

All answers are based on the writer's knowledge of the project and include information collected through discussions with Roche colleagues responsible for tank asset tracking.

PROJECT NAME: Tank asset tracking
SUBMITTER: Iulian Novischi
DATE: April 21st, 2017
INTRODUCTION. SHORT DESCRIPTION
1) Describe the envisioned complete blockchain project in 10 to 20 rows
R_1: 1. Roche uses special vessels (tanks) to transport raw chemicals or product substance internally or to CMOs; 2. Tanks travel around the World and require special authorizations to stay or to enter into certain countries; 3. Deliver real time location information by using a combination of sensor generated data and data received from logistics partners; 4. Tank life cycle is around 2 years, and can be gradually reduced in the future through better supervision and improved planning; 5. Tanks and content are valuable and therefore important to not be delayed or redirected - use of sensors to track real time location; 6. Content transported falls under international regulation for dangerous chemicals - necessary to monitor tank location and to report it to government authorities; 7. Location information during transport between sites can be obtained from logistic providers, as they have the information readily available; 8. Tanks are powered during transport to assure cooling, thus can supply energy to active sensors; 9. Blockchain is a central component in the project as it serves as source of trusted data regarding tank location which can be used by government authorities; 10. The process stakeholders validate the sensor data therefore assuring immutability of location information; 11.The project also supports organizational learning related to writing real-time location data from sensors on blockchain, and using data on the blockchain for both internal purposes and regulatory reporting.
2) Design a rough process flow
R_2: Informational process flow is described in Appendix 6, figure 1
3) Are changes in the organization or in the industry driving the need for adopting blockchain technology?
R_3: 1. Expected upcoming regulatory requirements focusing on proving compliance of tank location, making data integrity and transparency important features 2. Organizational efficiency targets which can be achieved by working more collaboratively with external stakeholders
4) What are the main changes that blockchain enforces?
R_4: Data integrity and distributed architecture that offers an integrated way of sharing sensitive data, thus building trust
5) What are the main benefits of implementing blockchain technology?
R_5: Proof of tank traceability by using inputs from multiple process stakeholders

6) What are the main expected implementation hurdles?
R_6: I. IoT related – assumed to be mitigated by all scenarios presented in chapter 5: 1) technology is still in early stages and might prove difficult to obtain consistent results with active sensors over a tank life span of 2 years; 2) a SIM card for each tank is necessary to transmit real time information from sensors – high cost and compatibility issues across countries. II. Blockchain related – discussed in section 5.4: 1) regulatory uncertainty; 2) technology setbacks can affect the implementation effort, causing time and cost overruns; 3) disagreements between stakeholders while building or implementing the blockchain solution can cause time and cost overruns.
PART 1. TECHNOLOGICAL AND STRATEGIC EVALUATION
SECTION A. BLOCKCHAIN FIT
Q_A1. Does the project require storage of data? (Yes – 1p / No – 0p)
R_Q_A1: Yes – 1p; Storage of data from sensors plus data from logistic providers
Q_A2. What is the size of data that needs to be stored in one transaction? (Small, under 1MB – 1p / Large, over 1 MB – 0p)
R_Q_A2: Small, under 1MB/Transaction – 1p; A transaction will hold the time and date (timestamp), tank identification number, latitude and longitude coordinates, validation timestamp; hash of validation document. This series of characters occupies less than 1 MB of space.
Q_A3. Is the process defined in the project 100% deterministic? / Can you prove that the status of an asset reflects reality? (Yes – 1p / No – 0p) [Related to Q_B1]
R_Q_A3: No – 0p. Information from sensors or reported by stakeholders can differ from reality if: 1) sensors malfunction; 2) wrong data is written on the blockchain; 3) the sensor or the information exchange is hacked, while the tank is manipulated by non-friendly actors. If the first two situations occur, then data will not be accepted by the blockchain, as the location provided does not fit to the tank's previous location and to the next forecasted location, requiring a manual check to identify the tank's location. However, it would be more dangerous to have sensors hacked into transmitting location correct data, according to tank movement plan, while the tank is hijacked to another location.
Q_A4. Is there a need for multiple database writers? (Yes – 1p / No – 0p)
R_Q_A4: Yes – 1p; multiple sensors, multiple logistic providers, multiple CMOs
Q_A5. Does Roche trust the data provided by partners or do partners trust data shared by Roche? (Yes – 0p / No – 1p)
R_Q_A5: Yes and No – 0.5p; Blockchain is a technology well suited to address business situations where stakeholders do not trust each other. The informational relationship with governments is viewed as untrusted, requiring the use of blockchain, while the collaboration with the active stakeholders is trusted and does not require a blockchain.
Q_A6. Is there a need to remove the intermediary or existing interfaces between systems? (Yes – 1p / No – 0p)
R_Q_A6: Yes – 1p; Simplify system landscape and avoid to pay a 3rd party partner to provide tank tracking

Q_A7. Do transactions or information flows depend upon each other? (Yes – 1p / No – 0p)
R_Q_A7: Yes – 1p; Tanks follow a step by step movement process throughout their lifetime and their movement is planned
SECTION B. DIFFERENTIATE BETWEEN A STRONG AND A WEAK CASE
Q_B1. Can you enforce the status of the asset as registered on the blockchain to reality? (Yes – 1p / No – 0p) [Related to Q_A3]
R_Q_B1: No – 0p. The tanks cannot be physically controlled when they are not in a Roche site, however the stakeholders are trusted.
Q_B2. Would the partners included in the network have any motivation to collaborate between themselves? (Yes, stakeholders have connections between themselves – 1p / No, Roche is the main contact point for all stakeholders – 0p)
R_Q_B2: No, Roche is the main contact point for all stakeholders – 0p; If partners would have a motivation for collaborating between themselves on the network, they would be more inclined to join and build the network.
Q_B3. Can the project deliver value even if not all process stakeholders become network partners (ecosystem not crucial for success)? (Yes – 1p / No – 0p)
R_Q_B3: No – 0p; The project assumes that Roche collects and shares tank data with all required process partners. By having all parties on the blockchain, can the tank location be validated and agreed upon by every participant.
Q_B4. Can the blockchain project be developed without government support or oversight? (Yes – 1p / No – 0p)
R_Q_B4: No – 0p; Government agencies are the main compliance counterparty for the process and the main reason why blockchain is selected as an infrastructure solution for real time tank tracking.
SECTION C. INDUSTRY INVOLVEMENT
Q_C1. Does the project require industry collaboration to assure project success? (Yes / No)
R_Q_C1: No; Industry collaboration is not necessary as it involves the tracking and reporting of Roche tanks; the movement of tanks, compound transported and locations used can be viewed as potential business secrets, information that should not be shared with industry peers
Q_C2. Could the project be improved if industry partners collaborate? (Yes / No)
R_Q_C2: No. Although other pharma companies use similar tanks for comparable manufacturing operations, sharing tanks between companies is not viewed internally as a good idea because there could be a risk of disclosing finished product samples with competitor companies, causing financial damages larger than the possible savings generated by sharing tank fleets;
SECTION D. DIFFERENTIATE BETWEEN A PERMISSIONED AND A PERMISIONLESS CASE
Q_D1. Does the project require restricted access to data based on contractual/ disclosure agreements? (Yes - permissioned / No – permissionless)
R_Q_D1: Yes – permissioned; Data related to individual tank movement should only be shared between the stakeholders involved in handling it; Governments will have an overview over the tank fleet present at locations under their jurisdiction; Roche will be the only party that has overview over all tanks, as it is the owner of the fleet
Q_D2. Does the project require a complete identity check of all partners on the network?

(Yes - permissioned / No – permissionless)
R_Q_D2: Yes – permissioned; All partners included on the blockchain network need to be identified first and will receive a set of public and private keys to authenticate the tank movements (transactions) for which they are responsible
SECTION E. BLOCKCHAIN AND SUPPORTING TECHNOLOGIES
Q_E1 .Does the project require a combination between blockchain and additional technologies? (Yes/ No)
R_Q_E1: Yes; Blockchain is a secured and distributed storage environment that reunites location data from and information provided by logistic providers. The other process stakeholders validate the location information when the tank is in their direct control. On important additional technology is IoT location sensors.
SECTION F. BLOCKCHAIN TECHNOLOGY FOCUS:
Q_F1. Are there existing applications that are not built upon blockchain but satisfy all requirements?
R_Q_F1: Several IT applications that can satisfy all requirements better and faster than blockchain exist. However, they do not fulfill the immutability feature as Roche would own the application and could modify the data as desired, in contrast with the strict process imposed by collaborating with partners on the blockchain. Another solution for Roche would be to contract a completely independent 3rd party company to run the tank tracking reporting to governments and to guarantee for the accuracy of the data.
Q_F2. Does blockchain stand out as unique or are there many additional solutions for the project?
R_Q_F2: There are conventional solutions already on the market, satisfying most, but not all requirements presented in the project, as discussed in Q_F1.
Q_F3. Are there similar applications on the market using blockchain?
R_Q_F3: Yes. Everledger is a London start-up that tracks diamonds and aims to offer buyers full diamond traceability from the mine to the store. It uses laser encryption on diamonds and records on the blockchain 40 different diamond specifications. It collaborates with diamond industry authorities, insurers, insurance claims processors and with evaluators of diamond and jewelry. Other ideas related to using blockchain technology for product tracking and product traceability throughout the supply chain exist or are in prototype phase.
Q_F4. What is the stage of development for blockchain? (e.g. prototype, proof of concept, in development, market ready application, application in use)
R_Q_F4: Except for Everledger, which is an application in commercial use, the other applications are either in prototype phase or in evaluation phase (ideas).
Q_F5. Is blockchain a complex or simple technical solution to implement?
R_Q_F5: Blockchain is a complex technical solution to implement because it involves multiple parties in exchanging data and requires everyone to agree on a data standard and process.
Q_F6. How does blockchain's performance stand out against the other technologies?
R_Q_F6: As it is a new technology, blockchain has lower performance levels compared to conventional databases. Blockchain is best suited to record transactions, a positive aspect in the current project description, as the movement of a tank from site to site is a transaction that reflects the movement of an asset. However, for the moment, blockchain lacks a powerful reporting tool, as it is otherwise available for conventional databases.

Q_F7. What is the track record of blockchain?
R_Q_F7: Blockchain has been successfully used as a distributed ledger for recording transactions on cryptocurrency platforms, where its basic function was to track the movement of assets (cryptocurrency units) between users. All cryptocurrency hacks or issues have occurred in companies that were operating without using a blockchain.
Q_F8. Are there providers of applications based upon blockchain available for the specific project?
R_Q_F8: All major IT software providers and start-ups offer blockchain solutions, but it is not clear which one are commercially ready and which are still prototypes.
Q_F9. Should the blockchain solution be developed in-house or licensed from a third party?
R_Q_F9: Roche is not an IT company, and from the perspective of the writer, it would be beneficial if a solution could be purchased.
INTERMEDIARY DECISION POINT – IS THE PROJECT COMPATIBLE WITH BLOCKCHAIN TECHNOLOGY? (Yes – continue to Part 2 / No – jump to Part 3)
R: Accept, continue analysis to part 2. 1) Main benefits: - blockchain helps process stakeholders collaborate on validating tank location data thereby transforming raw sensor data into a trusted source of tank location that can be reported to government authorities; - blockchain is a platform that can help stakeholders in replacing paper based documentation and contracts by digitally sharing information - the project supports organizational learning regarding blockchain and IoT sensors. 2) Main adoption hurdles: - it is not known when and how government authorities will issue regulation that will require blockchain technology; - all process stakeholders must agree on the blockchain set-up and must collaborate to develop the blockchain network.

Table 1: Answers to the questions included in the first part of the framework

Appendix 8: Assumptions used in the financial valuation

The following table contains the assumptions used for the scenarios developed in the financial evaluation. Additional comments are located after the table.

<table>
<tr><th>Assumptions</th><th>Current</th><th>Enhanced simplified</th><th>Enhanced</th><th>Blockchain baseline</th><th>Blockchain delayed</th></tr>
<tr><td>Probability that project implementation is delayed</td><td>-</td><td>-</td><td>-</td><td>0%</td><td>30%</td></tr>
<tr><td>Project financing</td><td colspan="5">100% equity</td></tr>
<tr><td>Discount rate (%)</td><td colspan="5">9%</td></tr>
<tr><td>Solution can be used outside of tank tracking</td><td colspan="5">No</td></tr>
<tr><td>Change in working capital ($)</td><td colspan="5">0</td></tr>
<tr><td>Terminal value ($)</td><td colspan="5">0</td></tr>
<tr><td>Tax</td><td colspan="5">All estimated cash flows are assumed after tax</td></tr>
<tr><td>Blockchain solution</td><td colspan="3">-</td><td colspan="2">(Operational cost) Service subscription paid to IT provider</td></tr>
<tr><td>Cloud collaboration platform</td><td colspan="2">-</td><td>Operational cost</td><td colspan="2">-</td></tr>
<tr><td>Project IT infrastructure</td><td>-</td><td colspan="4">(Operational cost) Monthly service subscription paid to IT provider</td></tr>
<tr><td>Depreciation of sensors</td><td>-</td><td colspan="4">2 years, linearly</td></tr>
<tr><td>Number of tanks currently in fleet (#)</td><td colspan="5">2,500</td></tr>
<tr><td>Average cost of a new tank ($)</td><td colspan="5">150,000</td></tr>
<tr><td>Average residual value of a tank ($)</td><td colspan="5">10,000</td></tr>
<tr><td>One time cost for 1 sensor ($)</td><td colspan="5">250</td></tr>
<tr><td>Yearly cost of additional services performed for 1 sensor ($)</td><td colspan="5">10,000</td></tr>
<tr><td>Yearly cost - cloud infrastructure for conventional data exchange ($)</td><td colspan="2">-</td><td>100,000</td><td colspan="2">-</td></tr>
<tr><td>Yearly cost – blockchain license fees ($)</td><td colspan="2">-</td><td>-</td><td colspan="2">660,000</td></tr>
<tr><td>Operational saving generated by collaboration platforms per tank movement ($)</td><td colspan="2">0</td><td colspan="3">200</td></tr>
<tr><td>Estimated reduction in tank fleet (%)</td><td colspan="2">0%</td><td colspan="3">5%</td></tr>
<tr><td>Probability of receiving a fine for non-compliance with regulation (% of total yearly tank trips)</td><td>0.1%</td><td colspan="4">0%</td></tr>
<tr><td>Average value of fine ($)</td><td colspan="5">2,000,000</td></tr>
<tr><td>Probability of having a tank delayed in transit leading to total loss of content (% of total yearly tank trips)</td><td>0.7%</td><td colspan="4">0%</td></tr>
<tr><td>Average value of content for 1 trip ($)</td><td colspan="5">1,000,000</td></tr>
<tr><td>Number of IoT sensors (#)</td><td>-</td><td colspan="4">Equal to the number of tanks (2,500)</td></tr>
<tr><td>Roll out pal</td><td></td><td colspan="4">Estimated to take 2 years; in the first-year half of the tanks are equipped with sensors</td></tr>
</table>

Table 1: Assumptions table – columns hold the three main scenarios analyzed

Comments for assumptions that apply for all scenarios except current:

- implementing the project does not impact the following operational costs: tank maintenance, tank cleaning, tank transportation, logistic handling, insurance premiums, ERP license fees, and cost of full time employees;
- the average value of a new tank, the average residual value of a tank, the average value of content transported and the average value of a fine remain constant throughout the life time of the project;
- the number of Roche sites and CMO sites remains constant during the evaluation period;
- the investment does not have further uses outside of tank tracking as it is a niche area in supply chain operations – described in section 5.2;
- the project has no terminal value as a new investment is required for upgrading sensors and IT infrastructure;
- the number of trips for the entire fleet stays constant over the project timeline as manufacturing is planned over long production cycles (usually 5 years); the manufacturing base load is high and little on demand manufacturing occurs, therefore, tank utilization is not impacted;
- based on historical values, the current probability of being fined during one business year is 0.1%, applied to the total number of shipments;
- having oversight over the real-time location of all tanks eliminates the risk of being fined;
- based on historical values, the current probability of a tank being delayed in transit leading to the total loss of content is 0.7%, applied to the total number of shipments;
- having oversight over the real-time location of all tanks eliminates the risk of having a tank delayed in transit;
- the yearly service fee for sensors remains constant for the entire period of the project;
- contracted logistic partners provide real time tank location information free of charge as an additional service that offers them a competitive advantage compared to similar suppliers;

Comments for assumptions that apply only to the enhanced simplified scenario:

- no reduction in fleet size occurs as blockchain is not implemented, and as a result, the process of collaboration with stakeholders cannot be improved;
- no additional IT infrastructure is needed compared to the current state as sensor data is stored internally on the Roche ERP.

Comments for assumptions that apply only to the enhanced scenario:

- a cloud collaboration platform is considered to keep the valuation comparable to the blockchain scenario;
- it delivers the same advantages as blockchain in relation to active stakeholders; thus, tank fleet reduction, operational savings, fines cost savings and savings from eliminating tank delays are considered;

Comments for assumptions that apply only to the blockchain scenarios:

- the reduction in fleet size is a one-time event that occurs in the first year once the project is successfully implemented; the tank fleet reduction can be interpreted as a saving by not requiring the purchase of new tanks for the replacement of used ones;
- having oversight over the real-time location of all tanks and sharing the location with process stakeholders leads to improved joint management of tanks, eliminating the risk of having tanks delayed;
- the cost of storage for location data and information exchanged with partners is estimated based upon the number of sensors used in the project, the number of transactions generated in the system and upon the number of stakeholders that validate the data; the cost of storage increases yearly as the data stored on the blockchain is not deleted;
- the cost of the blockchain solution is based on the IBM's publicly available offer, and is assumed that the price increases linearly with an increase in network partners.

Comments for assumptions that apply only to the blockchain delayed scenario:

- probability of a project delay occurring during the implementation phase: 30%; the probability is used in calculating the risk adjusted value of the blockchain scenarios;
- average length of delay: the implementation time stated in the estimated project timeline for the blockchain baseline scenario is extended by 50%;
- average size of cost overrun: 50% increase in yearly costs for the blockchain solution, applied to all operational years considered in the project evaluation.

Appendix 9: Financial valuation model

The following valuation model was utilized for estimating yearly cash flows.

Row	Item
1	Savings generated by a reduction in the number of tanks (USD)
2	Operational savings generated by using a digital collaboration solution (USD)
3	Benefits from saving fine costs (USD)
4	Benefits from saving delayed content costs (USD)
5	TOTAL Yearly benefits (USD) [5=1+2+3+4]
6	Yearly cost of fines (USD)
7	Yearly cost of unusable content due to delayed tanks (USD)
8	Yearly cost of additional services performed for IoT sensors (USD)
9	Yearly license costs of the collaboration solution (blockchain or cloud platform) (USD)
10	Yearly cost for the cloud infrastructure supporting the data exchange solution (USD)
11	Depreciation cost (USD)
12	TOTAL Yearly costs (USD) [12=6+7+8+9+10+11]
13	NET RESULT (USD) [13=5-12]
14	Depreciation
15	Investments
16	Net Working Capital
17	Total cash flow adjustments (USD) [17=14-15-16]
18	TOTAL YEARLY CASH FLOW (USD) [18=13+17]

Table 1: Valuation model utilized for estimating yearly project cash flows

Using the yearly cash flows, the initial investment and the WACC, the NPV of the project was calculated, as described in chapter 5.