NTNU
Norwegian University of
Science and Technology

The Application of Blockchain Technology in Norwegian Fish Supply Chains

A Case Study

Magnus Mathisen

Master of Science in Mechanical Engineering
Submission date: June 2018
Supervisor: Jan Ola Strandhagen, MTP
Co-supervisor: Olumide Oluyisola, MTP

Norwegian University of Science and Technology
Department of Mechanical and Industrial Engineering

Preface

This master's thesis (TPK4930) is the final product of a five-year program in Mechanical Engineering. The field of specialization is Production Management at NTNU's Department of Mechanical and Industrial Engineering. The focus of the thesis is supply chain management, which has grown to be an integral part of the management of production businesses.

The aim and scope of this thesis has been to investigate the usefulness of blockchain technology in the supply chain management of fish producers. Blockchain technology is already an important technological trend in multiple industries, and the work conducted in this master's thesis aims to explore further use cases and applications of the technology.

Magnus Mathisen

Trondheim, June 2018

Summary

The work conducted for this thesis is meant to benefit both industry and the scientific community. Creating an assessment for blockchain technology in a specific industrial (supply chain) setting and later expand to a more general setting might prove useful for companies planning to use blockchain in the future or wanting to understand blockchain technology better. There is scarce academic research on blockchain technology in fields besides computer science and finance. Expanding the research territory is key to understand this new technological trend and in the case of supply chain management, blockchain technology might prove to be a key technological development in the years to come. This thesis is formed as an assessment of the strategic fit of blockchain technology in Norwegian fish supply chains. Further, the key findings from this specific strategic fit is used to find indicators for which types of supply chains blockchain technology could bring positive strategic implications. The thesis is structured so that relevant scientific theory and data is presented before making an assessment of the strategic fit and discussing the implications. Using the theory on supply chain management Fisher (1997) and Lee (2002) and key supply chain management objectives together with theory on innovation, through Rogers (1962), the following research questions were answered.

RQ1: Why is blockchain technology beneficial for fish supply chains?	
RQ1.1: How is it beneficial?	**RQ1.2: Does the findings indicate benefits for other supply chains?**

The research arrived at the conclusion that Norwegian fish supply chains might benefit from blockchain technology. This is mainly a conclusion drawn by the fact that Norwegian aquaculture producers were viewed to have lean supply chains and have functional products in the material flows as found through the models of Fisher (1997) and Lee (2002), and that the supply chain management objectives cost, quality and sustainability, with the cost and quality being integral to lean supply chain practices, were found to get the highest advantages. In addition, blockchain technology was found to benefit lean supply chains in general, especially food supply chains.

Acknowledgements

I want to thank my supervisors Jan Ola Strandhagen and Olumide Oluyisola for all the great input and their patience when working with me during my master's thesis. I also want to thank Olga Kravchenko, Blockchain Spokesperson at IBM Norway, for providing me with useful insights into the technology and general input for my work. In addition, I want to thank Dr. Bjørn Jæger at Molde University College and Stephan Nilsson at Norway Bitcoin and Blockchain Association for letting me attend their insightful course on blockchain technology.

Abbreviations

CSR	Corporate Social Responsibility
DOF	Norwegian Directorate of Fisheries
DOI	Diffusion of Innovations
EDI	Electronic Data Interchange
EEZ	Exclusive Economic Zone
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FOF	Future of Fish (The Nature Conservatory)
GGN	GLOBALG.A.P. Number (certification for aquaculture producers)
GUI	Graphic User Interface
HOREC	Hotels, Restaurants and Cafés
MFCA	Norwegian Ministry of Fisheries and Coastal Affairs
MRP	Material Requirements Planning
MTS	Make-to-Stock
MoTIF	Norwegian Ministry of Trade, Industry and Fisheries
NEA	National Environmental Agency
NSF	Norwegian Seafood Federation
RQ	Research Question
SC	Supply Chain
SCM	Supply Chain Management
SFIH	Marine Harvest's Salmon Farming Industry Handbook
SKU	Stock Keeping Unit
Tx	(Blockchain) Transaction
VAP	Value-Added Processing
VMI	Vendor Managed Inventory

Table of Contents

List of Figures

List of Tables

1 Introduction

With an accelerating rate of innovation, multiple industries face disruptions that could leave incumbent business models obsolete. Failing to adapt to the continuously changing competitive environment can have dire consequences. With an even faster pace of innovation in 2018, the challenge has not become easier for companies. A major challenge for companies is to foresee disruptive technologies making an impact in their industry and what the consequences of the disruption could end up being.

On the other hand, embracing technological changes early can lead to strong competitive advantage for companies, something companies such as Walmart have proved. Walmart identified the need for low procurement costs and low inventory levels to be able to provide their customers with the low prices they are famous for. As early as in 1983, Walmart had set up its own satellite communication system to coordinate the supply chain management of their vast network of distribution centers and retail sites.

Walmart quickly identified the value of sharing information regarding demand and inventory levels directly with their suppliers and by the 1990's about 90% of their suppliers were connected to Walmart's own information system, *Retail Link*. This lead to Walmart being able to do business directly with its suppliers without the need for intermediaries and at the same time having VMIs with decreased stock out rates on their most popular products while maintaining lower inventory levels overall.

Walmart's decision to embrace EDI technologies early lead the company to make their supply chain substantially more efficient through lower inventory levels, lower stock out costs and lower procurement costs as a consequence of the decrease in the bullwhip effect through higher availability of information for their suppliers.

Today blockchain technology has already been identified as a potential disruptive innovation for supply chain management. A few innovative companies, such as Walmart and Boeing, have identified the benefits of using blockchain technology in their supply chains, and are exploring their opportunities with the technology (Galvin, 2017, IBM, 2017). A major hurdle for companies that do not typically follow the behavior of early adopters, is to identify the disruptive innovations as beneficial to their supply chain management or operations. This master's thesis aims to effectively identify the opportunities blockchain technology brings for supply chain managers and aid them in their decision whether to adopt the technology or not.

1.1 Motivation

Blockchain technology appeared for the first time in 2008 through Nakamoto's (2008) whitepaper for *Bitcoin*, a digital currency built on principles such as cryptography and decentralization. In recent years blockchain technology has been in the process of moving from solely fintech to other applications. Supply chains are believed to be one of the next big beneficiaries through applying the technology to increase consumer confidence and quality assurance through, amongst other properties, increased traceability.

Supply chain management has become a great focus for both industry and academia. For industrial players, especially as a consequence of increased global trade and competition (Zeng and Yen, 2017), cost related to supply chain processes have become a significant share of the overall costs. This has resulted in increased scientific work in the fields of supply chain strategy and process optimization (Gunasekaran et al., 2008).

The emergence of innovations such as blockchain technology leads to disruptions in both traditional operations and competitive environment (IBM, 2018). While some innovations, such as Gerald Ford's conveyor belt, might be quickly identified as useful in a given industry setting, other innovations might be more ambiguous and be available for years before the true usefulness is discovered and leveraged properly. Blockchain technology might be a prime example of such a situation, and it is highly likely that future innovations might grow in complexity and be more difficult to identify as useful in specific industrial settings.

The scientific community has started to give blockchain technology serious attention and nearly a decade after its first appearance, academic work on blockchain technology is beginning to appear in fields besides computer science and finance, such as for example supply chain management. This raises the question if the technology could have been applied to these new fields earlier if decision makers had an easier way of assessing the strategic fit of blockchain to their specific situation.

1.2 Research

The research conducted in this thesis is aimed at answering the questions raised in the previous subchapter. To initiate such a discussion the work in this thesis is built around the applicability of blockchain technology in Norwegian fish supply chains. Through what is already addressed in academic literature regarding supply chain management, blockchain technology and innovations in general in addition to second hand empirical data available on the Norwegian fish industry, the strategic fit of blockchain technology can be assessed.

1.2.1 Research Objective

The research conducted in relation to this master's thesis is done to address the strategic fit of blockchain technology in Norwegian fish supply chains. To assess this, the objective of the thesis is to present an easy way for supply chain managers to assess if there is a strategic fit between their supply chain and blockchain technology as supply chain management tool.

1.2.2 Research Questions

The research objective leads to one main research question which further raises two additional sub-questions. These are presented in the table below.

Table 1.2.1: Research Questions

RQ1: Why is blockchain technology beneficial for fish supply chains? Answered through literature study on blockchain technology, supply chain management and a case study on the Norwegian fish industry through secondhand empirical data	
RQ1.1: How is it beneficial? Answered through aligning findings in the literature review about SCM objectives and blockchain properties.	**RQ1.2: Does the findings indicate benefits for other supply chains?** Answered through generalizing the findings from RQ1.1.

1.2.3 Scope

The scope of this research is chosen to the supply chain management of Norwegian aquaculture producers. This sector of the industry has had tremendous growth since the 1970's and has become a strong presence in the industrial environment of Norway. In addition, while the supply chain for aquaculture producers and capture producers get increasingly similar downstream, the upstream activities can be viewed to be generally more complex for aquaculture producers. This is because aquaculture producers are involved in the whole life cycle of the fish, leading to the need for suppliers of fertilized eggs and fish feed along the production cycle. Further, this thesis will focus on the production of Atlantic salmon (Salmo salar), as it makes up more than 80% of total aquaculture production in Norway, with remaining production mainly being rainbow trout (Oncorhynchus mykiss) which is a highly similar species of fish when looking at product characteristics.

1.3 Thesis Structure

To answer the defined research questions, chapter 2 is descriptive in regard to how key literature was gathered and assessed, and how and where information about Norwegian fish supply chains were gathered. Further, methodology on case studies and making control models are presented in this chapter as these methods for research are central themes in this thesis.

Chapter 3 presents general theory on supply chains and supply chain management. In Chapter 4 the selected case to assess is described and presented, namely Norwegian fish supply chains. Initially, general theory on supply chain management, supply chain strategy and supply chain management objectives are presented. This chapter aims to give an essential insight to key supply chain characteristics and characteristics of the products moving through the supply chain of Norwegian fish producers. Chapter 5 describes the theory gathered and built from the available literature regarding innovation in general and blockchain technology specifically.

Chapter 6 presents the findings from the research and discusses the implication of these findings. Additionally, an overview of the findings is presented in such a way that supply chain managers and decision makers easily can compare their supply chain with the blockchain technology advantages before making the decision whether to implement the technology or not. This chapter also discusses the advantages blockchain technology proposes to supply chain management, and how these advantages affect the key supply chain management objectives found in chapter 4.

In chapter 7 the findings from the research conducted are summarized and concluding remarks are presented.

2 Methodology

Research methodology is the systematic approach to deriving a problem (in the form of research questions and research objectives) and working towards solving that problem (Rajasekar et al., 2013). After defining the problem to solve, this systematic approach is, at its core, the process of gathering information and data, the analysis of the gathered information and data and finally proposing possible solutions to the problem.

Research can be defined as either being quantitative or qualitative. Quantitative studies build theories based on quantifiable measurements through numbers (Rajasekar et al., 2013), such as results from multiple experiments in a controlled environment. Qualitative research is appropriate when assessing research problems that are difficult to quantify. Quantitative research is numerical and conclusive, while not being descriptive in nature. Qualitative studies are exploratory and descriptive, helping the researcher in answering the *why* and *how* rather than the quantitative *what, where* and *when* (Rajasekar et al., 2013).

For this thesis, a qualitative approach is deemed most suitable. The theme for this research is the applicability of blockchain technology in Norwegian fish supply chains. An argument for using qualitative methods over quantitative methods for this subject is that there is still not a significant industry usage of blockchain technology and it is therefore hard to quantify implications of using the technology. In addition, the lack of real-world examples of use-cases makes it interesting to qualitatively assess if the few use-cases, or planned near-future use-cases, can provide any indication for use in different types of industries. With this it is meant that before trying to quantify the possible improvements blockchain technology could have on specific supply chain-types, there should be an assessment regarding *why* the technology might be useful in supply chain management and *how* there is advantages in using blockchain technology.

2.1 Key Literature Reviewed

There are multiple topics in this thesis, that all should be given the same amount of focus. To properly assess the research objective, a strong foundational understanding of operations and supply chain management is needed. Further, it is important to review literature that specialize on specific supply chains, here mainly fish supply chains, but also food supply chains in general. This, of course, is also the case for blockchain technology. In addition, literature on the role of information technology in supply chain management is of importance for the work related to this thesis.

Conducting literature studies yield not only insights into specific research topics, but also gives an overview to the researcher about the how deep earlier research has gone in the field and whether it is the topic and research questions are researchable. It should be noted that while having access to an extensive body of literature regarding supply chain management in general and fish supply chains especially, there is still a gap in the literature on the use of blockchain technology as a tool for supply chain management. This comes with both the disadvantage of a lack of insights through academic literature, but also highlights the need for new research on the topic. The strategy to tackle the problem of lacking literature on blockchain technology has been to team up with IBM, which is one of the companies with the strongest competence-base in the field and to leverage available documentation from open-source blockchain projects alongside reviewing the available literature. It should also be noted that during the period of research for this thesis there has been an increase in the number of papers published with blockchain for supply chain as a topic.

To give a systematic angle of attack for the literature study, keywords for the different topics was identified and run through search engines at different literature databases (i.e. Science Direct, Web of Knowledge, Google Scholar and Emerald Insight). The search strategy was laid out to have a primary set of keywords and a secondary set of keywords. The primary keywords were designed to cast a wide net and return a varied body of literature on a given subject, while the secondary keywords where used to narrow the search and return articles discussing more specific topics. The only primary keyword which was used in a stand-alone search was *Blockchain*, as the expected number of findings was a lot lower than for the rest, in addition to all articles on the technology being judged relevant for this thesis. The results from the different searches were assessed by title, abstract and journal of publication to find the articles deemed most relevant. When finding relevant articles, the reference list of the article would be assessed to further gather background literature on a specific topic.

Table 2.1.1: Primary and Secondary Keywords Used in Literature Study

Primary keyword	Secondary keyword
Value Chain	• Seafood • Aquaculture • Fish • Food • Perishables
Supply Chain Management	• Objectives • Performance Indicators • Performance Measurement • Strategy • Technology • Seafood • Aquaculture • Food • Perishables
Blockchain	• Supply Chain
Innovation	• Diffusion • Supply Chain • Technology

In addition to literature available from academia, a lot of resources has been gathered from relevant institutions connected to the fish industry. These are mainly the *Foods and Agriculture Organization of the United Nations* (FAO), *Directorate of Fisheries* (DOF), *Future of Fish* (FOF, as a part of *The Nature Conservatory*), *Marine Harvest*'s *Salmon Farming Industry Handbook* (SFIH), the *Norwegian Seafood Federation* (NSF) and the *Norwegian Ministry of Fisheries and Coastal Affairs* (MFCA). In addition, multiple open source blockchain projects and blockchain-based start-ups gives availability to resources regarding the benefits and limitations of the technology. From these resources project whitepapers and similar documentation has been gathered and analyzed to increase the theoretic background on blockchain technology.

2.2 Conducting a Case Study

To support this qualitative study, the research method chosen has been in the style of a case study. For a long time, there has been a call for more case studies in the primary operations management journals (Stuart et al., 2002, Flynn et al., 1990). In research related to operations management and supply chain management the methodology preferred by researchers is often that of mathematical and statistical modelling and optimization schemes (Meredith, 1998). It is important to remember that academic fields such as operations management and supply chain management are closely tied to industry and real-world business processes. Often times academia can highlight how business processes might be optimized, while actually optimizing these prove difficult or impossible in real life. A study conducted in the fall of 2017 provides an example (Mathisen, 2017). Through a systematic literature review it was found that the scientific community puts a strong emphasis on the importance of information sharing between actors in a supply chain, while there was a clear lack of mechanisms for effective information sharing in real world supply chains.

Blockchain technology, which is a central theme for this thesis, is a technology that is not yet used by industry in any significant scale. Because of this, it is expedient to conduct research in such a manner that the theory deducted from a case study has sufficient generalizability (Gomm et al., 2000). The case study methodology used in this thesis has been grounded in Eisenhardt's (1989) seminal article. The approach is definable through eight activities, i.e. (1) defining research questions and objectives, (2) selecting appropriate cases, (3) crafting the needed protocol for the study at hand, (4) entering the field, (5) analyzing the data, (6) shaping hypotheses, (7) enfolding literature and (8) finalization. It should be added that "entering the field" in this context would equal to reviewing all available information on blockchain initiatives that are being conducted around the world through the internet and correspondence with involved actors where needed. In addition, second hand empirical data is gathered from credible sources in the fish industry to make up a comprehensive study of Norwegian fish supply chains. Stuart et al. (2002) provides a simplified overview (i.e. a five-stage process) of Eisenhardt's process, which can be seen in the figure below.

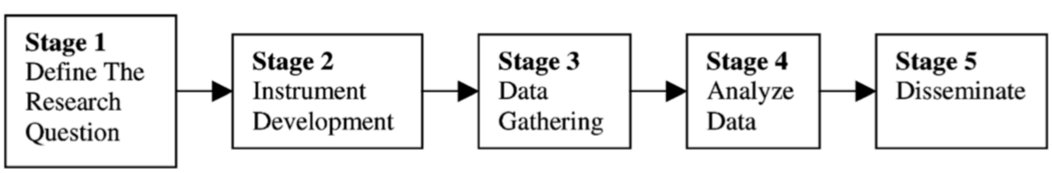


Figure 2.2.1: The case study process (Stuart et al., 2002)

The aim of this study has been to increase knowledge of blockchain usage for improving supply chain management objectives. While being a popular tool in social sciences, a case study can provide the foundation for theory exploration and implementation built on qualitative research (Eisenhardt and Graebner, 2007) in a supply chain management context. In addition, triangulation of data and theory gathered from multiple sources can provide a stronger background for further theory building (Rowley, 2002).

2.3 Making a Control Model

A control model is an abstraction of a company's logistics and production processes in either an AS-IS state (how the system is at present time) or TO-BE (how the system will be in the future with specific changes made) (Strandhagen, 2015). When exploring the effects blockchain technology might have on Norwegian fish supply chains it is useful to understand the situation as it is before any changes are made. To do this an AS-IS model is built for this thesis using Strandhagen's (2015) control model methodology. With secondhand empirical data available through sources such as those presented in chapter 2.1, it is possible to make a representative AS-IS control model, which can be further assessed to find the TO-BE control model. Note that in this thesis the AS-IS and related TO-BE models are meant to be generic representations of Norwegian fish supply chains. As a consequence, the control models present material and information flows in a way that could represent any Norwegian aquaculture producer to give an illustrative picture of how blockchain technology might improve the information flows in a supply chain. In addition, the focus for the control models is the dynamics of the flow of information in the supply chain. For this reason, some aspects of the AS-IS and TO-BE are left out as they are not deemed essential for the work of this thesis. The AS-IS model is presented in chapter 4.5, while the TO-BE is presented in chapter 6.3.

2.4 Quality of Information

When it comes to the literature used to build the theoretic background for this study it is reasonable to trust that it is of sufficient quality as long as it has been peer-reviewed, accepted and published in a journal with an acceptable reputation. For the secondhand empirical data used when analyzing Norwegian aquaculture supply chains, the quality is accepted as long as the empirical data is gathered from institutions with credibility, such as governmental institutions, big industry players and central non-profit organizations such as FAO.

3 Supply Chain Management

A supply chain is a network, consisting of a wide variety of actors, in which materials and products move downstream, from origin at the suppliers to destination at the end customer (Slack et al., 2013). In addition to the flow of materials, finance and information flows are an integral part of a supply chain. The flow of finance is usually upstream in the form of payments for goods or services delivered from supplier to customer. The flow of information in a supply chain is as important upstream as it is downstream (Khan et al., 2016, Resende-Filho and Hurley, 2012, Dominguez et al., 2017).

Supply and demand dynamics are what forms a supply chain, and for the suppliers to make precise decisions regarding how much to produce they are dependent on insights on the demand-side, which is more easily accessible for retailers as they are in direct contact with the end consumer. This illustrates the importance of informational flows through the supply chain. If a supplier was to get information of demand only through the actual orders they got from retailers, as opposed to shared insights into demand forecasts, it would be harder for them to prepare to meet expected demand. This is often illustrated through the Bullwhip effect, where information regarding demand gets more distorted as information flows upstream (Metters, 1997, Disney and Towill, 2003). In this scenario the supplier might incur costs as they buy excessive materials or set up machinery that ends up not being used.

Supply chain management refers to the activities of decision makers along the supply chain that have different roles such as controlling inventory levels (Alfaro and Rábade, 2009), handling procurement deals (Presutti, 2003) and the strategic planning of logistics and manufacturing (Wanke and Zinn, 2004, Morash et al., 1996).

3.1 Supply Chain Management Objectives

The literature offers different characteristics of supply chains. It is often useful to measure supply chain performance after how it performs against certain objectives (Kshetri, 2018). These have traditionally been (1) quality, (2) speed, (3) dependability, (4) cost and (5) flexibility (Agrawal et al., 2017, Aung and Chang, 2014, Brusset, 2016, Ge et al., 2016, Gregory, 1996, Slack et al., 2013). In addition to these five objectives, sustainability (6) has become an supply chain management objective of greater concern and focus from both industry and researchers in recent years (Rao and Holt, 2005). This is a consequence of a consumer base that is more conscious about, and has growing concern for the environment, health issues related to food safety and social responsibilities (Barnett et al., 2016, Porter and Kramer, 2006).

(1) Quality is related to the ability to keep products and processes "*fit for purpose*" and error-free (Kshetri, 2018), to avoid costly and time-consuming reparations or product recalls. (2) Speed in supply chain management is to be able to expedite the customer fast and to minimize time between value-adding activities. (3) Dependability is the ability to deliver products or services at the promised time. (4) Flexibility allows a company to adapt quicker to unforeseen circumstances such as shifts in demand. (5) One of the key objectives of any company is to keep their costs at acceptable levels. To be able to sell products at a reasonable price compared to competitors and still return positive earnings, companies need to have a focus on costs related to their operations (Slack et al., 2013). (6) Sustainability is the objective to not let operations be the source for social or environmental issues. One initiative often used to ensure different supply chain objectives are being met, is supplier evaluation programs (Beske et al., 2006, Hahn et al., 1990) or supplier self-evaluation (Trowbridge, 2006). These measures are mostly used to address concerns regarding sustainability, but also lets companies evaluate their suppliers on other supply chain management objectives.

3.2 Supply Chain Strategy

Supply chain decision makers face a multitude of challenges. One of the most costly and difficult challenges is the uncertainty in demand (Petrovic, 2001, Christopher and Lee, 2004). Fisher (1997) tried to tackle this challenge by devising a framework for aligning supply chain strategy and the type of products in the given supply chain. The result was the now famous Fisher (1997) model. Fisher (1997) identified the root cause for many supply chain management problems to be the mismatch between product characteristics and supply chain characteristics.

According to the article "*the first step in devising a supply chain strategy is to consider the nature of the demand for the product one's company supplies*" (Fisher, 1997). In other words, to understand the most fitting supply chain strategy one must understand the demand for the product, and to understand the demand for the product it is essential to understand the product itself. According to Fisher (1997) there are two classifications of products if they are classified on the basis of their demand patterns. These are the functional products and the innovative products. The functional products are the consumer staples and typically have stable and predictable demand. For innovative products the demand is unpredictable, and oftentimes the innovative products are replaced by advances in technology or "*gone out of fashion*" after few years, seasons or months

(Fisher, 1997). This is what is meant with the product life cycle in table 3.2.1 below, i.e. the product's *market* life cycle. The table is a direct replication of the product classifications presented in the Fisher (1997) model.

Table 3.2.1: Product characterization as presented in Fisher (1997)

Aspects of Demand	Functional Products (Predictable Demand)	Innovative Products (Unpredictable Demand)
Product life cycle	More than 2 years	3 months to 1 year
Contribution margin	5% to 20%	20% to 60%
Product variety	Low (10 to 20 variants per category)	High (often millions of variants per category)
Average margin of error in the forecast at the time production is committed	10%	40% to 100%
Average stock-out rate	1% to 2%	10% to 40%
Average forced end-of-season markdown as percentage of full price	0%	10% to 25%
Lead time required for made-to-order products	6 months to 1 year	1 day to 2 weeks

Fisher (1997) defines a supply chain to have two main functions. These are the physical functions and the market mediation functions. With this, Fisher (1997) proposes that supply chains both have processes that are physical and value-adding such as converting raw material into goods, but also processes that ensures that the product variation matches the marketplace demand (Fisher, 1997). Fisher (1997) identifies that supply chain strategy can either be focused on being physically efficient or market-responsive. The physically efficient supply chain strategies are mainly to cut cost as much as possible, keep inventories as low as possible and increase utilization rates throughout the value chain. The market-responsive strategies are focused on not losing sales through minimizing chances for stockouts and keep lead times as low as possible to meet customer needs as faster. Fisher's (1997) main reasoning for this is that some products have thin profit margins, while others have sufficient profit margins to make investing in buffer inventories and ways to minimize lead times more profitable than to lose potential sales.

Table 3.2.2: Supply chain characterization as presented in Fisher (1997)

	Physically Efficient Process	Market-Responsive Process
Primary purpose	Supply predictable demand efficiently at the lowest possible cost	Respond quickly to unpredictable demand in order to minimize stockouts, forced markdowns, and obsolete inventory
Manufacturing focus	Maintain high average utilization rate	Deploy excess buffer capacity
Inventory strategy	Generate high turns and minimize inventory throughout the chain	Deploy significant buffer stocks of parts or finished goods
Lead time focus	Shorten lead times as long as it does not increase costs	Invest aggressively in ways to reduce lead time
Approach to choosing suppliers	Select primarily for cost and quality	Select primarily for speed, flexibility and quality
Product-design strategy	Maximize performance and minimize cost	Use modular design in order to postpone product differentiation for as long as possible

With the product classifications of functional and innovative products, and the efficient or market-responsive supply chain strategies, Fisher (1997) proposes that there are possible matches and mismatches when aligning supply chain strategy with product type. If the products moving through the supply chain are functional products with low profit margins and long market life cycles, the best approach, according to Fisher (1997), is to keep the supply chain processes efficient and cut cost where possible. This by implementing higher utilization and following the lean philosophy in general (Bhasin and Burcher, 2006). For the companies with innovative products, such as producers of smart-phones, it is essential to be sure to produce enough to meet the market demand, instead of focusing solely on cost-cutting. When a smart-phone producer loses sales it can become much more costly than to it would be to keep buffer inventories and investing in methods to decrease lead times.

Fisher's (1997) framework is presentable as a two-by-two matrix, showing the matches and mismatches of product types and supply chain strategies. The companies that have either an innovative product with an efficient supply chain (upper right quadrant) or a functional product with a responsive supply chain (lower left quadrant) are the ones that tend to have problems (Fisher, 1997). The framework is illustrated in figure 3.2.1. Fisher's (1997) model is extremely useful for assessing why some companies struggle with their supply chain management but is also useful in the case assessment conducted later in this thesis to align supply chain strategies with fitting supply chain management objectives. Each supply chain case can be assessed by the type of product it focuses around to see if there are some pattern in the use of blockchain technology for specific supply chains based on the Fisher (1997) model.

	Functional products	Innovative products
Efficient supply chain	Match	Mismatch
Responsive supply chain	Mismatch	Match

Figure 3.2.1: Alignment of product and supply chain characterizations (Fisher, 1997)

Lee (2002) saw the value in Fisher's (1997) model and proposed that it is essential for companies to include the uncertainty in supply when choosing the most effective supply chain strategy. The result was a framework that helped companies to identify what strategy was the most effective based on the uncertainties in both supply and demand. Lee (2002) built on the concepts proposed by Fisher (1997) and agreed that products were typically functional or innovative, but that supply chains tended to be either stable or evolving. When classifying products as functional or innovative Lee (2002) chose a broader approach and made the characteristics more generic (as can be seen in table 3.2.3 below). For the classification of supply chains, Lee (2002) identified that there are stable supply chains which are highly efficient with well-established processes and high reliability, and that there are evolving supply chains that have yet to reach a mature and stable phase. Lee (2002) argued that this is a fact that needs to be taken into consideration when assessing the uncertainties involved in supply chain management. Stable supply chains generally create less uncertainty upstream than evolving supply chains, much in the same way as functional products generally create less uncertainty in demand than innovative products. The classifications used by Lee (2002) for both product types and supply chain characteristics are presented in tables 3.2.3 and 3.2.4 below.

Table 3.2.3 & 3.2.4: Lee's (2002) product and supply chain characterizations

Functional	Innovative
Low demand uncertainties	High demand uncertainties
More predictable demand	Difficult to forecast
Stable demand	Variable demand
Long product life	Short selling season
Low inventory cost	High inventory cost
Low profit margin	High profit margin
Low product variety	High product variety
Higher volume per SKU	Lower volume per SKU
Low stockout cost	High stockout cost
Low obsolescence	High obsolescence

Stable	Evolving
Less breakdowns	Vulnerable to breakdowns
Stable and higher yields	Variable and lower yields
Less quality problems	Potential quality problems
More supply sources	Limited supply sources
Reliable suppliers	Unreliable suppliers
Less process changes	More process changes
Less capacity constraint	Potential capacity constraint
Easier to changeover	Difficult to changeover
Flexible	Inflexible
Dependable lead time	Variable lead time

While Fisher (1997) proposed two main types of supply chain strategies, Lee (2002) built on the framework and argued that there are four strategies. The best choice would depend on both the uncertainty in supply and demand. While it is generally a good strategy to decrease supply and demand uncertainties as much as possible, Lee (2002) proposes a framework for effectively aligning strategy to product type and type of supply chain, as they are presented in the tables 3.2.3 and 3.2.4 above. The results are four supply chain strategies. These are the efficient supply chains, the risk-hedging supply chains, the responsive supply chains and the agile supply chains. Much like the Fisher (1997) model, the Lee (2002) model is presentable as a two-by-two matrix (as illustrated in figure 3.2.2 below). In Lee's (2002) model, each quadrant in the matrix represents the most fitting of the four strategies presented earlier. The efficient and responsive supply chains are similar to those in the Fisher (1997) model, while there are two additional supply chain strategies. Risk-hedging supply chains utilizes strategies aimed at pooling and sharing resources between actors in the supply chain so that the risk of disruptions in supply is hedged for each individual actor (Lee, 2002). The agile supply chains utilize strategies aimed at being responsive and flexible to customer needs, while at the same time hedging the risk of disruption in supply by polling inventory or other capacity resources with other supply chain actors (Lee, 2002). Using Lee's (2002) model together with Fisher's (1997) model when analyzing the supply chain of Norwegian aquaculture producers can possibly reveal whether blockchain technology is beneficial.

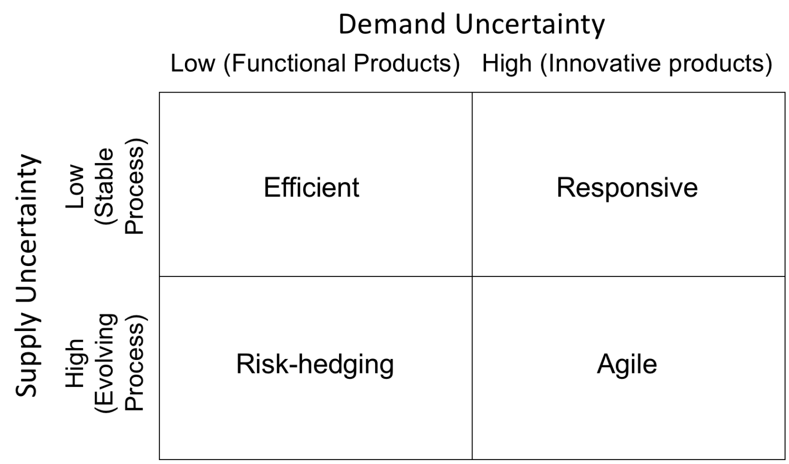


Figure 3.2.2: Aligning supply chain strategy with degree of uncertainty (Lee, 2002)

3.3 Food Supply Chains

The materials in the material flow of fish supply chains are food products. Fish supply chains are therefore comparable to generic food supply chains or supply chains of perishables in general. To better understand how supply chain actors in the fish industry operates, it is useful to understand the dynamics of food supply chains in general. Romsdal (2014) proposes a comprehensive way to characterize food supply chains and this chapter presents her findings on said topic. There are three main aspects to assess when characterizing the food supply chain. The products should be assessed by themselves. This to get an understanding of the perishability, complexity, variety, life cycle, volume and variability. Understanding the products in a supply chain helps understanding the specific needs for processes such as product handling and distribution. To paint a picture of the demand-side of the supply chain, some characteristics of the market are useful. Romsdal (2014) proposes delivery lead-time and lead-time variability, demand uncertainty and inventory management and stock-out rates as key characteristics for food supply chains. The last aspect to characterize is the production system, which can give an impression on the supply-side through characteristics that tackle the capital-intensiveness, complexity of processes and supply uncertainty.

Products in the food supply chain can be characterized as being perishables, meaning they have a finite shelf life and often will deteriorate in value and quality over time. The products complexity can be both very low or very high. While fruits and vegetables often are only produced and distributed, there are multiple food products that go through several steps of processing, such as the ready-to-eat meals. The variety in food products is high and has been seen to be increasing

(Axtman, 2006) due to increases in packaging sizes and varieties, number of brands, and new products and recipes brought to market. Food products are often produced and sold in large volumes. In the processing stage the product variety is generally low, which leads to larger volumes and batch sizes (Romsdal, 2014).

The demand-side of food supply chains can be characterized by delivery lead time and lead time variability, demand uncertainty and inventory management and stock-out rates. Delivery lead times of food products can vary from a few days to several months. But because the downstream actors, such as the retailers or wholesalers, demands short lead times, the food products are often produced MTS (Romsdal, 2014). This is a consequence of the production lead times often being longer than the demand lead time expectations from customers. Uncertainty in demand is generally low for functional products and high for innovative products (Fisher, 1997). For perishable products the demand uncertainty is generally lower than for non-perishable products (van Donselaar et al., 2006). Inventory replenishments typically happen periodically for food products and the products often needs to be stored with special conditions, such as refrigeration. These implications are mainly because of the perishability. In addition, the stock-out rates for food products have generally been found to be high at between 5% and 10%. Stock-out-rates are often a consequence of inefficient ordering, replenishment and planning in the supply chain (Romsdal, 2014).

The production lead time for food products varies greatly, with some products having short lead times due to a low degree of processing, while other products have long lead times as they need processing or maturation. The production is generally capital-intensive, with continuous production and work flow through advanced machinery and equipment. The supply uncertainty also varies with the type of food product but can be generalized to be mostly dependent on seasonality. For most food products the supply of raw materials has a stable reliability (Romsdal, 2014). The flow chart below represents a typical food supply chain as it presented by Romsdal (2014).

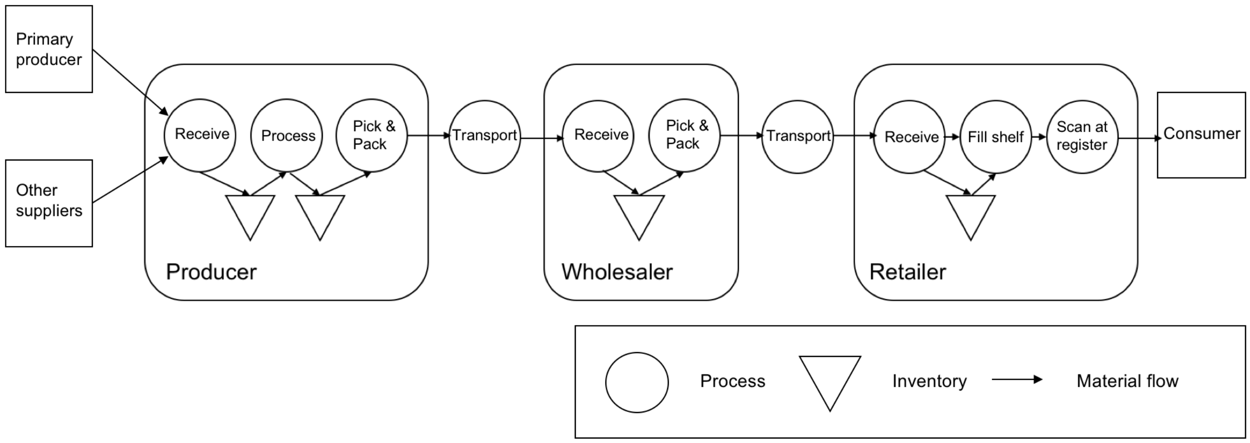


Figure 3.3.1: A generic food supply chain (Romsdal, 2014)

4 The Norwegian Fish Industry

4.1 Introduction

Fishing has been one of the most important sources of food for many centuries in Norway. The sea has been an important source of food for inhabitants all along the coast. Today, Norway is one of the world's biggest fishing nations. The Norwegian fish industry makes up 2.5% of the total capture production and 1.8% of the total aquaculture production of fish worldwide (FAO, 2015). Although this might appear to be low percentages, Norway is by far the country with the highest per capita production and per capita exports, which can be seen in figure 4.1, where Norway is compared with nine other big fish producing nations. Norway is also the second biggest exporter of fishery commodities, with only China exporting larger quantities (measured in USD) as illustrated in figure 4.2 (FAO, 2015). This illustrates the importance of the industry for the Norwegian economy.

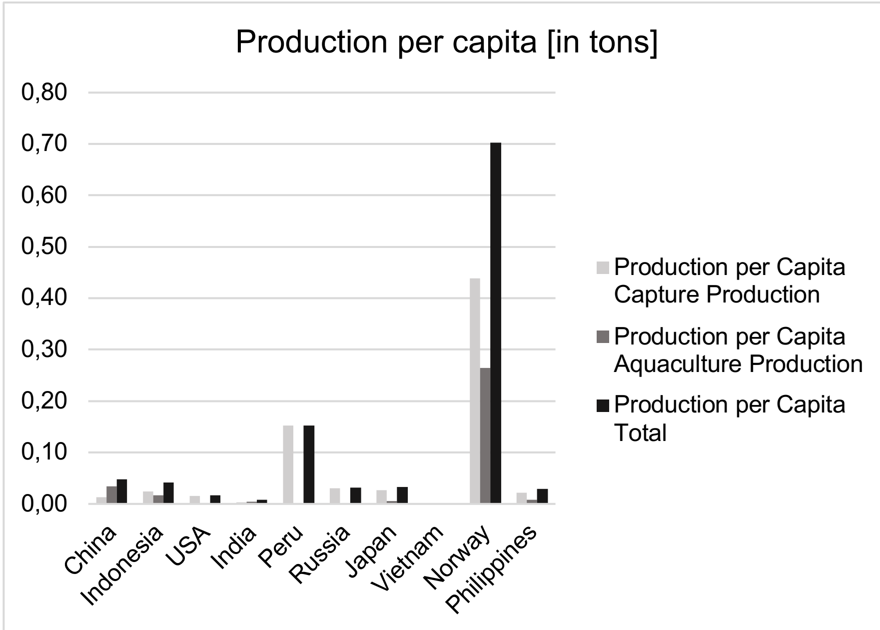


Figure 4.1: Production of fish per capita (FAO, 2015)

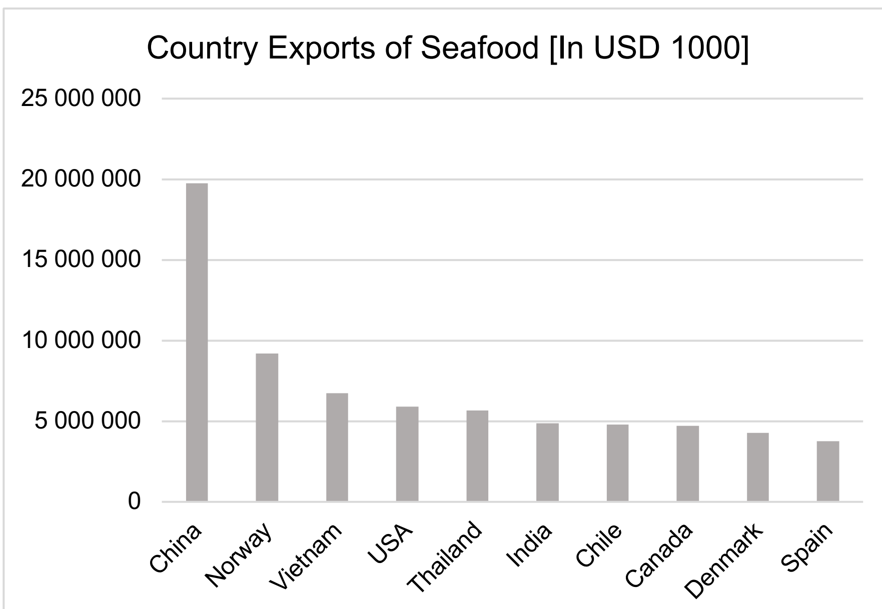


Figure 4.2: Exports of seafood by country in USD 1000 (FAO, 2015)

Today, the industry is typically split into two main sectors, namely capture production and aquaculture production. The producers are often referred to as fisheries and fish farmers, respectively. Both sectors of the industry will be given a quick introduction to illustrate in which aspects they diverge.

4.1.1 Capture Production

The most commonly captured species in Norway, measured in tons are the pelagic species making up 57% of all capture production. These species are, in order of tons captured, Atlantic herring (Clupea harengus), blue whiting (Micromesistius poutassou) and Northeast Atlantic mackerel (Scomber scombrus). The ground fish species makes up 34% of all capture production measured in tons, but since the ground fish species are more valuable they make up 62% of the total value of catch, while the pelagic species make up 30% of total value of catch. Among the ground fish species, the capture of Atlantic cod (Gadus morhua) is the biggest both measured in tons of capture and value of catch. The most captured ground fish species (measured in tons), after Atlantic cod, are saithe (Pollachius virens) and haddock (Melanogrammus aeglefinus). The remaining percentages account for crustaceans and seaweed species. Among these species, the Antarctic krill (Euphausia superba) make up the most tonnage of capture, while the Northern prawn (Pandalus borealis) makes up the most value of catch. All numbers are based on the statistics report for 2017 made by the Norwegian Directorate of Fisheries (DOF, 2017).

The Norwegian fisheries use vessels for the capture production of fish along the Norwegian coast and offshore. The fish are mainly caught in the EEZ and international waters in the Norwegian Sea, but also to some extent in the Barents Sea and the North Sea (NSF, 2012). The capture is landed in ports along the coast of Norway, where they are either processed on-site or transported to processing facilities. Most of the processing consists of salting, drying, filleting, packing and freezing. In addition there is some production of processed products such as frozen fish fingers, fish balls and fish cakes (FAO, 2014). The products are then distributed to wholesalers and retailers downstream.

The size of the fleet of Norwegian fishing vessels has decreased substantially during the last ten years. Total number of vessels have decreased from more than 26,000 vessels in the 1980's to a total of 6,134 vessels in 2017 (DOF, 2017). This is a consequence of factors such as higher efficiency and industrialization of the fisheries and higher fees for registered fishing vessels (FAO, 2014).

4.1.2 Aquaculture Production

Aquaculture production has long traditions in Norway, but the real growth in the industry started in the 1970's. New technologies let the industry grow Atlantic salmon (Salmo salar) and rainbow trout (Oncorhynchus mykiss) in seawater-cages and since then the industry has seen tremendous growth (FAO, 2018). Today, 95% of all aquaculture produce in Norway is exported, with the EU being the main market (FAO, 2018). The Norwegian production is centered around Atlantic salmon, with the species making up 80% of total aquaculture production. The second most important species is the rainbow trout, which makes up most of the remaining aquaculture production (10-15%), and aquaculture production of cod (Gadus morhua), halibut (Hippoglossus hippoglossus), spotted wolffish (Anarhichas minor) and several shellfish species are in the process of becoming commercialized (FAO, 2018).

Any company wanting to produce fish for commercial purposes needs to get a license from the Norwegian Directorate of Fisheries (Aarset, 1998). In Norway there are 1,105 licenses for farming of salmon and trout (DOF, 2018). The aquaculture producers operate on a single year class basis (FAO, 2018), which means that when a production site is provided smolt, it has to wait until the produce is on-grown and harvested offshore before new smolt can be put into the offshore production process.

Both Atlantic salmon and rainbow trout are anadromous species, meaning they both have freshwater and saltwater phases in their life cycle. Atlantic salmon is put in freshwater tanks as spawn when it has been hatched, and through the process called smoltification the fish goes through physiological changes that changes the fish from freshwater to seawater fish. This adds to the complexity of the production and creates the need for onshore hatching and smolt production and later on-growing in sea water in the final stages of the production cycle. The on-growing takes place in cage systems at different locations along the Norwegian coastline from Agder in the south, to Finnmark in the north. There are some minor differences in the two species, but the production of both species is done in the very similar ways.

The production cycle consists of multiple stages. As indicated above, Atlantic salmon and rainbow trout needs a freshwater and a saltwater production phase. The freshwater production is located at onshore facilities, with availability of power and freshwater. The production cycle starts with the production of broodstock fish from eggs. Today this is based on genetic breeding programs and there are ten companies specializing in the fertilization of salmon eggs in Norway (FAO, 2018). The fertilized eggs are descendants from original populations of wild salmon or trout multiple generations back.

Salmon is stripped (i.e. roe is extracted from the fish) between October and January and the trout between February and April. After this the fertilized eggs are incubated, hatched and periodically fed with formulated feed. The first part of the smoltification process is conducted with the help of artificial lights to speed up the process. The smoltification process starts in August and is concluded by June the following year. The on-growing phase of the production is offshore and takes from 14 to 24 months. The on-growing happens in cage systems mainly made up of steel structures with nets ranging in volume from 3,000 to 40,000 m^3. The production at one production site is very large and typically ranges from 800 to 4,000 tons of biomass per production cycle (FAO, 2018).

The costs related to aquaculture is mostly through feed, which accounts for about 50% of the total production cost (FAO, 2018). The feed used for salmon and trout is almost exclusively formulated dry feed. In addition, power to the production sites, salaries and costs related to incidents of salmon lice makes up most of the costs of production (SFIH, 2017). The profitability of production has been varying, mainly because of volatility in the price of fish commodities such as Atlantic salmon and rainbow trout (Guttormsen, 1999, Oglend, 2013).

Summarizing, aquaculture is the process of breeding and cultivating seaborne species that are mainly used as food or as ingredients in food products (FAO, 2014). The research in this thesis has been chosen to focus on the Norwegian aquaculture production of fish. This is because this can be viewed to have a more complex production cycle than capture production. To illustrate this, aquaculture production involves the breeding of fish over several months, something that generates the need for suppliers of fish-feed and fertilized eggs for the aquaculture producers. Capture producers do not need to provide feed to the produced fish and the production lead time for capture production is much shorter due to the fact that there is no breeding.

4.2 Product Characteristics

The product moving through the supply chain of Norwegian aquaculture producers are mainly Atlantic salmon or rainbow trout (FAO, 2018). In the product assessment in this chapter, only Atlantic salmon (Salmo salar) will be analyzed. This is both because more than 80% of all aquaculture production in Norway is Atlantic salmon (FAO, 2018) and the fact that the products are highly similar, yielding similar results when analyzing either species.

Atlantic salmon is a red-meat fish, and it is high in omega-3 fatty acids making it a popular dietary choice for consumers. The food conversion rate (kg feed/kg edible weight) of the fish is also a lot lower than for its substitute products with an conversion rate of 2.3 against 4.2 for chicken, 10.7 for pork and 31.7 for beef (GGN, 2018). Atlantic salmon, and fish in general, are also rich in protein having a protein efficiency of 30%, with chicken having the second highest protein efficiency with 25%.

With base in Fisher (1997) and Lee (2002) the product characteristics of farmed Atlantic salmon will be presented in this chapter, with one subchapter for each of the main characteristics the two models find to be most important when aligning supply chain strategy and product type.

4.2.1 Supply and Demand Dynamics

As the world population is growing at increasing speed the total demand for food is increasing similarly. Salmon is rich in the omega-3 and vitamins and has a high protein retention, meaning that the protein in the food product is high compared to the amount of feed needed to produce the animal (SFIH, 2017). This makes it an especially sought-after food product in the worlds growing middle class (GLOBEFISH/FAO, 2017). The price of salmon relative to other major sources of protein have been decreasing, but the price saw sharp increases in 2015-16 giving it a relative higher price increase over the last 37 years than all other protein sources except chicken (SFIH, 2017).

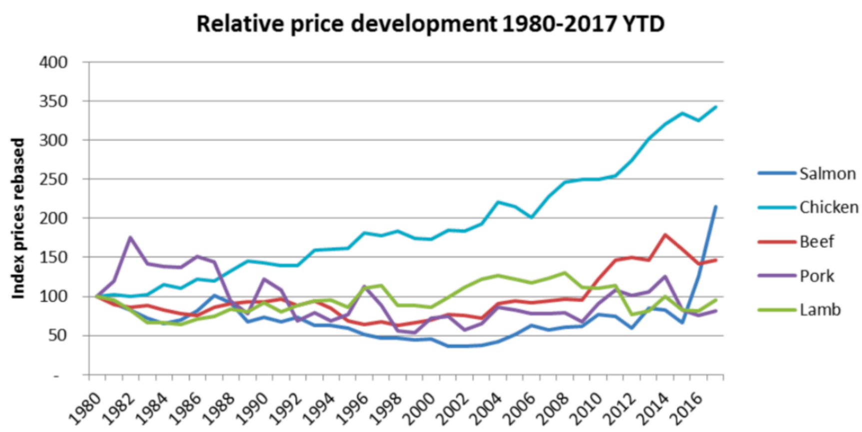


Figure 4.2.1: Relative price development of salmon compared to other major sources of protein for human consumption (SFIH, 2017)

The market for farmed Atlantic salmon has yet to reach maturity. The demand side have been growing in similar pace as productivity in aquaculture production (SFIH, 2017). This means that the demand side is somewhat predictable, stable and certain for Norwegian aquaculture producers.

The supply of Atlantic salmon has grown with a total of 385% since 1995, a growth rate of 8% per year. In recent years (2005-2016) the growth in supply has slowed and is now at about 5% per year (SFIH, 2017). There have also been examples of shortages of Atlantic salmon, such as the high mortality of salmon in Chile in and around 2009 (Asche et al., 2009). This shows that there are possible disruptions in supply patterns from the aquaculture producers themselves. This generally concerns supply chain actors downstream from the aquaculture producers, such as wholesalers and retailers. The supply of fertilized eggs, feed and electric power can be considered to be stable and certain, with multiple suppliers available to the Norwegian aquaculture producers (SFIH, 2017).

4.2.2 Market Life Cycle

In the Fisher (1997) and Lee (2002) models, product life cycle is used as a term for how long a product type will be relevant in the market, i.e. its market life cycle. For some electronic products, such as computers and smart phones, the market life cycle can be considered to be short as they are superseded by the next generation of products with higher computing power, better screens and longer battery life. For food products in general this type of life cycle is generally very long. There are some food products that might be classified somewhere between functional and innovative (Romsdal, 2014), but demand for food products rely on the consumers tastes and preferences with most consumers wanting to have variety in their diets. This leads to most basic food products never going completely “*out-of-style*”. As a consequence of this, the market life cycle for the various Atlantic salmon products have no foreseeable disruptions in the future and can be considered to be long, in the sense of a magnitude of years.

4.2.3 Inventory Costs, Stockout Cost and Obsolescence

Fresh fish is a highly perishable product type. There are challenges in maintaining inventory and the supply chain actors are dependent on the products moving at sufficiently speed downstream in the supply chain so that the fresh fish does not expire before being bought by the consumer. While having profit margins that are in the higher range of functional products, the fish do not carry with them substantial stockout costs or costs related to obsolescence of inventory (Kouki et al., 2013).

4.2.4 Cost Structure and Profit Margin

The cost structure of Atlantic salmon produced in Norway is as illustrated in figure 4.2.2. As presented in the sector diagram, the biggest cost in production comes from feed making up almost half the total cost (SFIH, 2017). Other major costs are related to production and processing activities. The cost structure presented in the figure is illustrative for the cost structure of Norwegian aquaculture producers and is taken from the SFI Handbook (2017).

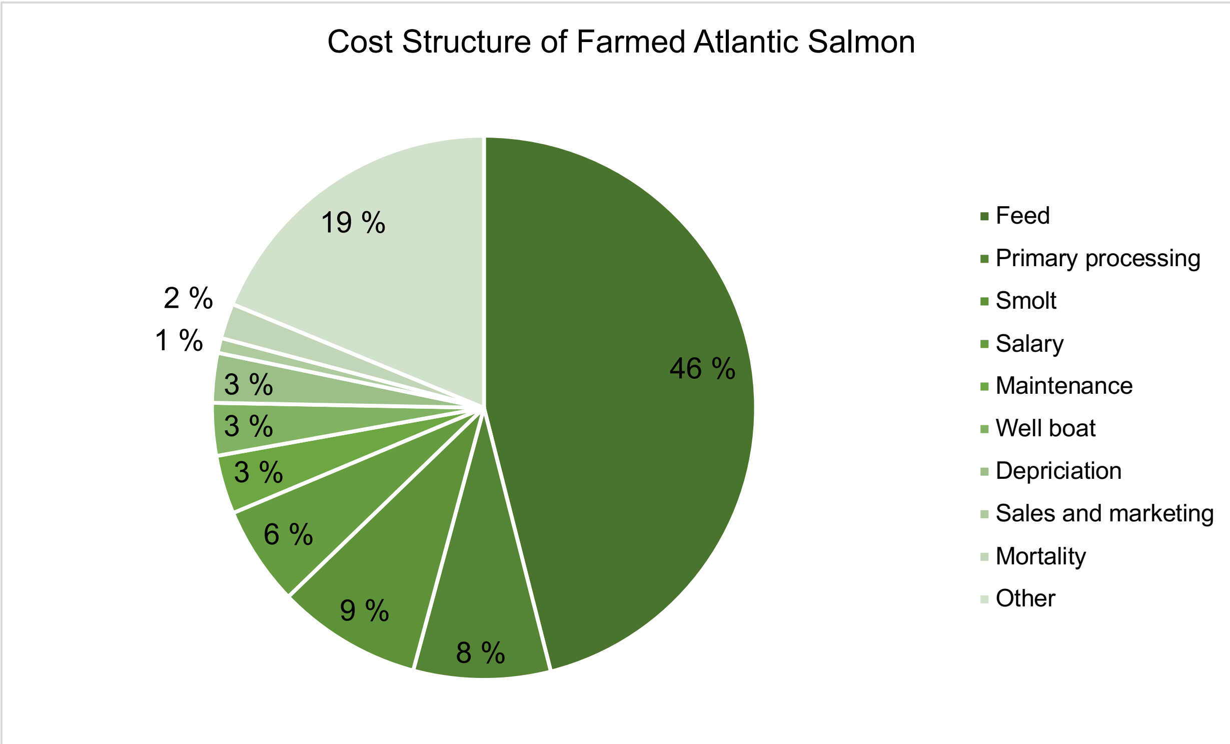


Figure 4.2.2: Cost structure of Atlantic salmon farmed by Marine Harvest (based on numbers from SFIH, 2017)

Although the aquaculture production of Atlantic salmon is capital intensive (Constance and Kirk Jentoft, 2011), Atlantic salmon is regarded as a high-quality product making it possible to sell at a premium price (Ankamah-Yeboah et al., 2016). This leads to Norwegian aquaculture producers having a profit margin at about 24% (Liu et al., 2016, SFIH, 2017).

4.2.5 Product Variety

The processing of Atlantic salmon is divided into two categories. First is the primary processing, which is similar for all salmon products. The primary processing consists of slaughtering and gutting of the fish. Secondary processing, or value-added processing (VAP) varies with what the final product should be. Examples of secondary processing is filleting, portioning, smoking and production of ready meals (SFIH, 2017). For Marine Harvest, the biggest aquaculture producer in Norway, the product mix was as presented in the sector diagrams below (figures 4.2.3 and 4.2.4).

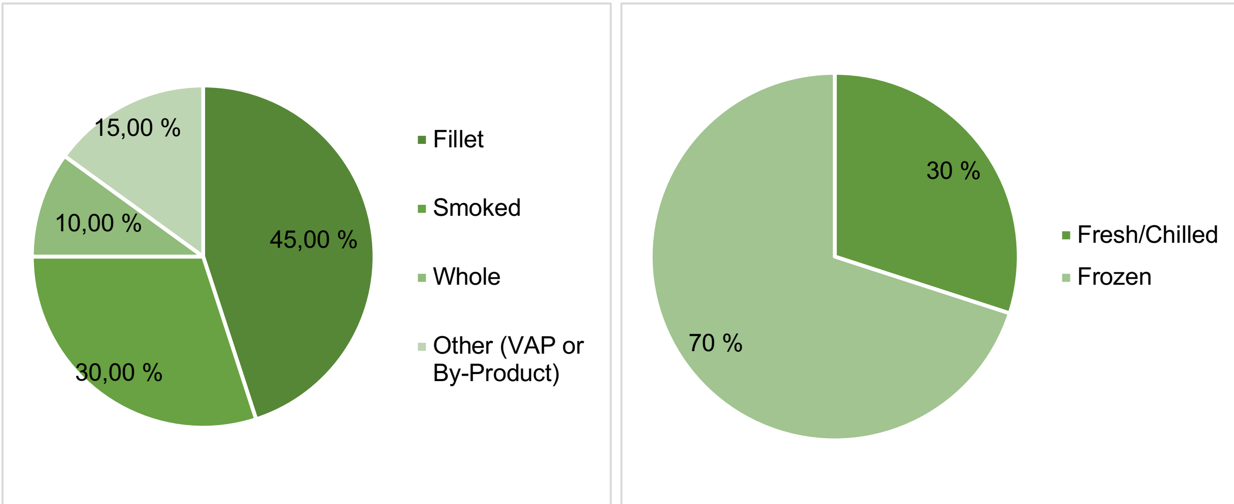


Figure 4.2.3: Product mix (left) and amount of fresh and frozen fish produced by Marine Harvest (SFIH, 2017)

The product mix produced by Norwegian aquaculture producers can be regarded as little in variety. The fish is mainly sold as whole, in fillets, and to some extent as processed products, such as ready meals (SFIH, 2017). The fish products are either sold fresh or frozen.

4.2.6 Assessing the Product Using Fisher and Lee

To understand which supply chain management strategies are the most fitting for a company, it is essential to understand the product moving throughout the supply chain. The first step to understand the product is to use Fisher's (1997) product characteristics. Fisher (1997) identified products to fall into one out of two categories when classifying the product based on its demand patterns. Lee (2002) further built on the Fisher (1997) demand-centered framework and added the effect of supply uncertainties. The resulting list of key characteristics for products is highly useful in the following assessment of the strategic fit of blockchain technology.

Both Fisher (1997) and Lee (2002) viewed products to be either mainly functional or mainly innovative. In the assessment of supply chain strategy and the strategic fit of blockchain technology, the characterization of products as either functional or innovative will be used as the first step. The product will be analyzed by the key characteristics presented in the table (4.2.1) below, which is a direct representation of the Lee's (2002) product classifications. With these characteristics it becomes possible to give a classification of the product.

Table 4.2.1: Product charactersitcs (Lee, 2002)

Functional	Innovative
Low demand uncertainties	High demand uncertainties
More predictable demand	Difficult to forecast
Stable demand	Variable demand
Long product life	Short selling season
Low inventory cost	High inventory cost
Low profit margin	High profit margin
Low product variety	High product variety
Higher volume per SKU	Lower volume per SKU
Low stockout cost	High stockout cost
Low obsolescence	High obsolescence

After classifying the product by the Fisher (1997) and Lee (2002) models, using the information gathered for the theory presented in subchapter 4.2, it becomes clear that the product (i.e. Atlantic salmon) is characterizable as functional.

4.3 Norwegian Aquaculture Production and Supply Chain

In the following subchapters the production cycle for farmed Atlantic salmon and the overall supply chain for Norwegian aquaculture producers is presented.

4.3.1 The Production Cycle

The production cycle for farmed Atlantic salmon takes about three years. During the first 10-16 months, (1) the eggs are fertilized and (2) brought to a controlled freshwater environment, where it is grown to about 100 grams. This process, where the fish goes through physiological changes from freshwater fish to seawater fish is called smoltification. The fish is then (3) brought to saltwater cages where it is (4) grown to full-size adults in 14-24 months. When the fish has reached a full-grown size of about 4-5 kilograms it is brought back to shore where it is (5) slaughtered and (6) processed depending on it being planned sold as whole fish, fillets or other VAP-products (SFIH, 2017).

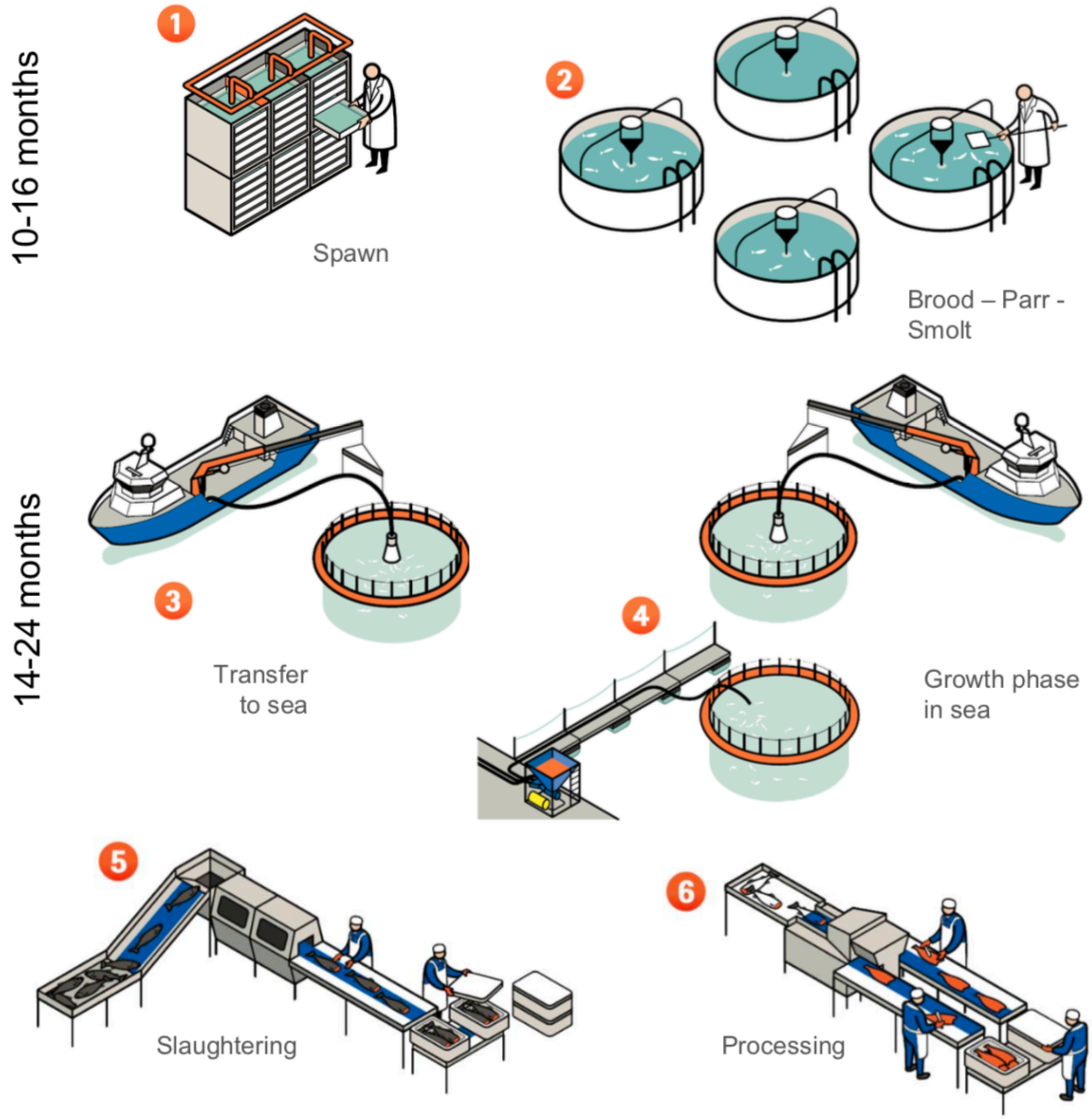


Figure 4.3.1: Production cycle for farmed Atlantic salmon (SFIH, 2017)

The smolts are mainly released into seawater twice a year. To meet the year around demand of Atlantic salmon, the harvesting and slaughtering of grown salmon is spread throughout the year. Because the salmon growth is best during the last quarter each year, this is the period with most harvest. In addition, the period during summer when a new generation is brought to seawater cages there are lower supply of Atlantic salmon to market. This is because the harvesting pattern shifts from the previous generation to the next (SFIH, 2017).

4.3.2 The Supply Chain

The supply chain of Norwegian aquaculture producers is comparable to that presented by Romsdal (2014). The materials flowing downstream are perishable, with a high deterioration rate. The distribution channel of the finished goods consists of distributors, wholesalers and retailers selling the products to consumers or to HOREC costumers domestically and abroad (SFIH, 2017, FAO, 2018).

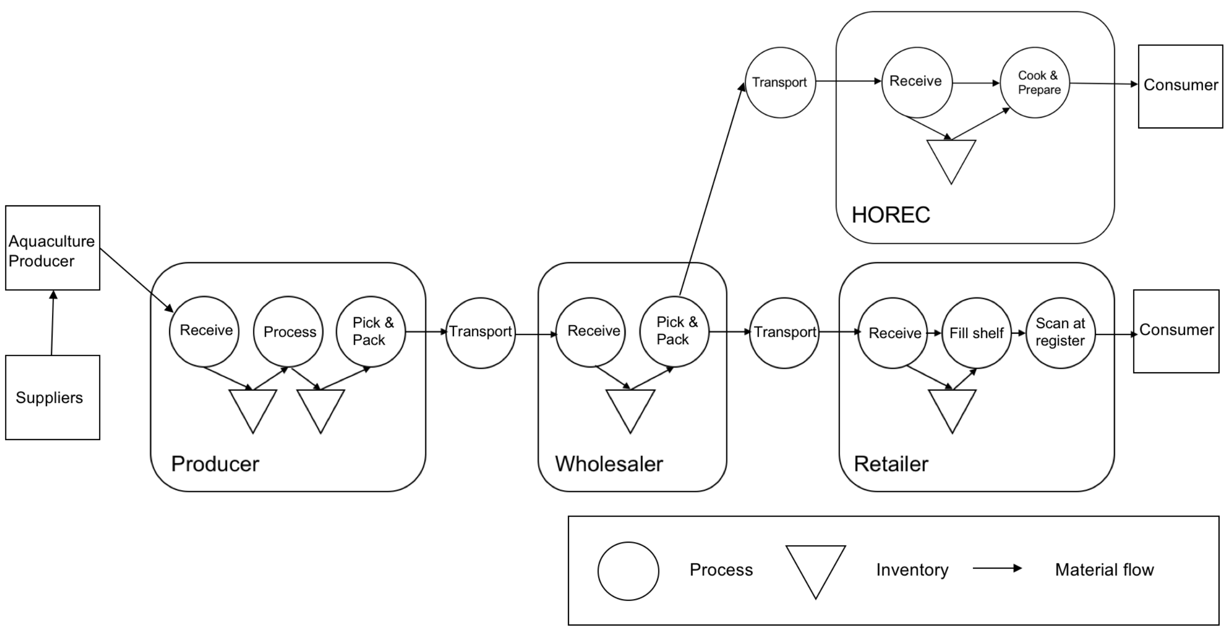


Figure 4.3.2: An aquaculture supply chain based on Romsdal (2014)

A more detailed view from the perspective of the aquaculture producers show the supply chain as perceived by producers (figure 4.3.2). Upstream are the suppliers of salmon eggs and hatcheries which is either done in-house or outsourced (SFIH, 2017). There are multiple suppliers of salmon eggs available to Norwegian aquaculture producers, with Aquagen AS, Fanad Fisheries Ltd and

Salmobreed AS among the biggest. The production of eggs is easily scalable, and production is adjusted to demand by obtaining more or less fish for breeding from the preceding season (SFIH, 2017).

Production of smolt is usually done in-house. The smolt-rearing facilities are done onshore where there is availability of freshwater and transportation to seawater cages is not too long (SFIH, 2017, Stradmeyer, 1994). In the seawater cages the grow-out phase of the production cycle is conducted. The suppliers of cages and facilities for smolt and grow-out are used for single capital intensive investments and further maintenance of the facilities (SFIH, 2017). In addition, there is a need for supply of feed throughout the whole production cycle from the fish is hatched to it is harvested. This later part is a running cost that alone makes up almost half of the total cost structure for the production of the fish (SFIH, 2017). The main suppliers of feed to Norwegian aquaculture producers are Skretting, BioMar, Polarfeed, EWOS and Marine Harvest who all operate internationally. The raw materials used in fish feed is mainly wheat, fish oil, fish meal, rapeseed oil and soymeal. Except for wheat, which has had a stable balance between supply and demand throughout the years, there are some increases in the price of raw materials over time and the raw materials used in feed production has shifted from fish-based products to plant-based protein sources (Shepherd et al., 2017, Ytrestøyl et al., 2015). This leads to some extent to risks regarding costs of fish feed, but since the norm in the industry is to operate with cost-plus contracts for feed suppliers. The risk for price fluctuations is carried by the aquaculture producers and the supply uncertainty of fish feed is minimized (SFIH, 2017).

4.4 Supply Chain Characteristics

The supply chain for Norwegian aquaculture production is as represented in subchapter 4.3. In this chapter the characteristics of Norwegian aquaculture supply chains will be assessed and presented as they are described by Fisher (1997) and Lee (2002).

4.4.1 Supplying Demand

Norwegian aquaculture producers have seen a stable and growing demand for farmed Atlantic salmon worldwide. With the degree of certainty on both the demand and the supply side (SFIH, 2017), the primary purpose of Norwegian aquaculture supply chains is to supply somewhat predictable demand efficiently.

4.4.2 Inventory

The inventory management in aquaculture supply chains is similar to that of perishable supply chains in general (Asche et al., 2016). For some perishable products the shelf life can be long, while other are highly perishable with relatively short shelf lives. The shelf life of Atlantic salmon is relatively short, and the quality of the fish deteriorates quickly (Fey M and Regenstein J, 1982). Because of lacks of standardized criteria for the freshness of fish it is difficult to quantify the shelf life of Atlantic salmon precisely, but the shelf life is usually no more than one week when stored between 2 and 8°C (Amanatidou et al., 2000). This leads to the necessity for aquaculture producers and downstream actors in the supply chain to limit inventories of fresh fish and keep a steady supply to the market instead (SFIH, 2017, FOF, 2015).

4.4.3 Lead Times

Lead times for farmed Atlantic salmon is long, as seen in figure 4.3.1. The production cycle for one generation of farmed salmon takes about three years in total. The lengthy grow-out phase of the production cycle is dependent on water temperature and the temperature dictates how long it takes for the fish to grow. Generally, the lead time from slaughter to the product being placed on retailer's shelves can be rather short. Something the fish fillets made by aquaculture producer *Salma*, with their process from their farmed salmon is brought ashore to them being vacuum-packed taking under four hours, illustrates. As a consequence, for aquaculture producers the lead time focus should be on shortening lead times as long as it does not increase cost (Fisher, 1997).

4.4.4 Selection of Suppliers

As established in chapter 4.3.1, the supply and demand dynamics for aquaculture producers in Norway is stable and predictable both upstream and downstream. This leads to selection criterion for feed, cage and fertilized eggs suppliers to mainly focus on cost and quality. As presented in figure 4.2.2 the main contributing cost comes from feed. This illustrates that the selection of suppliers based on cost has impactful effects on the profit margin.

4.4.5 Efficient versus Responsive Supply Chain Operations

The production strategy for Norwegian aquaculture producers is today mainly to operate efficiently, meaning maintaining acceptable levels of quality in production while lowering cost as far as possible. Objectives such as maximizing output, minimizing cost and shortening the production cycle through technological advancements should be the focus for Norwegian aquaculture producers (Slack et al., 2013). The focus in supply chain strategy is not to be market responsive, where the product differentiation is postponed, and inventory levels are kept sufficiently high to satisfy fluctuations in demand (Lee, 2002).

4.4.6 Assessing the Supply Chain using Fisher and Lee

Once again, the Fisher (1997) and Lee (2002) models appear as a natural first step when conducting the analysis. Both models present characteristics of supply chain strategies. These characteristics can help to address whether the supply chain strategy focuses around making the supply chain processes efficient or to be able to quickly adapt to changes in the market.

Table 4.4.1: Characterizations of physically efficient processes and market-responsive processes (Fisher, 1997)

	Physically Efficient Process	Market-Responsive Process
Primary purpose	Supply predictable demand efficiently at the lowest possible cost	Respond quickly to unpredictable demand in order to minimize stockouts, forced markdowns, and obsolete inventory
Manufacturing focus	Maintain high average utilization rate	Deploy excess buffer capacity
Inventory strategy	Generate high turns and minimize inventory throughout the chain	Deploy significant buffer stocks of parts or finished goods
Lead time focus	Shorten lead times as long as it does not increase costs	Invest aggressively in ways to reduce lead time
Approach to choosing suppliers	Select primarily for cost and quality	Select primarily for speed, flexibility and quality
Product-design strategy	Maximize performance and minimize cost	Use modular design in order to postpone product differentiation for as long as possible

Using the information gathered regarding the case in subchapter 4.3 and 4.4, it is clear that the aquaculture supply chain for farmed Atlantic salmon can be characterized as being physically efficient.

4.5 AS-IS Control Model

With the data gathered in this chapter, it is possible to present a representative AS-IS control model of the supply chain for a typical Norwegian aquaculture producer. In the center of the figure (4.5.1), the internal processes at a Norwegian aquaculture producer is presented with a darker blue frame. The numbers in the figure present (1) growth of fish from spawn, (2) smoltification of fish, (3) ongrowing in seawater, (4) slaughtering, (5) primary processing and (6) secondary processing. The green figures represent support activities in the supply chain, while the light red represent downstream POS. The solid black arrows represent the flow of materials and the blue dotted arrows represent the flow of information.

The flow of information moves in the opposite direction of the flow of materials. The information moving upstream goes through a number of points for the aquaculture producer. From the end consumer, retailers and HORECs get the demand. This information is given to the wholesaler as product refill orders. It is at this point in time that the wholesaler gets information regarding demand. The wholesaler sends orders to the aquaculture producer's order handling based on the perceived demand at wholesaler's point in the supply chain.

The aquaculture producer uses said information to forecast future demand and find the needed resources and materials to produce equivalent to the forecasted demand. The material needs are communicated to the aquaculture producer's suppliers who provide sufficient fertilized eggs, feed and packaging material to meet the forecasted the demand.

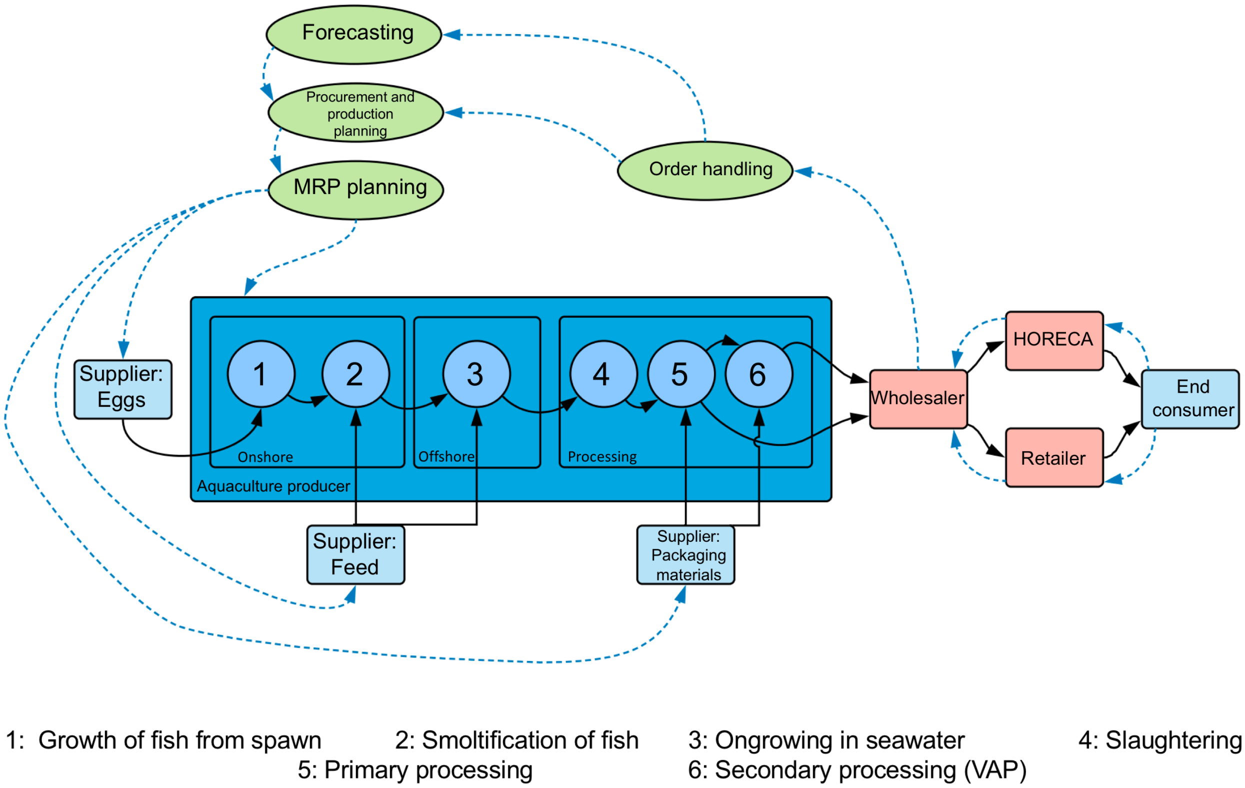


Figure 4.5.1: AS-IS control model

5 Blockchain Technology and Innovation Theory

Blockchain technology is an emerging technology and the possible use cases are still being explored. Because of this, a thorough explanation of the core concepts is key to grasp the mechanisms that make this technology unique. When Nakamoto (2008) came up with the concept of a blockchain it was with peer-to-peer financial transactions in mind. The problem the proposed concept was looking to solve was that of the need of costly and in some cases untrustworthy third parties needed to verify and conduct the transactions. Prior to blockchains there was no way to conduct a transaction without intermediaries, without the receiver knowing that the sender did not spend his money in two places at the same time leaving one of the receivers without spendable money. This is what is known as the "*double-spend problem*" and the solution to this problem is one of the unique traits blockchain technology offers.

To better understand how blockchain can provide benefits for supply chain management it is essential to look at technological properties and make an assessment based on those properties to identify where the possible advantages might arise. Please note that because there are multiple blockchain protocols available today, every description and example that follows in this chapter is made to apply to a generic blockchain that in some way can be seen as a permutation of Nakamoto's (2008) original blockchain, namely the *Bitcoin* blockchain.

This chapter is divided into subchapters. The first subchapter addresses some needed innovation theory to be able to make assessments regarding the technology, while the remaining subchapters dive into details about how blockchain technology works.

5.1 Diffusion of Innovations

Corporations often experience different degrees of inertia when having to adapt to change in the competitive environment they operate within. As the acceleration of technological advancement keeps on increasing, both academia and industry have an increasing need for the ability to adapt to change. There is extensive research on innovation, and one of the most famous theories is the one of *diffusion of innovations* (Rogers, 1962). Rogers (1962) identified the difference in communication and diffusion, when information spread through social systems. The main difference, according to Rogers (1962), was that while communication is a process where participants in the social system creates and shares information, diffusion is the process where new ideas and innovations spread throughout said system.

Rogers (1962) highlighted four main elements in the diffusion of new ideas. These are (1) an innovation, (2) the communication channels, (3) the time it takes for an innovation to be communicated throughout the social system and (4) the social system in which the innovation is communicated (Rogers, 1962).

An innovation is a new idea, practice or objective. In the setting of this thesis innovations are mainly thought of as technological solutions perceived as new by corporations. There are five attributes of innovation, (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability and (5) observability (Rogers, 1962). These five attributes are what dictates the rate of adoption, which is how fast the innovation is adopted throughout the social system. Relative advantage (1) is how the innovation can be viewed to be better than the existing technologies in use. Compatibility (2) describes how well the innovation aligns with existing ideas, technologies, needs and values among the entities in a social system. The complexity (3) of an innovation describes the degree of difficulty entities in the social system experience when trying to understand and use the innovation. The trialability (4) of an innovation describes to which degree it is possible to experiment and investigate before adopting the innovation. The observability (5) describes the degree of visibility of the results of using the innovation. The five attributes of innovation dictate how fast the innovation is diffused in the social system. The complexity of an innovation is negatively related to the rate of adoption, while the remaining four are positively related to the rate of adoption, as perceived from the members of the social system (Rogers, 1962).

The communication channels are the means by which messages get from one entity to another (Rogers, 1962). Social media, interpersonal channels and clusters of cooperative businesses are examples of such channels. While Rogers (1962) proposed the theory to work as a tool in social sciences, there is a clear usage of the theory in business networks, such as supply chains. Because of this, the social system to be considered in this thesis will mainly be networks consisting of multiple corporations.

The last element described about diffusion of innovations is time. The element of time is important when assessing the different adopter categories. Adopter categories are classifications of the members in a given social system based on their innovativeness. With innovativeness it is meant how some entities are relatively earlier to adopt new ideas than others in the social system (Rogers, 1962). These five adopter categories are, order by innovativeness, innovators, early adopters, early majority, late majority and laggards.

As the market share of innovations (relative to the preceding idea or solution) follow the S-curve when accepted by more and more entities over time in a system, the number of adopters at a given time can be expressed by the mean and standard deviation and represented as a normal distribution. The horizontal axis in the figure below represents time moving chronologically from left to right. The majority of the adopters will find themselves within on standard deviation from the distribution mean. These are the early majority and the late majority, depending on being before or after the mean adoption time respectively. The innovators are the ones that accepts the innovation earlier than two standard deviations from the mean, while the early adopters and the laggards find themselves more than one standard deviation from the mean on the earlier and later side respectively.

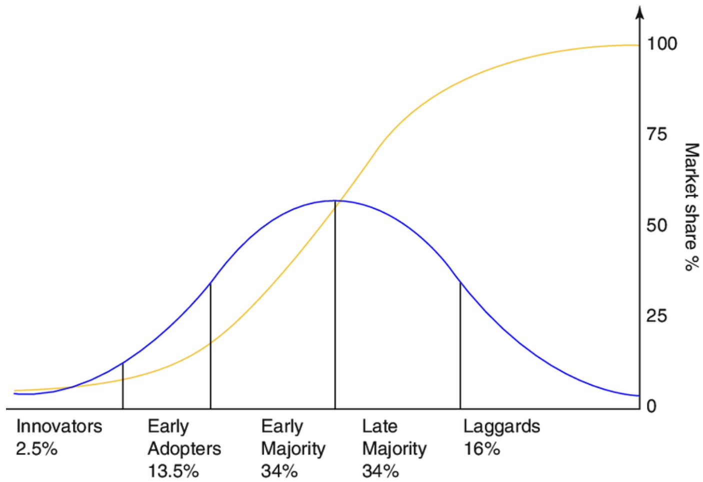


Figure 5.1.1: The distribution of different adopter categories in a population (Rogers, 1964)

For the analysis related to this thesis, the innovativeness of organizations and companies is central. Organizations are stable systems of individuals divided by divisions of labor and different positions in a hierarchical structure (Rogers, 1962). For organizational innovativeness the innovation process can be divided into two sub-processes. These are the initiation and implementation. The initiation process consists of the agenda-setting and matching. Setting the agenda occurs when the organization has identified a problem that an innovation can perceivably help to solve. When the agenda is set, the matching of the innovation with the organizations needs is done. The suggested adoption of the innovation is in other words assessed and design to fit the organization and the problem at hand. If the innovation is accepted by the organization the innovation-process moves to the implementation phase. It is now essential for the organization to restructure, clarify and routinize the organization in regard to the innovation. The organization restructures itself and redefines the innovation to make sure there is a fit between the organization and the innovation. During the process of clarifying, the innovation is put into widespread use within the organization. When all these processes are completed, the organization can make routines regarding how to incorporate the innovation into their operations and business activities (Rogers, 1962).

5.2 The Distributed Ledger

At the heart of the blockchain technology is the shared book of records. Blockchain technology and other similar technologies often go under the shared term of distributed ledger technologies because of this important feature of the technology. The shared book of records is referred to as a distributed ledger because each participant in the network possesses a copy of the ledger and with each new entry into the ledger each copy throughout the network is updated to include that new entry. To get a more detailed understanding of the distributed ledger we can think of it as a row of blocks of information growing in a line at steady speed. This chronological line of blocks is the blockchain. The way these blocks are chronologically interlinked is that the most recent block is always referencing the previous block by including its hash (hashes will be closer examined in chapter 5.6). The fact that it is distributed means that every participant in the network has a copy of the ledger, which they can compare to the copy of the blockchain their peers in the network have, to make sure that every participant is following the rules and updating the ledger in a way that follows a common set of rules.

5.3 Tokens

In any financial transaction there needs to be some form of monetary value. In most cases in Norway these transactions will include the exchange of Norwegian kroner (NOK) for some given good or service. In blockchain systems these monetary values are called *Tokens* and they are one of the essential building blocks for the technology (Nakamoto, 2008). The most famous types of blockchain-tokens are, amongst others, the *Bitcoins* (BTC) of the *Bitcoin*-blockchain and *Ethers* (ETH) of the *Ethereum*-blockchain. In simplified terms a token is the chain of signatures which were provide when the token changed owners throughout its lifetime. Each owner of a token transfers it to the receiver by digitally signing a hash of the previous transaction and the public key of the receiver. This means that a token which had an owner at block zero (also known as the genesis block) would be provable to be that exact token by all the signatures generated when transactions involving that specific token happened up until present time (Antonopoulos, 2017).

Tokens are also what fuels the network. This in the sense that to provide the network with the computational power to run it the participants are compensated with tokens corresponding to how much they contribute to the aggregate computational power of the network. This provides the participants with a strong incentive for helping in keeping the network running.

The tokens described in the paragraphs above are tokens that are native to a blockchain, meaning that they are the predefined, base-currencies for their blockchain. In addition to having native tokens, it is possible to generate asset-backed tokens. A term often used for providing a real-life asset with a blockchain identity is *tokenizing*. Tokenizing is possible with virtually any type of asset. A batch of products, or even single products on a detail-level, prepared for shipping can be provided with a token in the same manner as any type of serial number. These tokenized products can then be included in transactions when they change ownership downstream in a supply chain.

Another interesting aspect of tokens is that they can be pegged to the value of Fiat currencies. This provides the opportunity to exchange tokens during blockchain transactions that are guaranteed to not lose value against the Fiat currency they are pegged to during the exchange. An example of such a project is *Tether* (USDT), which is pegged to the American dollar (Tether, 2014).

5.4 The Blocks

The blocks making up the blockchain are what contains information about transactions. The set of rules in the blockchain (i.e. the blockchain protocol) is what decides how long it should take from one block is added to the chain to the next one is added. In this gap of time a number of transactions might occur and therefore a block might contain a multitude of transactions.

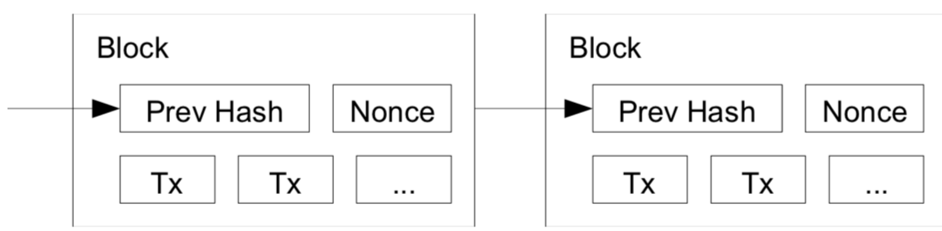


Figure 5.4.1: Each block in a blockchain references the previous block by including its hash (Nakamoto, 2008)

5.5 The Components of a Block

Each block in a generic blockchain consists of a few crucial components. These components are *hashes*, *transactions* (Tx) and *nonces*. They will all be briefly examined and explained in the following chapters. The hashes are essential to linking the blocks in a blockchain together. To provide an unbreakable link between blocks in a blockchain each block references the previous block by including its hash in addition to information about transactions that have taken place since the last block was produced, and a timestamp (provided through the nonce) to prove that the blocks are in chronological order. These hash references go all the way back to the first block ever produced (i.e. block zero, also called the genesis block).

5.6 Hashes and Hash-functions

One of the central cryptographic principles used in blockchain technology is hashes. In simple terms a hash can be viewed as a digital fingerprint of some binary input (Antonopoulos, 2017). This fingerprint works only one way, and if someone possess the fingerprint it is practically impossible to generate the data that was used as input. This fact, together with the fact that a dataset will yield the same identical hash as long as the data is not changed, provides useful properties for the cryptography used in blockchain technology. A hash-function works by taking the binary value of a given set of data and producing a binary output of a given length. This output can then be converted from a string of binary values to a string of hexadecimals. Because of its strength, hashing algorithms such as SHA-256 (Secure Hashing Algorithm producing an output of 256 bits) are widely used today. With these algorithms, any given data input will produce a 256-digit string of ones and zeros as an output. Since 256 bits equals 32 bytes, the output can be converted into a 64-digit string of hexadecimals (one hexadecimal character consists of one half of a byte). Converting to hexadecimals provides increased readability for humans which is beneficial when auditing blockchain identities and transactions manually.

To provide an example, the previous paragraph of text has been run through SHA-256 to give the 64-digit hexadecimal string provided below.

```
9356fc276e53b7aae0cbb99ed7b0fd1d63c90144886161f56e62a686a71cc3fb
```

5.7 Blockchain Transactions and Generating Blocks

To understand the mechanisms at work it is of interest to first understand what happens when someone makes a transaction through blockchain technology. The list below is a step-by-step walkthrough of a transaction happening between participant A and participant B in a blockchain network using simplified terms (Nakamoto, 2008).

1) Participant A sends participant B 10 blockchain-tokens, and broadcasts to the network that the transaction has happened.
2) Everyone in the network puts it into a block.
3) Everyone competes to produce the block (given the rules of the specific blockchain protocol).

4) The first one to successfully produce the block tells all participants in the network.
5) All participants verify the entire blockchain including the newly produced block.
6) If accepted, everyone in the network adds the new block to their copy of the blockchain.

In the general example given above the chronological order of these blocks are what makes up the whole blockchain. Since there might be a great number of participants, it is more feasible to group transactions together in blocks instead of making one block for every single transaction.

To further understand the transaction mechanism, consider the tokens discussed in chapter 5.3. With blockchains as in real life, the currency is sent to the receiving part and the receiving part will split the value so that he receives only the agreed upon amount, sending the rest back as change. This follows the exact same principal as handing a 100 kroner bill for a 50 kroner transaction and getting a 50 kroner bill back as change. The difference lies in what the token actually is. As described in chapter 5.3, a token is the chain of signatures as that specific token changes owners.

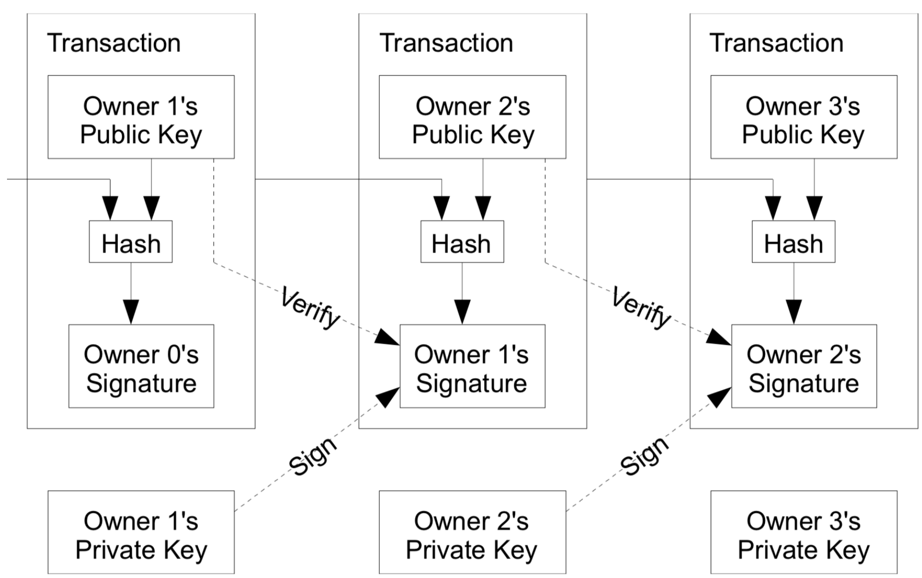


Figure 5.7.1: Sequence of transactions in a blockchain (Nakamoto, 2008)

5.8 Identities on the Blockchain

In a network designed for financial transactions, there is a clear need for identities to know that your transaction is made out to the right counterparty. In addition, there is a need for security so that only you can provide signatures or generate transactions with the tokens at your possession. This is done through using cryptographic principles such as encryption and hashing.

Identities on the blockchain are provided through public-private key pairs. These key pairs make asymmetric encryption possible. Asymmetric encryption makes it possible for two parties to share an encrypted secret without ever having to exchange the key that decrypts the secret (such an exchange run the risk of being intercepted by malicious actors) (Diffie and Hellman, 1976). The blockchain participants provides digital signatures using their private key, which can later be verified by any other participant by matching the signature with the public key.

The way these keys relate to each other is that the private key is used to derive the public key using something called *elliptic curve cryptography*. This is a one-way cryptographic function, making it impossible to derive a private key from a public key. Public keys are further used to derive *addresses* which are used to send tokens to or from. The tokens connected to an address can only be spent by the person possessing the private key from which the address was derived. The key pairs can be used to prove one's identity and therefore to digitally sign transactions, documents or anything else where proof of identity is essential.

6 Discussion

As a consequence of the properties presented in chapter 5, there are multiple reasons why blockchain technology could prove useful in supply chain management. Relative advantage over AS-IS solutions can possibly improve key supply chain management objectives. The objectives that gain an advantage are identified to be quality, cost, sustainability, speed and dependability, in descending order of advantage gained by the technology. Note that flexibility is not included in this list as the improvements to this objective is not as apparent as for the ones mentioned above. In this chapter, the fit for blockchain technology in Norwegian aquaculture supply chains will be discussed, in addition to more general findings on the strategic fit of blockchain technology for different companies' supply chains. Lastly, the main challenges related to blockchain technology are discussed in subchapter 6.4.

6.1 Blockchain Properties and Expected Value

Initially blockchain technology should be classified as either incremental or radical (Ettlie et al., 1984). Incremental innovation is easier to utilize quickly, as the increments bring with them minor changes compared to the disruptive changes radical innovations sometimes bring. Radical innovations appear more suddenly and needs to be addressed by their strategic fit as they first appear. The radical innovations can lead to unforeseen disruptions to whole industries and the ability for a company to adapt to the changes directly reflects the chances for said company to survive (Downes and Nunes, 2013, IBM, 2018). Blockchain technology can be viewed to be a radical innovation, with expectations of disruptions in multiple industries.

As Rogers (1962) defined there are five attributes of innovations. These are, as presented in chapter 5.1, (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability and (5) observability. When assessing the strategic fit of blockchain technology in the supply chain management of Norwegian aquaculture producers, the relative advantage should be analyzed first. In this way it is possible to identify and later assess *why* and *how* blockchain technology might be utilized in supply chain management.

In addition to the five attributes of innovations, the six supply chain management objectives should be used to assess the innovation. In this regard, the first of the attributes (i.e. relative advantage) is used to identify if there are improvements to key supply chain management objectives relative to the situation as it is before blockchain technology is implemented. The relative advantage is systematically presented in tables 6.1.1 through 6.1.5, to show what the relative advantage of blockchain technology means for the key supply chain management objectives. In table 6.2.1 the remaining attributes of the innovation are listed and mapped towards the findings from the research to further understand where there might be challenges or opportunities when implementing the technology.

6.1.1 Effect on Quality

Table 6.1.1:Relative advantage of blockchain technology affecting quality

SCM Objective	Relative Advantage	Argument
Quality	Immutability of records	• Chain of hash-referenced blocks makes it exponentially harder to rewrite earlier blocks (Nakamoto, 2008), making it practically impossible to change the recorded data.
	Enhanced traceability	• Increased supply chain provenance (Galvin, 2017) • High availability of product transaction history (Mathisen, 2017) • Easier to keep detailed records (Ambrosus, 2017)
	Quality assurance	• Possibility of purchasing contracts based on product quality and handling (Ambrosus, 2017) • Can provide data that can be used to assess useful, meaningful and representative indicators for quality (Kshetri, 2018)
	Minimize bureaucracy and streamline document handling	• All documentation can be digitally signed with public-private-keys and registered in the blockchain (Kshetri, 2018) • All documentation can be made available through one digital system (IBM/Maersk, 2017)
	Decentralized power structure	• No information silos at the most powerful actors in the supply chain, leading to higher accessibility of information and easier verification
	Improved information flow	• Decrease in erroneous decision making • Shared records across all supply chain actors (Nakamoto, 2008) • Digital *fingerprinting* of all information exchanges and communications (Turk and Klinc, 2017)
	Low cost system for detailed track-and-trace	• Decrease in recall cost (Mathisen, 2017, Fritz and Schiefer, 2009) • Possible to trace back defect or substandard products to origin, making the identification of the problem easier.
	Better linkage between physical flow and informational flow	• When ownership of physical good changes (e.g. from producer to retailer), the transaction is registered in the blockchain. The resulting chain of blockchain transactions gives a realistic representation of the flow of the goods (Ambrosus, 2017) • Transactions are stored in near real time. Blockchain-stored information is also available to pull instantly (Nakamoto, 2008)
	Decreased chances for fraud	• Easier identification of liability exposes fraudulent supply chain actors (Foerstl et al., 2017) making it possible to avoid situations such as the horsemeat scandal which left consumers with decreased confidence in food suppliers (Barnett et al., 2016)
	Supplier assessment through data available in blockchain	• Information regarding multiple suppliers’ production practices and CSR standards available in one system

One of the main supply chain management objectives expected to be affected by blockchain technology is quality. Blockchain technology offers the possibility of a low cost, detailed system for product identification and record keeping. In addition to be being a system for product identification, blockchain technology has properties that make it possible to both digitally sign contracts and other crucial documentation throughout the supply chain, as well as providing a universal platform for supply chain finance management. With all these operations done through one system, with an open and easily auditable record keeping, both the availability and quality of information can be expected to increase. Increased availability and quality of information is integral to improve other types of supply chain processes. The increased degree of detail in the available information makes it possible to trace back the material flow of defect or substandard products. In this way, the root cause of the defect can be localized quickly, and measures can be taken to improve the quality in production by addressing the root cause. Being able to quickly identify and remove causes of defects or product malfunctions that can be hazardous to the end consumer has a preventive effect for potential negative effects on a company's or brand's reputation (Porter and Kramer, 2006).

In addition, if blockchain technology is combined with sensor systems, attributes such as temperature, pH-values and product contamination can be monitored. In these instances, a sensor-connected farmed salmon can be tracked as it moves from the aquaculture producer and into the retailers shelf (Ambrosus, 2017). The sensor can be programmed to send data regarding the temperature of the fish at short intervals into the blockchain-based record book. When this data is stored in the blockchain they are permanent and cannot be changed at a later point in time. This means that any supply chain actor can access the temperature data regarding the fish product through its unique blockchain identity and audit whether the fish has been out of a predefined range of accepted temperatures. If it has been out-of-range regarding temperature at any point in the supply chain, the liability is easily tied to the supply chain actor which had the product at that specific point in time. In this way the overall process quality can be improved by identifying the weak points in the supply chain quickly and improving them.

Another challenging task for companies is to ensure the quality at their suppliers. For Norwegian aquaculture producers, the final quality of the products depends on the quality of the fertilized eggs that are brought to smolt and the feed that is used throughout the production cycle. Using blockchain technology to audit production practices at the suppliers makes it possible for the aquaculture producers to ensure that the feed and fertilized eggs are consistent with the quality requirements for successful production of Atlantic salmon.

6.1.2 Effect on Cost

Table 6.1.2: Relative advantage of blockchain technology affecting cost

SCM Objective	Relative Advantage	Argument
Cost	Minimize bureaucracy and streamline document handling	• All documentation can be digitally signed with public-private-keys and registered in the blockchain (Kshetri, 2018) • All documentation can be made available through one digital system (IBM/Maersk, 2017)
	Improved information flow	• Decrease in erroneous decision making • Shared records across all supply chain actors (Nakamoto, 2008) • Digital *fingerprinting* of all information exchanges and communications (Turk and Klinc, 2017)
	Low cost system for detailed track-and-trace	• Decrease in recall cost (Mathisen, 2017, Fritz and Schiefer, 2009)
	More focused recall processes	• High traceability on individual product level instead of batch level for food products (Mathisen, 2017) • Recall processes less costly as a consequence of higher precision (Fritz and Schiefer, 2009)
	Ease for regulatory audits	• Regulatory compliance costs can be reduced (Kshetri, 2018)
	Low financial costs	• Financial transactions can be done real time, with low transaction costs (Nakamoto, 2008) • Higher economic sense to generate smaller transactions (Kshetri, 2018)
	Low maintenance cost	• The responsibility of maintenance to the system is not at any single actor, as opposed to centralized server systems

The other main beneficiary of blockchain technology is expected to be the cost objective. As an example, the availability of information regarding demand forecasts can decrease the level of safety stock across the supply network (Forslund and Jonsson, 2007) and with the increased availability and quality of information, fewer erroneous decisions will be made upstream regarding production volume because of demand fluctuations (Zhou and Benton, 2007). In this way the infamous bullwhip effect can be decreased.

For functional products, profit margins are generally low (Fisher, 1997, Lee, 2002). This leads to small percentages in cost reduction having potentially big impact on the company's bottom line (Dahan and Srinivasan, 2011). For this reason, costly investments in detailed traceability systems for functional products are not attractive for producers of functional products. In other words, the benefits of using traceability systems for functional products have not yet outweighed the cost and subsequently the decrease in profit margins. The possibility blockchain technology proposes is a traceability system that brings the increased level of detail without the need for high continued costs. The combination of blockchain technology for recordkeeping and AS-IS solutions for product identification (e.g. barcodes or QR-codes) makes blockchain-based recordkeeping an attractive alternative for detailed track and trace mechanisms in companies where the lean philosophy plays an integral part of the supply chain strategy. In addition, the fact that the responsibility for maintenance of the system no longer is at one single point in the supply chain also has a positive effect on cost, as alternative tracing systems might create such costs for the company.

The implementation of blockchain technology might have several positive effects on the cost structure of production. The possibility to gather all bureaucratic paper flows into one place and allowing parties to sign needed documentation with digital signatures provided their unique blockchain identities can streamline the documentation (IBM/Maersk, 2017). In addition, the fact that audits are easier to conduct when there is extensive records available might help in reducing compliance costs for the companies (Deloitte, 2017).

Another major benefit that is expected from blockchain technology is the increased control during recall processes. For functional products such as food, product safety is a key concern for the consumer (Barnett et al., 2016). When there are outbreaks of foodborne illnesses or there are other major issues with food products that have made it to market, the recall process can bring with it substantial economic impact on a company through both the negative effect on branding and the costs of actually recalling the majority of a specific product line and losing sales (Fritz and Schiefer, 2009). As the key property of blockchain technology is the possibility for extensive recordkeeping and detailed traceability, it is easier to identify the specific batches or products that are affected and needs to be recalled. In that way the recall process can be more focused, and the costs incurred minimized.

In this thesis blockchain technology has mainly been assessed as a technology for recordkeeping, but it is originally a technology built for financial transactions (Nakamoto, 2008). Using stable blockchain tokens (such as tether is an example of, which is discussed in chapter 5.3), it is possible to make financial settlements directly through the blockchain. This has two main implications. First, the cost of each transaction is minimal as there are no need for intermediaries to settle the payment between two participants. This leads to it making more economical sense to generate miniscule financial transactions where needed (Kshetri, 2018). Second, the flow of capital throughout the supply chain is greatly improved as payments on the blockchain are settled near instantly. With this, the cash conversion cycle is shortened, freeing up capital that can be put back in to operations as working capital, possibly leading to increased revenue and profit (Tangsucheeva and Prabhu, 2013, Kroes and Manikas, 2014).

6.1.3 Effect on Sustainability

Table 6.1.3: Relative advantage of blockchain technology affecting sustainability

SCM Objective	Relative Advantage	Argument
Sustainability	Product provenance	• Ethically produced products can be registered with provenance (Ambrosus, 2017, Craik, 2017) • Easier to identify which actor has liability (Mathisen, 2017) • Increased product provenance (Turk and Klinc, 2017)
	Ease for regulatory audits	• All transactions are visible to authorized network participants (Deloitte, 2017) • All accounts identifiable on pseudo-anonymous basis (Deloitte, 2017)
	Decreased chances for fraud	• Easier identification of liability exposes fraudulent supply chain actors (Foerstl et al., 2017) making it possible to avoid situations such as the horsemeat scandal which left consumers with decreased confidence in food suppliers (Barnett et al., 2016)

As a consequence of growing consumer awareness and higher pressure from regulators, sustainability has become a supply chain management objective of increased importance (Ageron et al., 2012). Through the expected quality increase in recordkeeping, it is possible that blockchain technology could prove to have a positive impact on sustainability. With detailed recordkeeping it is possible to provide digital proof that products are produced following ethical standards. Today these standards are presented to the consumer through certification programs (e.g. *Fair Trade*) or through product classifications (e.g. organic or halal foods). In some instances, certification programs might pose a challenge to the consumer to understand what is actually done in the production to qualify for the certification, while for organic or halal foods there is no easy way to get a verification other than the promises from the producer. Through the blockchain-based recordkeeping, consumers could be given access to all product information stored on the blockchain through scannable QR-codes, or similar solutions, on the product packaging. In this way information regarding production processes, origin of raw materials and exact geographical origin of the product can help the consumer in verifying whether the product meets expected standards.

With a new dimension of product information available to the consumer, there is stronger incentive for companies to meet sustainability and CSR expectations of consumers (Porter and Kramer, 2006) and to make sure that there is no opportunistic behavior from upstream actors in the supply chain, leading to decreased consumer confidence (Barnett et al., 2016). With blockchain-based recordkeeping it also becomes possible for consumers to directly audit the books themselves, leading to easier decision making when wanting to buy sustainable products.

6.1.4 Effect on Speed and Dependability

Table 6.1.4: Relative advantage of blockchain technology affecting speed

SCM Objective	Relative Advantage	Argument
Speed	Minimize bureaucracy and streamline document handling	• All documentation can be digitally signed with public-private-keys and registered in the blockchain (Kshetri, 2018) • All documentation can be made available through one digital system (IBM/Maersk, 2017)
	Decentralized power structure	• No information silos at the most powerful actors in the supply chain
	Improved information flow	• Decrease in erroneous decision making • Shared records across all supply chain actors (Nakamoto, 2008) • Digital *fingerprinting* of all information exchanges and communications (Turk and Klinc, 2017)

Table 6.1.5: Relative advantage of blockchain technology affecting dependability

SCM Objective	Relative Advantage	Argument
Dependability	Minimize bureaucracy and streamline document handling	• All documentation can be digitally signed with public-private-keys and registered in the blockchain (Kshetri, 2018) • All documentation can be made available through one digital system (IBM/Maersk, 2017)
	Decentralized power structure	• No information silos at the most powerful actors in the supply chain
	Better linkage between physical flow and informational flow	• When ownership of physical good changes (e.g. from producer to retailer), the transaction is registered in the blockchain. The resulting chain of blockchain transactions gives a realistic representation of the flow of the goods (Ambrosus, 2017) • Transactions are stored in near real time. Blockchain-stored information is also available to pull instantly (Nakamoto, 2008)

The objectives of speed and dependability are interlinked and is therefore discussed together in one subchapter. As the flow of information is improved, each supply chain actor has more readily available data needed for their operations. With faster access to relevant information, decision makers throughout the supply chain can arrive at the best decision earlier, as opposed to either having to make a decision without sufficient information, leading to the possibility of bad decisions, or to wait for the needed information becomes available at the cost of lower speed and dependability.

6.1.5 DOI Attributes of Blockchain Technology

Table 6.1.6: Attributes of blockchain technology (less relative advantage) as defined by Rogers (1964)

Innovation Attribute	Characteristics	Implication
Compatibility	• Dependent on multiple actors using the same technology • Open-source projects make it possible for each actor or third parties to make different GUIs all interacting with the same underlying system (i.e. blockchain) (Buterin, 2013)	Blockchain technology is not highly compatible for firms as they need to operate with the same blockchain protocol.
Complexity	• Lack of available expertise • High theoretical complexity • Lack of intuitive GUIs for SCM applications	The complexity of blockchain technology can be viewed to be high. This creates the need for specialized expertise at companies wanting to implement the technology.
Trialability	• Open-source software • Large-scale trials would require heavy investing	A large number of blockchain initiatives are available as open-source projects. This could lead to high trialability of the technology, but large-scale trials could generate great costs and be time-consuming for companies lowering the overall trialability.
Observability	• Dependent on trial-projects • Open-source software lets any company try it out before deciding to use it	The observability of the technology is high, with the possibility to observe how the multiple open-source projects work. For the observability of specific SC use cases the observability is high as long as it is successfully implemented in trial projects.

The decentralized and distributed structure of the technology makes it a highly collaborative innovation. The expected value from blockchain technology comes from the ability to set an industry standard for record-keeping and making the records immutable, meaning no changes can be done to the records as soon as they are stored in the blockchain. The blockchain works as a shared book of records where any actor can access the provenance of a product. As an example, the end consumer buying a fish filet can scan a QR-code on the packaging of the filet to view the production and logistics processes the final product has been through before reaching the retailer's shelves.

There are some barriers with regards to the technology's compatibility to old systems. In addition, compatibility issues might arise in cases where only a minority of the actors in a supply chain choose to adopt blockchain technology for their record keeping. In these cases, the end consumer might access parts of the provenance of a product, but without complete records the whole meaning of provenance might fall apart.

There are concerns that blockchain technology is too complex for the average consumer or company to use. With the lack of standardized GUIs, the barrier for using the technology is still high. On the other hand, one of the main attributes of the technology is that it is highly collaborative. Most blockchain initiatives are open-source (e.g. Bitcoin, Ethereum and Hyperledger), making it possible for third parties to develop GUIs to interact with them in an intuitive manner.

The fact that most blockchain initiatives are open-source also lowers the barriers for it to be tried in small scale by companies and industries interested in its applications. Proof-of-Concepts can be developed and tried without having to commit to the innovation or invest heavily.

6.2 The Strategic Fit of Blockchain Technology in Norwegian Fish Supply Chains

The advantages blockchain technology was found to give on key supply chain management objectives (table 6.1.1-6.1.5) were mainly affecting the quality, cost and sustainability aspects of operations. Blockchain technology is expected to increase the detail in control of product flows in supply chains (Mathisen, 2017). This property of blockchain technology is one the main reasons why process and product quality can be increased, and costs decreased. When a higher level of control and overview is available for supply chain managers, the job of filtering out substandard products is made easier.

There are some major differences between supply chains operating with the efficient strategy and the responsive strategy. For a lean strategy (i.e. efficient strategy) the objectives mainly focus around reducing cost, while maintaining quality and dependability (Slack et al., 2013). For an agile strategy (i.e. responsive strategy) the importance of flexibility and speed supersedes that of cost-cutting. Because the profit margins are higher for innovative products than for functional products, the consequence of a lost sale justifies higher investments in ways to reduce lead times (i.e. increase speed) and increase flexibility (Fisher, 1997). Notice that both quality, dependability and sustainability are important regardless of supply chain strategy type. These are closely related to customer expectations and in the case of sustainability often to the standards set by industry regulators.

Norwegian aquaculture producers are focused on having low cost, while providing a product of high quality. An illustrative example of this can be seen through the focus of Atlantic salmon producers to cut the cost of feed, which makes up almost half of the total cost structure and to decrease the mortality in fish stocks (i.e. increase process quality). In addition to these major objectives, sustainability stands out as key for Norwegian aquaculture producers. There are multiple institutions with the task of keeping salmon farming sustainable with regards to areal usage, salmon diseases, salmon escapes and total bio mass allowance (MoTIF, 2005, NEA, 1999, SFIH, 2017), to name a few. Among the most central supervisory regulators are the Directorate of Fisheries, the National Environmental Agency, the Norwegian Food Safety Authority, the Norwegian Water Resource and Energy Directorate and the Norwegian Coastal Administration.

In chapter 4, the Norwegian aquaculture supply chain was presented. It is apparent that with fish being a functional product the most fitting for aquaculture producers of Atlantic salmon is to adopt a lean supply chain management strategy. The findings from the case proved this to be the situation. For companies who seek to keep processes lean, the cost and quality aspects of the operations should be in focus (Slack et al., 2013). This implicates that blockchain technology not only is highly fit for aquaculture producers, but for lean supply chains with functional products in general.

Table 6.1.1 through 6.1.5 are used to summarize these findings. In it, the dimensions that are essential when assessing the fit between aquaculture supply chain strategy and blockchain technology are presented. As already discussed, aquaculture supply chains are believed to draw an advantage when using blockchain technology for recording essential information about the product. This is mainly because the blockchain-based system is cheap to run and can store immense quantities of data without the need for a single company to keep information silos through own or rented server systems. In addition to aquaculture supply chains, the findings presented in table

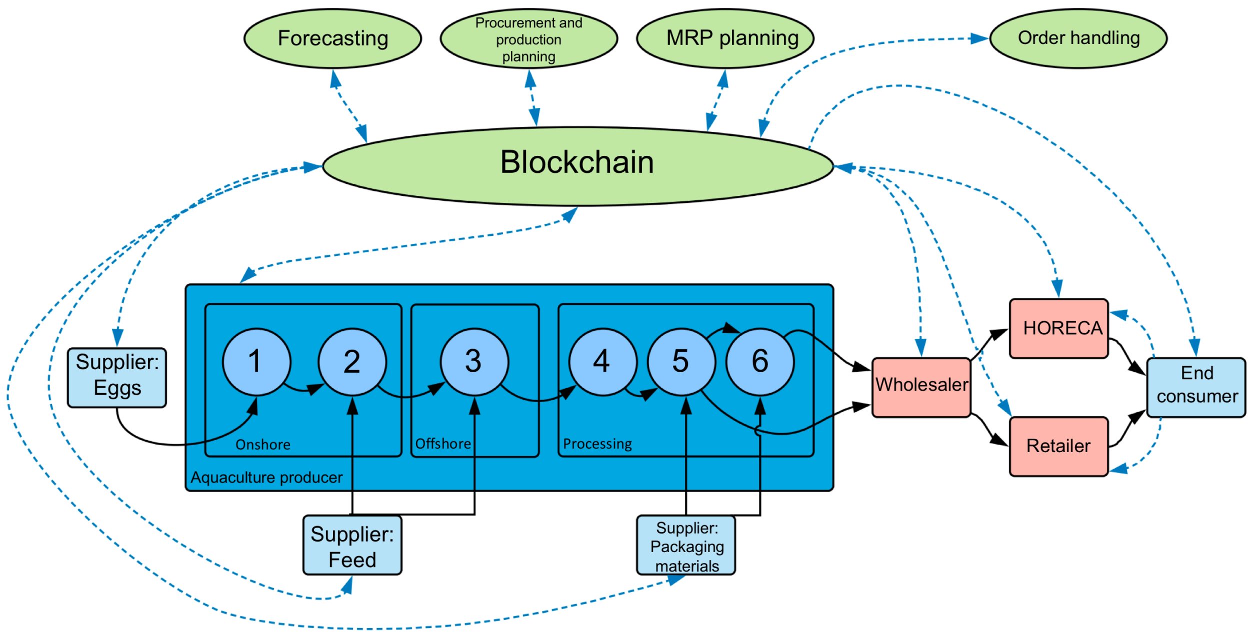
6.1.1-6.1.5 are useful to assess the fit for blockchain technology for any type of company. That is, if a company can identify its supply chain management with the suggestions made in table 6.2.1 below, it might be highly useful to implement blockchain technology for said company. This is a consequence of the expectations of product provenance of functional products such as food from consumers. The consumer wants high standards regarding what they eat, and product provenance is key to provide the consumer with quality assurance. The issue is that systems for detailed tracing data on products might prove costly in food supply chains. With blockchain technology tracing data can be made available for both consumers and supply chain actors without the need for high continued costs.

Table 6.2.1: Characteristics for supply chains that might gain an advantage of using blockchain technology

Product Characterization	**Supply Chain Characterization**	**SCM Objectives in focus (in order of descending importance)**
• Functional product • Long product market life cycle • Low profit margins • Stable and predictable supply and demand dynamics	• Physically efficient processes • SCM following lean philosophy • Food supply chains	• Cost • Quality • Sustainability • Dependability • Speed

6.3 TO-BE Control Model

Based on the AS-IS control model presented in chapter 4.5, a TO-BE control model can be designed. Note that in this control model each arrow indicating an information flow flows both ways (except from end consumer to POS and from blockchain to end consumer), with a blockchain working as an information hub for the whole supply chain. With the central information hub, data regarding both product and demand and material flows can be pushed to the hub and pulled by permissioned supply chain actors whenever needed. To illustrate this, end consumers can access the blockchain to review when and where the fish is produced while suppliers can review demand data directly to be able to better plan their own production.



1: Growth of fish from spawn 2: Smoltification of fish 3: Ongrowing in seawater 4: Slaughtering 5: Primary processing 6: Secondary processing (VAP)

Figure 6.3.1: TO-BE control model with blockchain as information hub

6.4 Limitations and Challenges

A key limitation of the technology is the need for multiple actors in the supply chain to collaborate. To get full advantage from blockchain technology, all the actors in the supply chain have to use the same blockchain protocol to store information about the product moving downstream. There is still the possibility for a single actor in the supply chain to leverage blockchain technology, but to get full provenance of a product, information gathered from all points in the supply chain is needed. Bringing all the relevant supply chain actors together can prove to be challenging. The CEO of Everledger, a company that has created a blockchain-based register for digital certifications of rough cut diamonds, noted that it took about 18 months to negotiate the relationships needed to make a fully functional system for provenance (Kshetri, 2018).

In addition, blockchain technology requires a high degree of computerization. A lot of suppliers of functional products, such as food, are small farmers or capture producers in developing or least developed countries. It might prove challenging for such actors to take part in blockchain registration of their produce (Kshetri, 2018). If, in fact, the information at this point in the supply chain is not registered, the value of the provenance from the rest of the supply chain decreases significantly.

Another barrier which stands out as critical is the degree of complexity that blockchain technology brings. The technology is built on complex cryptographic and mathematical principles making it a challenging technology for potential participants without this skillset. This leads to companies wanting to use blockchain technology for their supply chain either having to invest in internal competencies or pay for access to competencies available through third-parties.

The fact that companies look for ways to protect market shares and revenue leads to the possibility of multiple closed and private blockchains arising. These blockchains will have a lot of the mechanisms that public blockchains have, but operate with less decentralization and openness making them potentially more vulnerable for attack (Casey and Wong, 2017).

In addition, the fact that blockchain technology still has not reached maturity can prove challenging. To invest in something companies might perceive to be experimental might be viewed to carry with it too much risk. Further, the fact that extreme improvements in computing capabilities (e.g. advances in quantum computing) could make the underlying cryptographic principles a lot less secure might prove to be an important challenge in the future.

Lastly, one huge limitation needs to be addressed. The fact is that blockchain technology brings with it the possibility to decrease fraud through the keeping of immutable records regarding information on a highly detailed level. But there will always be the need for human interaction with the system. At this touchpoint between human and machine, there is still room for fraudulent and opportunistic behavior. If opportunistic actors in the supply chain decide to register an event into the blockchain but not conduct the same event in the physical world, this is still possible. The main argument against this is that at each change of ownership of a product downstream, the incentives for the receiving party will be high when liability is more easily identified through the detailed recordkeeping. Regardless, this boundary between the physical and digital worlds keeps being a weakness that is challenging, or even impossible to eliminate.

7 Conclusions

This thesis is meant to assess the strategic fit of blockchain technology as a tool in the supply chain management of Norwegian aquaculture producers. As presented in chapter 6, the theory that was built in chapter 4 and 5, indicated a fit between the technology and the way the Norwegian aquaculture producers manage their supply chains. This fit is mainly a consequence of the improvements to quality and sustainability and decrease in cost that blockchain technology have the potential of bringing. Since cost reduction and quality improvements are central themes to keep efficiency high, the fit of blockchain technology in the supply chain management for lean supply chains is apparent. As a consequence, blockchain technology can be believed to have a high degree of usefulness for Norwegian aquaculture supply chains as they are found to be focused on efficiency, rather than flexibility, with functional products in the form of farmed fish moving downstream.

To assess the usefulness of blockchain technology in the supply chain management of Norwegian aquaculture producers, Fisher (1997) and Lee (2002) was used as a theoretical background to analyze the supply chain. The characterization of product type and supply chain strategy was used in combination with key supply chain management objectives, as found in the literature, to assess if blockchain technology had the potential of improving the same objectives that were believed to be of most importance to Norwegian aquaculture producers. Using theory on innovation (Rogers, 1962), blockchain technology was analyzed with a focus on the potential relative advantage of the technology over AS-IS systems.

An additional finding is that blockchain technology might have benefits for lean supply chains in general. The relative advantage that blockchain technology might provide supply chain strategy (as presented in chapter 6) show that not only fish supply chains, but supply chains where the product is characterizable as functional and the processes physically efficient can draw strong advantages from using blockchain technology. Especially for some functional products, such as foods, there are high consumer expectations regarding quality and safety. At the same time, consumers might not be willing to pay extra for products, to be able to access product provenance data. Blockchain technology might address this issue by providing a system for product provenance without having to sacrifice profit margins.

7.1 Suggested Further Research

There is still scarcity in the academic work on blockchain technology. Most academic work as of today focus on the technology itself, and not the implications it might have in different real-world use cases.

The next step to the research conducted in this thesis should be to quantify the implications blockchain technology might have on supply chain management objectives.

This thesis proposed a way to analyze the fit of blockchain technology in a highly specific setting. Working with the used analysis in this thesis a generalized framework for assessing strategic fit of technologies and innovations might be built. Such a framework could help ease the process for companies to make the decision whether to implement an innovative solution or leave it be, regardless of their supply chain strategy. Such a framework should take into account the specific supply chain management objectives and strategies on one hand and the attributes and properties of the innovation on the other.

8 References

AGERON, B., GUNASEKARAN, A. & SPALANZANI, A. 2012. Sustainable supply management: An empirical study. *International Journal of Production Economics,* 140**,** 168-182.

AGRAWAL, A., MUTHULINGAM, S. & RAJAPAKSHE, T. 2017. How Sourcing of Interdependent Components Affects Quality in Automotive Supply Chains. *Production and Operations Management,* 26**,** 1512-1533.

ALFARO, J. A. & RÁBADE, L. A. 2009. Traceability as a strategic tool to improve inventory management: A case study in the food industry. *International Journal of Production Economics,* 118**,** 104-110.

AMANATIDOU, A., SCHLÜTER, O., LEMKAU, K., GORRIS, L. G. M., SMID, E. J. & KNORR, D. 2000. Effect of combined application of high pressure treatment and modified atmospheres on the shelf life of fresh Atlantic salmon. *Innovative Food Science & Emerging Technologies,* 1**,** 87-98.

AMBROSUS 2017. Ambrosus White Paper. *www.ambrosus.com*.

ANKAMAH-YEBOAH, I., NIELSEN, M. & NIELSEN, R. 2016. Price premium of organic salmon in Danish retail sale. *Ecological Economics,* 122**,** 54-60.

ANTONOPOULOS, A. M. 2017. *Mastering Bitcoin: Programming the Open Blockchain*, O'Reilly.

ASCHE, F., COJOCARU, A. L. & ROTH, B. 2016. The development of large scale aquaculture production: A comparison of the supply chains for chicken and salmon. *Aquaculture*.

ASCHE, F., HANSEN, H., TVETERAS, R. & TVETERÅS, S. 2009. The Salmon Disease Crisis in Chile. *Marine Resource Economics,* 24**,** 405-411.

AUNG, M. M. & CHANG, Y. S. 2014. Traceability in a food supply chain: Safety and quality perspectives. *Food Control,* 39**,** 172-184.

AXTMAN, B. 2006. Ripe opportunities. *Progressive Grocer,* 85**,** 76-80.

BARNETT, J., BEGEN, F., HOWES, S., REGAN, A., MCCONNON, A., MARCU, A., ROWNTREE, S. & VERBEKE, W. 2016. Consumers' confidence, reflections and response strategies following the horsemeat incident. *Food Control,* 59**,** 721-730.

BESKE, P., KOPLIN, J. & SEURING, S. 2006. The use of environmental and social standards by German first-tier suppliers of the Volkswagen AG. *Corporate Social Responsibility and Environmental Management,* 15**,** 63-75.

BHASIN, S. & BURCHER, P. 2006. Lean viewed as a philosophy. *Journal of Manufacturing Technology Management,* 17**,** 56-72.

BRUSSET, X. 2016. Does supply chain visibility enhance agility? *International Journal of Production Economics,* 171**,** 46-59.

BUTERIN, V. 2013. Ethereum White Paper. *https://github.com/ethereum/wiki/wiki/White-Paper*.

CASEY, M. J. & WONG, P. 2017. *Global Supply Chains Are About to Get Better, Thanks to Blockchain* [Online]. Available: https://hbr.org/2017/03/global-supply-chains-are-about-to-get-better-thanks-to-blockchain [Accessed 05.05 2018].

CHRISTOPHER, M. & LEE, H. 2004. Mitigating supply chain risk through improved confidence. *International Journal of Physical Distribution & Logistics Management,* 34**,** 388-396.

CONSTANCE, D. H. & KIRK JENTOFT, M. 2011. Chapter 6 Global productive capital mobility: The case of Chilean farmed Atlantic salmon. *Globalization and the Time?Space Reorganization.* Emerald Group Publishing Limited.

CRAIK, D. 2017. *Case study: How Walmart uses blockchain* [Online]. CIPS. Available: https://www.cips.org/supply-management/analysis/2017/june/case-study-walmart/ [Accessed 15.11 2017].

DAHAN, E. & SRINIVASAN, V. 2011. The impact of unit cost reductions on gross profit: Increasing or decreasing returns? *IIMB Management Review,* 23**,** 131-139.

DELOITTE 2017. Continous interconnected supply chain. *Deloitte,* https://www2.deloitte.com/content/dam/Deloitte/lu/Documents/technology/lu-blockchain-internet-things-supply-chain-traceability.pdf.

DIFFIE, W. & HELLMAN, M. 1976. New directions in cryptography. *IEEE Transactions on Information Theory,* 22**,** 644-654.

DISNEY, S. M. & TOWILL, D. R. 2003. The effect of vendor managed inventory (VMI) dynamics on the Bullwhip Effect in supply chains. *International Journal of Production Economics,* 85**,** 199-215.

DOF 2017. Economic and biological figures from Norwegian fisheries.

DOF. 2018. *Directorate of Fisheries: Statistics* [Online]. Available: https://www.fiskeridir.no/Statistikk [Accessed 18.04 2018].

DOMINGUEZ, R., CANNELLA, S., BARBOSA-PÓVOA, A. P. & FRAMINAN, J. M. 2017. Information sharing in supply chains with heterogeneous retailers. *Omega*.

DOWNES, L. & NUNES, P. 2013. Big-Bang Disruption. *Harvard Business Review,* March 2013.

EISENHARDT, K. M. 1989. Building Theories from Case Study Research. *The Academy of Management Review,* 14**,** 532-550.

EISENHARDT, K. M. & GRAEBNER, M. E. 2007. Theory building from cases: Opportunities and challenges. *Academy of Management Journal,* 50**,** 25-32.

ETTLIE, J. E., BRIDGES, W. P. & O'KEEFE, R. D. 1984. Organization Strategy and Structural Differences for Radical Versus Incremental Innovation. *Management Science,* 30**,** 682-695.

FAO. 2014. *Fishery and Aquaculture Country Profiles - The Kingdom of Norway* [Online]. Available: http://www.fao.org/fishery/facp/NOR/en [Accessed 18.04 2018].

FAO 2015. Fisheries and Aquaculture Statistics. *Yearbook 2015*.

FAO. 2018. *National Aquaculture Sector Overview: Norway* [Online]. Available: http://www.fao.org/fishery/countrysector/naso_norway/en [Accessed 18.04 2018].

FEY M, S. & REGENSTEIN J, M. 1982. Extending Shelf-Life of Fresh Wet Red Hake and Salmon Using CO2-O2 Modified Atmosphere and Potassium Sorbate Ice at 1°C. *Journal of Food Science,* 47**,** 1048-1054.

FISHER, M. L. 1997. What Is the Right Supply Chain for Your Product. *Harvard Business Review,* 75**,** 105-116.

FLYNN, B. B., SAKAKIBARA, S., SCHROEDER, R. G., BATES, K. A. & FLYNN, E. J. 1990. Empirical research methods in operations management. *Journal of Operations Management,* 9**,** 250-284.

FOERSTL, K., SCHLEPER, M. C. & HENKE, M. 2017. Purchasing and supply management: From efficiency to effectiveness in an integrated supply chain. *Journal of Purchasing and Supply Management,* 23**,** 223-228.

FOF 2015. Making Sense of Wild Seafood Supply Chains. *Future of Fish, The Nature Conservancy*.

FORSLUND, H. & JONSSON, P. 2007. The impact of forecast information quality on supply chain performance. *International Journal of Operations & Production Management,* 27**,** 90-107.

FRITZ, M. & SCHIEFER, G. 2009. Tracking, tracing, and business process interests in food commodities: A multi-level decision complexity. *International Journal of Production Economics,* 117**,** 317-329.

GALVIN, D. 2017. *IBM and Walmart: Blockchain for Food Safety* [Online]. https://www-01.ibm.com/events/wwe/grp/grp308.nsf/vLookupPDFs/6%20Using%20Blockchain%20for%20Food%20Safe%202/$file/6%20Using%20Blockchain%20for%20Food%20Safe%202.pdf: IBM. [Accessed 08.03 2018].

GE, H. T., NOLAN, J., GRAY, R., GOETZ, S. & HAN, Y. 2016. Supply chain complexity and risk mitigation - A hybrid optimization-simulation model. *International Journal of Production Economics,* 179**,** 228-238.

GGN. 2018. *Aquaculture and Sustainability II* [Online]. Available: https://aquaculture.ggn.org/en/aquaculture-and-sustainability-ii.html [Accessed].

GLOBEFISH/FAO. 2017. *Salmon market expects global supply boost in second half of 2017* [Online]. Available: http://www.fao.org/in-action/globefish/market-reports/resource-detail/en/c/1052029/ [Accessed 18.04 2018].

GOMM, R., HAMMERSLEY, M. & FOSTER, P. 2000. Case Study Method: Key Issues, Key Texts. Sage Publications.

GREGORY, P. W. 1996. A survey and taxonomy of strategy-related performance measures for manufacturing. *International Journal of Operations & Production Management,* 16**,** 42-61.

GUNASEKARAN, A., LAI, K.-H. & EDWIN CHENG, T. C. 2008. Responsive supply chain: A competitive strategy in a networked economy. *Omega,* 36**,** 549-564.

GUTTORMSEN, A. G. 1999. Forecasting weekly salmon prices: Risk management in fish farming. *Aquaculture Economics & Management,* 3**,** 159-166.

HAHN, C. K., WATTS, C. A. & KIM, K. Y. 1990. The Supplier Development Program: A Conceptual Model. *Journal of Purchasing and Materials Management,* 26**,** 2-7.

IBM. 2017. *The food industry gets an upgrade with blockchain* [Online]. Available: https://www.ibm.com/blogs/blockchain/2017/06/the-food-industry-gets-an-upgrade-with-blockchain/ [Accessed 15.11 2017].

IBM 2018. Insights From the Global C-Suite Study. *IBM Institue for Business Value*.

IBM/MAERSK. 2017. *Digitizing Global Trade with Maersk and IBM* [Online]. Available: https://www.ibm.com/blogs/blockchain/2018/01/digitizing-global-trade-maersk-ibm/ [Accessed 05.05 2018].

KHAN, M., HUSSAIN, M. & SABER, H. M. 2016. Information sharing in a sustainable supply chain. *International Journal of Production Economics,* 181**,** 208-214.

KOUKI, C., SAHIN, E., JEMAÏ, Z. & DALLERY, Y. 2013. Assessing the impact of perishability and the use of time temperature technologies on inventory management. *International Journal of Production Economics,* 143**,** 72-85.

KROES, J. R. & MANIKAS, A. S. 2014. Cash flow management and manufacturing firm financial performance: A longitudinal perspective. *International Journal of Production Economics,* 148**,** 37-50.

KSHETRI, N. 2018. 1 Blockchain's roles in meeting key supply chain management objectives. *International Journal of Information Management,* 39**,** 80-89.

LEE, H. L. 2002. Aligning Supply Chain Strategies with Product Uncertainties. *California Management Review,* 44**,** 105-119.
LIU, Y., ROSTEN, T. W., HENRIKSEN, K., HOGNES, E. S., SUMMERFELT, S. & VINCI, B. 2016. Comparative economic performance and carbon footprint of two farming models for producing Atlantic salmon (Salmo salar): Land-based closed containment system in freshwater and open net pen in seawater. *Aquacultural Engineering,* 71**,** 1-12.
MATHISEN, M. 2017. Blockchain Technology in Supply Chain Traceability Systems. *Project Thesis MTP*.
MEREDITH, J. 1998. Building operations management theory through case and field research. *Journal of Operations Management,* 16**,** 441-454.
METTERS, R. 1997. Quantifying the bullwhip effect in supply chains. *Journal of Operations Management,* 15**,** 89-100.
MORASH, E. A., DRÖGE, C. L. M. & VICKERY, S. K. 1996. Strategic logistics capabilities for competitive advantage and firm success. *Journal of Business Logistics,* 17**,** 1-22.
MOTIF 2005. Law of Aquaculture. *In:* MINISTRY OF TRADE, I. A. F. (ed.). https://lovdata.no/dokument/NL/lov/2005-06-17-79.
NAKAMOTO, S. 2008. Bitcoin: A Peer-to-Peer Electronic Cash System. *www.bitcoin.org*.
NEA 1999. Environmental objectives for Norwegian aquaculture. Report on results achieved for 1997
and 1998 *Directorate for Nature Management,* 1999-7b**,** 41.
NSF 2012. Norske Fiskerier. *Fiskeri- og Havbruksnæringens Landsforening*.
OGLEND, A. 2013. RECENT TRENDS IN SALMON PRICE VOLATILITY. *Aquaculture Economics & Management,* 17**,** 281-299.
PETROVIC, D. 2001. Simulation of supply chain behaviour and performance in an uncertain environment. *International Journal of Production Economics,* 71**,** 429-438.
PORTER, M. E. & KRAMER, M. R. 2006. Strategy and society. *Harvard Business Review,* 84**,** 78-+.
PRESUTTI, W. D. 2003. Supply management and e-procurement: creating value added in the supply chain. *Industrial Marketing Management,* 32**,** 219-226.
RAJASEKAR, S., PHILOMINATHAN, P. & CHINNATHAMBI, V. 2013. Research Methodology. *Cornell University Library*.
RAO, P. & HOLT, D. 2005. Do green supply chains lead to competitiveness and economic performance? *International Journal of Operations & Production Management,* 25**,** 898-916.
RESENDE-FILHO, M. A. & HURLEY, T. M. 2012. Information asymmetry and traceability incentives for food safety. *International Journal of Production Economics,* 139**,** 596-603.
ROGERS, E. M. 1962. Diffusion of Innovations. *New York: The Free Press*.
ROMSDAL, A. 2014. Differentiated production planning and control in food supply chains. *NTNU, Department of Mechanical and Industrial Engineering, ,* Production and Quality Engineering.
ROWLEY, J. 2002. Using case studies in research. *Management Research News,* 25**,** 16-27.
SFIH 2017. Salmon Farming Industry Handbook. *Marine Harvest*.
SHEPHERD, C. J., MONROIG, O. & TOCHER, D. R. 2017. Future availability of raw materials for salmon feeds and supply chain implications: the case of Scottish farmed salmon. *Aquaculture,* 467**,** 49-62.

SLACK, N., BRANDON-JONES, A. & JOHNSTON, R. 2013. Operations Management. *Operations Managment.* Pearson.
STRADMEYER, L. 1994. Survival, growth and feeding of Atlantic salmon, Salmo salar L., smolts after transfer to sea water in relation to the failed smolt syndrome. *Aquaculture Research,* 25**,** 103-112.
STRANDHAGEN, J. O. 2015. How to Make a Control Model. *Norwegian University of Science and Technology, Department of Mechanical and Industrial Engineering*.
STUART, I., MCCUTCHEON, D., HANDFIELD, R., MCLACHLIN, R. & SAMSON, D. 2002. Effective case research in operations management: a process perspective. *Journal of Operations Management,* 20**,** 419-433.
TANGSUCHEEVA, R. & PRABHU, V. 2013. Modeling and analysis of cash-flow bullwhip in supply chain. *International Journal of Production Economics,* 145**,** 431-447.
TETHER 2014. Tether: Fiat Currencies on the Bitcoin Blockchain. [*www.tether.to*](www.tether.to).
TROWBRIDGE, P. 2006. A Case Study of Green Supply Chain Management at Advanced Micro Devices. *In:* SARKIS, J. (ed.) *Greening the Supply Chain.* London: Springer London.
TURK, Ž. & KLINC, R. 2017. Potentials of Blockchain Technology for Construction Management. *Procedia Engineering,* 196**,** 638-645.
VAN DONSELAAR, K., VAN WOENSEL, T., BROEKMEULEN, R. & FRANSOO, J. 2006. Inventory control of perishables in supermarkets. *International Journal of Production Economics,* 104**,** 462-472.
WANKE, P. F. & ZINN, W. 2004. Strategic logistics decision making. *International Journal of Physical Distribution & Logistics Management,* 34**,** 466-478.
YTRESTØYL, T., AAS, T. S. & ÅSGÅRD, T. 2015. Utilisation of feed resources in production of Atlantic salmon (Salmo salar) in Norway. *Aquaculture,* 448**,** 365-374.
ZENG, B. C. & YEN, B. P. C. 2017. Rethinking the role of partnerships in global supply chains: A risk-based perspective. *International Journal of Production Economics,* 185**,** 52-62.
ZHOU, H. & BENTON, W. C. 2007. Supply chain practice and information sharing. *Journal of Operations Management,* 25**,** 1348-1365.
AARSET, B. 1998. Norwegian salmon-farming industry in transition: dislocation of decision control. *Ocean & Coastal Management,* 38**,** 187-206.