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Evaluation of the potential of emerging technologies for the improvement of seafood product traceability

Master Thesis in International Fisheries Management (30 ECTS, June 2020)

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Abstract

New and promising technologies are emerging at an accelerating rate. Their disruptive potential is significant, and they may have a considerable impact on our everyday life and on the socio-economic structures of our society. The use of these technologies may offer valuable solutions in multiple areas such as transportation, health care, energy production, food systems, supply chains or utilization of resources. There is a need to understand both the limitations and the potential advantages of these technologies before they disrupt every aspect of our lives. Authorities, academia, and the private sector show an increased interest in assessing the potential of these technologies in previously unexplored contexts. This thesis aims to explore in a structured way the potential of emerging technologies in the field of seafood product traceability. Functional traceability systems have the potential to ensure efficient and responsible production and sustainability of seafood resources, if implemented across entire supply chains. However, there are several risks and challenges of these systems that need to be addressed in order to maximise the potential of these systems (e.g. interoperability of systems, increased data collection and processing, trust and security issues). Due to the novelty of the topic investigated in this thesis, the nature of research chosen for the study is exploratory. The assessment of the potential of emerging technologies to improve traceability systems is based on inductive reasoning. The study uses secondary data about the two topics collected through an integrative review that also includes grey literature. The emerging technologies included for assessment are data driven; artificial intelligence, autonomous systems, extended reality, internet of things, digital twin, blockchain, 5G, quantum computing. After a comprehensive introduction of both traceability and traceability systems, and of the eight emerging data driven technologies, the thesis connects the two in a conceptual framework. Based on the analysis, the thesis suggests that there is considerable potential for these technologies to improve seafood product traceability. At this time, blockchain and the internet of things have the most substantial contribution to the domain of traceability. An important observation is that not a single technology is able to bring improvements by itself. There is a high interdependency between the technologies, meaning that ideally some of them would have to be implemented together in traceability systems in so called compositional architectures, which combine existing and emerging technologies in order to create best solutions. Transparent and trustworthy seafood product supply chains, improved data collection, increasing data processing capabilities, predictive algorithms, better decision making, reliable connection and virtualization of the product life cycle are just a few among the possible benefits of emerging data driven technologies in the new application domain of traceability. The results of this thesis can be used by several stakeholders in the seafood sector, among which: food business operators who are considering improving their traceability systems; authorities, associations, and organisations involved in the surveillance and monitoring of seafood supply chains; technology providers who are looking for new application domains.

Key words: 5G, *artificial intelligence, autonomous systems, blockchain, digital twin, emerging technology, extended reality, food, internet of things, seafood, traceability, quantum computing*

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ABBREVIATIONS

API – Application Programme Interface

CTP – Critical Traceability Point

EDI – Electronic Data Interchange

ERP – Enterprise Resource Planning

FAO – Food and agriculture organization

FBO – Food business operator

GDST – Global Dialogue on Seafood Traceability

IoT – Internet of Things

IUU – Illegal, Unregulated and unreported fishing

KDE – Key data elements

NGO – Non-governmental Organization

SME – Small Medium Enterprise

TRU – Traceable resource unit

TS – Traceability system

TU – Trade Unit

WHO – World Health Organization

VAN – Value Added Network

1. INTRODUCTION

1.1 BACKGROUND AND RESEARCH QUESTIONS

New and promising technologies are emerging at an accelerating rate. Their disruptive potential is significant, and they may have a considerable impact on our everyday life and on the socio-economic structures of our society. The use of these technologies may offer valuable solutions in multiple areas such as transportation, health care, energy production, food systems, supply chains or utilization of resources. There is a need to understand both the limitations and the potential advantages of these technologies before they disrupt every aspect of our lives (NOU, 2019, p. 125). Emerging technologies offer countless opportunities as they have the potential to enable and improve existing technologies and business models, transform key industries, and sustain natural ecosystems (DNV GL, 2020). Virtualization enables collaboration and flexibility, automation allows saving time and energy and reducing risk, digitalization and improved data processing capabilities allow for insight into areas of limited knowledge. Authorities, academia, and the private sector show an increased interest in assessing the potential of these technologies in previously unexplored contexts. Against this backdrop, this thesis aims to explore the potential of emerging technologies in the field of seafood product traceability.

Seafood products are among the most traded food commodities in the world (for example, approximately 35% of all seafood production was traded internationally in 2016 (FAO, 2018)). Such big volumes of trade come at a price, as continually increasing demand puts enormous pressure on the limited marine resources. As a result, it has been estimated that large amounts of seafood in the global market come from illegal, unreported, and unregulated (IUU) fishing practices (Macfadyen et al., 2019). Seafood fraud and IUU fishing are international concerns and, the global scale of supply chains adds to the complexity. Mislabeling and substitution of the seafood products are a common type of fraud throughout entire supply chains (Bora et al., 2019). In order to address these problems, a series of measures were put in place by bodies such as the European Union (EU) or the Food and Agriculture Organisation of the United Nations (FAO UN) (e.g. the EU IUU Regulation 1005/2008) (Borit & Olsen, 2012), the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (Macfadyen et al., 2019)). These measures promote the implementation of traceability systems throughout the seafood supply chains as a means to document sustainability. Building up on these regulatory requirements and several other drivers, ranging from production optimization to product quality assurance (Borit & Olsen, 2016) (for a summary of traceability drivers and benefits of implementing traceability systems in product supply chains see Appendix 1 & 2), in the recent years seafood Food Business Operators (FBOs) have given increased attention to traceability (e.g. the recently established initiative of the Global Dialogue on Seafood Traceability (GDST, 2020)). Functional traceability systems have the potential to ensure responsible production and sustainability of seafood resources if implemented across entire supply chains (for a summary of benefits of implementing traceability systems in product supply chains see Appendix 2). Nevertheless, despite increased pressures from consumers and non-governmental organizations (NGOs), many FBOs opt for the minimum functionality needed to meet traceability legal requirements. As such, presently, many traceability systems in the seafood industry are limited to the possibility of following the product in the supply chain only one link forward and one link backward (Borit & Santos, 2015). Therefore, there is a clear need for functional, transparent, and trustworthy sea to plate traceability systems in the seafood industry.

Technological developments may provide valuable solutions to a number of traceability challenges. Emerging data driven technologies can offer multiple improvements to the existing traceability systems, increasing trust and transparency in fisheries (Probst, 2019). Currently there are a couple of emerging technologies at the forefront of the discussion: Internet of Things (IoT) and Blockchain (Astill et al., 2019). Both technologies offer multiple benefits to the traceability systems when it comes to gathering data across the supply chains or documenting transactions along the chains. However, there are several emerging technologies that have not been assessed with regards to their potential to improve traceability. The aim of this thesis is to fill this gap by providing a structured assessment of several emerging technologies and their potential application in seafood traceability systems. Due to the limitations imposed by the size of this MSc thesis (30 ECTS), this study focuses primarily on emerging data driven technologies, i.e. artificial intelligence, autonomous systems, extended reality, internet of things, digital twin, blockchain, 5G, quantum computing. Thus, this study will not consider other types of technologies, e.g. biotechnology, nanotechnology or spectroscopy, some of which are used in the verification of claims recorded in the traceability systems. The purpose of this thesis is to provide a better understanding of the emerging data driven technologies and their potential to improve seafood traceability. Such an assessment might provide FBOs additional incentives to invest both in such technologies and sea to plate traceability systems.

Research Questions

1. What are the risks and challenges within food/seafood product traceability systems?
2. What are the latest emerging technologies relevant to food/seafood industry?
3. What is the potential of these technologies to address the limitations and challenges of food/seafood product traceability systems?

Firstly, the thesis explores the concept of traceability, traceability systems, and the multiple challenges such systems currently face. Secondly, it focuses on building a systematic way to evaluate emerging data driven technologies. The first two steps will allow answering research questions (1) and (2). Thirdly, with the intention of answering research questions (3), this study will evaluate the potential of each of the emerging technologies with regards to their ability to address traceability risks and challenges.

1.2 STRUCTURE OF THE THESIS

CHAPTER 2 provides an overview of the general approach and specific methods used to conduct this study.

CHAPTER 3 focuses on traceability; it provides definitions and a conceptual framework of food product traceability. The chapter provides detailed descriptions of traceability system (TS) components and a comprehensive overview of TS risks and challenges. This chapter creates a basis for evaluation of the emerging technologies with regards to their applicability in seafood product traceability.

CHAPTER 4 describes a number of emerging data driven technologies. Each technology is defined and described with regards to their characteristics: functionality, architecture/components, implementation, ownership, and impact.

CHAPTER 5 is investigating how relevant each of the technologies described in Chapter 4 are with regards to improvement of traceability. This chapter explores what traceability challenges could potentially be addressed by incorporating the emerging data driven technologies.

CHAPTER 6 discusses the findings, the limitations of the study and puts forward propositions of further research.

CHAPTER 7 provides concluding remarks.

1.3 DISCLAIMER

The author of this study is not an expert in either traceability or emerging data driven technologies. The author had no previous knowledge of these concepts in the beginning of the study except the general knowledge gained through non-academic channels. Thus, the information, the analysis, and the conclusions of this study have to be treated with caution, as they are limited by the understanding that the author was able to reach during the short time of the study and within the interaction limitations imposed by the measures taken in place to minimize the spread of the corona virus in Norway in the period from the beginning of March 2020 to the time this thesis was submitted (June 2020). The author of this study has been motivated to dive into the unknown domains of traceability and emerging data driven technologies by the desire to learn more about these exciting domains and to perform a study with applicability in the seafood industry and that builds on a subject that currently takes a considerable amount of space in the attention of the society. (i.e. the impact of emerging data driven technologies on our society).

2. METHODOLOGY

2.1 GENERAL APPROACH

Exploratory study

Due to the novelty of the topic investigated in this thesis, the nature of research chosen for the study is exploratory. Exploratory research or study design "is an examination into a subject in an attempt to gain further insight" (Winterton, 2008, p. 23). It provides a grounded setting for an exploration of a topic that either lacks theoretical refinement or has not been previously explored. This type of research is often used as a way of generating new ideas and it is specifically valuable when trying to clarify an understanding of a problem and build a necessary fundament for further research (Saunders et al., 2009). Exploratory studies allow for a certain level of flexibility and creativity.

Inductive research

The assessment in this study is based on inductive reasoning, "Inductive reasoning entails using existing knowledge or observations to make predictions about novel cases" (Hayes et al., 2010, p. 278). Inductive research is designed in a "bottom-up" manner, as supposed to a "top-down" approach, which relies on hypothesis testing (Woo et al., 2017, p. 255). Inductive research allows for the exploration and discovery of study fields in which the theory is not yet fully established. Although the concepts of traceability and emerging data driven technologies have been studied separately, their joined exploration is very limited. Inductive research will enable to bridge the gap between the two concepts and create a common approach for evaluating emerging data driven technologies against their potential application in traceability. Inductive research requires a certain level of creativity due to the novelty of the topic. The assessment is built on the knowledge of traceability risks and challenges exemplified in sections 3.4 and 3.5, and the understanding of technologies' functionalities and application presented in section 4. The research aims to explore a new field rather than confirm a pre-existing hypothesis. "Good science is as much about discovery as it is confirmation." (Woo et al., 2017, p. 263).

Secondary data

The thesis makes use of secondary data that were collected through a desktop study. Secondary data collection makes use of material that has been produced by someone else and this may include journal articles, books, and online resources coming from commercial or professional entities (Walliman, 2018). The use of secondary data allows the researcher to create a necessary background for the study and a setting for further exploration.

2.2 SPECIFIC METHODOLOGY

Integrative review

Integrative reviews aim to synthesize and assess existing literature on a given topic in a manner that will enable the creation of a new theoretical or conceptual perspective (Torraco, 2005). The method of integrative review can be used to address new emerging topics that often require a creative approach to data analysis as the aim of the method is not to review all existing articles on a given topic but rather combine the most important ideas and perspectives in a structured way (Snyder, 2019, p. 336). Such review should result in a new conceptual framework.

Conceptual framework

Conceptual framework can be defined as a "network of interlinked factors, ideas or variables that together provide a comprehensive understanding of a phenomenon or phenomena"(Jabareen, 2009; Miles & Huberman, 1994). Every concept is made up of a number of underlying components. Through visualization and narrative description, the conceptual framework is are able to illustrate the relationships between these components. The purpose of a creating conceptual framework is to expand the understanding of a particular area in order build a necessary foundation and create a setting for further research. This study explores the fields of traceability and emerging data driven technologies. Exploring the two fields and combining them enables a creation of a conceptual framework proving an insight into how the two domains can be bridged.

Grey literature

Due to the novelty of some concepts discussed in this thesis, the use of grey literature (*Figure* 1) has proven to be a good source of information in areas where the academic or "white" literature is lagging behind. "Grey literature is produced on all levels of government, academics, business and industry in print and electronic formats, but which is not controlled by commercial publishers, i.e., where publishing is not the primary activity of the producing body" (Garousi et al., 2019). Grey literature has received a lot of enthusiasm especially in the field of technology (Garousi et al., 2019). However, it is still a highly debated concept among researchers. The lack of controlled environment under which the grey literature is created and published can significantly affect the credibility of the data. Inclusion of such literature in academic work must therefore be reasonably justified. Grey literature such as white papers, technical reports, blogs or Questions and Answers sites can prove to be a valuable source of information. Such literature is often based on experience and can deliver important up to date insight into user and provider perspective. The use of technical reports or expert opinion from technology providers has demonstrated to be particularly beneficial when collecting data with regards to emerging data driven technologies presented in Chapter 4.

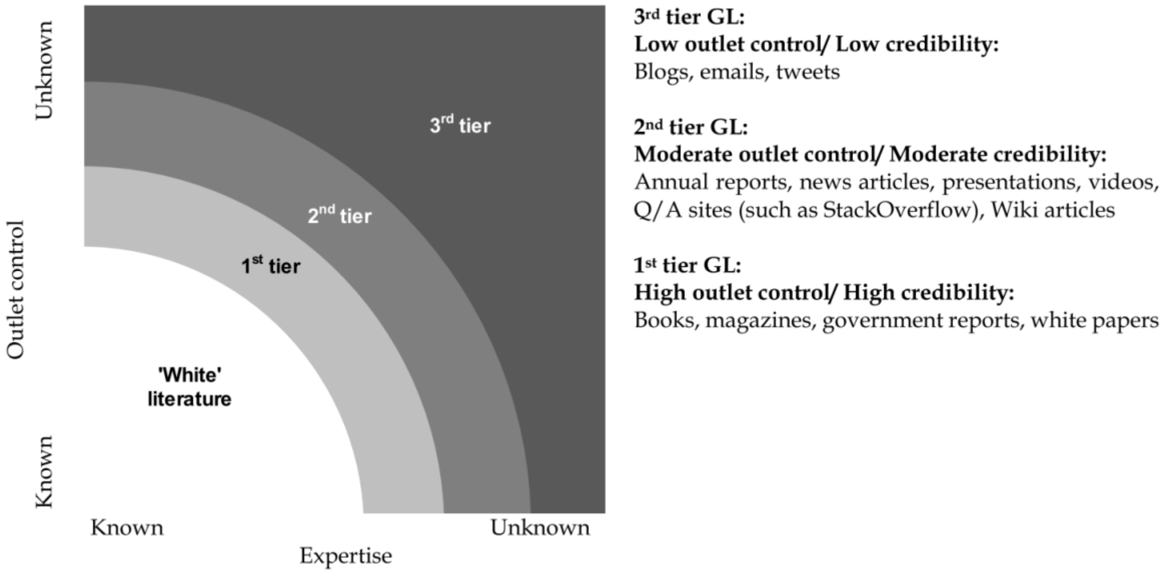


Figure 1 "Shades" and examples of grey literatures (GL) taken from (Garousi et al., 2019, p. 4)

3. TRACEABILITY AND TRACEABILITY SYSTEMS

In order to appropriately evaluate the potential of the emerging data driven technologies to address traceability problems, one must first describe the field of traceability itself. This chapter describes the theoretical and conceptual framework of traceability and traceability systems with focus on seafood products. Furthermore, it provides a review of data driven technologies used in traceability systems, as well as a detailed evaluation of risks and challenges of traceability systems.

3.1 DEFINITIONS, TERMS, AND CONCEPTS

Traceability is a term that belongs to the field of information logistics and considers the flow of the product and product related information both within a company and between different companies. Due to the widespread use of the term in different domains and by different stakeholders (policy makers, academia, FBOs, non-governmental organisations etc.), there is no general agreement with regards to the definition of traceability. Moreover, many of existing definitions of traceability suffer from numerous limitations (Olsen & Borit, 2013). The use of recursive verbs in definitions was a common problem (e.g. traceability is the ability to trace). The definition of traceability developed by Olsen & Borit (2013) particularly stood out from the rest, as the authors carried out a systematic literature review of scientific articles, legislation and standards relating to traceability of food products. Based on the results of the review, the authors were able to develop a comprehensive traceability definition that is used in this thesis (*Table 1*).

"The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications" (Olsen & Borit, 2013, p.148).

Table 1 Breakdown of the traceability definition followed by this thesis (Olsen & Borit, 2013, p.148)

Verb phrase	*ability to access*
Properties	*any or all information*
Trace what	*that which is under consideration*
Trace where	*through its entire life cycle*
Trace how	*by means of recorded identification*

In order to avoid confusion and linguistic difficulties associated with traceability, its components, and related concepts, a several terms are defined in this section (*Table 2*).

Table 2 Key terms and concepts associated with traceability (Olsen, 2017)

Batch	Batch can be defined as a "quantity of material prepared or required for one operation" (Borit & Olsen, 2016). It is an internal term and can differ from business to business. Separation of batches can be achieved either in space or time (Dillon & Derrick, 2004, p. 12), for example it can be associated with the time period during which the production took place e.g. one hour, one shift or one day or through physical separation for example in containers.
Chain of Custody (COC)	The set of measures, which is designed to ensure that the eco label product on the market comes from a certified fishery (Borit & Olsen, 2016). The COC is usually concerned with one important attribute and its purpose is to make sure that this attribute has been retained. This concept is often confused with traceability; therefore, it is important to make this distinction.
Supply vs Value Chain	Seafood supply and value chains can be very dynamic and the inclusion of a large number of stakeholders with different values and often conflicting objectives means that the relationships within the supply and value chains can be particularly complex. It is important to differentiate between the supply and value chains. Supply chain refers to the physical flow of the product, it is the integration of all activities that directly assist in the production process. Such activities can include extraction of raw materials, processing or logistics. Whereas, the value chain can be defined as a series of activities, which do not directly influence the physical state of the products. The traceability system follows the physical flow of the product, nevertheless, implementation of a TS can in fact add value to the products.
Traceable Resource Unit (TRU)	Traceable resource unit (TRU) refers to a unique unit or "that which is under consideration", the TRU is often a tradeable unit and FBOs are interested in recording its attributes or properties for the purpose of traceability (Olsen, 2017). TRU can come in different forms such as a single bottle, a case or a container. Meaning that all objects referred to as one TRU will have the exact same properties, originate from the same source and have been processed at the same time.
Trade Unit (TU)	Trade unit is a quantity of a product or service that is priced, ordered or exchanged between business partners. Trade units are usually transformed during the production process, they can be joined, split, mixed or transferred.

In order to fully understand what traceability is, what are the risks and challenges of traceability systems, and how they could be addressed, it is important to distinguish between the concepts of internal traceability and chain traceability.

INTERNAL TRACEABILITY

Internal traceability refers to the ability to access information relating to the traceable resource unit (TRU) within a single company or a single link along the chain. Internal traceability can be very advantageous (Storoy et al., 2013, p. 42). It enables companies to have a detailed overview of its own processes, allowing them to identify causal relationships and possible problems (such as the recall of a contaminated product). Internal traceability is the necessary foundation upon which the chain traceability can be built.

CHAIN TRACEABILITY

Chain traceability (also referred to as external traceability) refers to the information about the TRU that is shared between links or companies along the supply chain. It relies on single companies to record the data and making them available to their business partners, therefore, chain traceability depends on the robustness of internal traceability. The Food and Agriculture Organization (FAO) further explains that the implemented food chain approach means that "the responsibility for the supply of safe, healthy and nutritious food is shared along the entire food chain – by all involved with the production, processing, trade and consumption of food" (Ababouch et al., 2005, p. 5).

There are two ways of distributing the information.

1. The information follows the TRU along the supply chain. This is often practiced in situations where information about early production stages aims to reach the consumer (Moe, 1998). This is also referred to as "information push" and it is the most common practice (Olsen, 2017.) Nevertheless, "information push" may cause information overload, which will in the end cause information loss as companies are unable to process it.
2. The TRU is sent along with an identification code, meaning that the company receiving the product can access the information upon request while it remains stored locally with the seller. Olsen, (2017) refers to this as "information pull", it allows for access to information of one link in the chain at a time. Such systems usually work through the facilitation of intranet, and it deals with the problem of information overload.

Sharing of data between businesses adds to the complexity of traceability and it raises issues of confidentiality and data protection. Furthermore, it requires cooperation and agreements between the companies as well as compatibility of the traceability systems in place. Moreover, unlike internal traceability, chain traceability requires set standards to enable the information exchange between businesses (Bosona & Gebresenbet, 2013, p. 42). Nevertheless, there are many advantages of chain traceability such as increased improvement of supply chain management, efficiency of product recalls, increased quality and control, avoidance of repeating the measurements of the same properties (Mai et al., 2010).

3.2 COMPONENTS OF A TRACEABILITY SYSTEM

The components of a traceability system have been conceptualized by Olsen & Borit (2018). These authors have provided a detailed structure and description of the key components of a food traceability system (*Figure 2*). This framework is a good basis for modelling problems and designing component specific solutions.

These components are:

(1) mechanism for identifying the TRU under consideration

(2) mechanism for documenting transformations, i.e. joining or splitting of TRUs

(3) mechanism for recording the attributes of the TRUs.

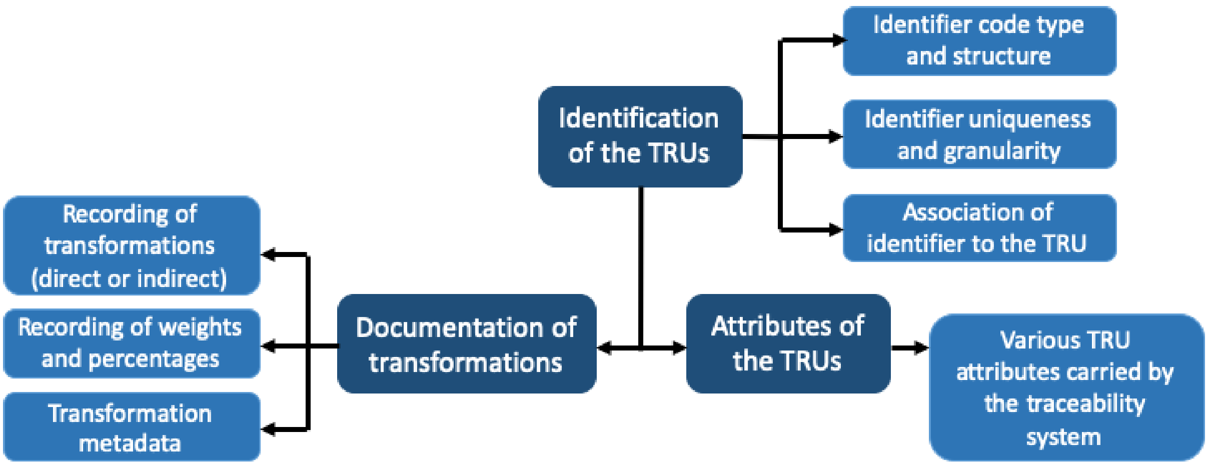


Figure 2 The components of a traceability system. From (Olsen & Borit, 2018). TRU – traceable resource unit.

3.2.1 IDENTIFYING THE TRACEABLE RESOURCE UNIT (TRU)

The fundamental principle of TS is the ability to identify the TRU one would like to know more about. The remaining two components of the TS, strongly rely on TRU and process elements to be unambiguously identifiable (Kemény & Ilie-Zudor, 2016, p. 50), in other words for the TRU to be identifiable it needs to be associated with a unique identification code.

3.2.1.1 IDENTIFIER CODE UNIQUENESS AND STRUCTURE

The codes can be created from both number and letters and their purpose is to both identify and describe the TRU. Guidelines for creating such codes are provided by an international, non-profit organization - GS1[1]. The GS1 symbology includes a prefix called Application Identifier, which explains the code and what information is included (Storoy et al., 2013, p. 43). There are many identification keys proposed by the GS1, however, there are two keys of particular use in the seafood industry. The

[1] https://www.gs1.org

Global Trade Item Number (GTIN), which enables unique identification of any items traded business to business, and the Serial Shipping Container Code (SSCC), which is the unique identification of Logistic Units such as containers or pallets. In order to further identify groups of trade items the GTIN must be supplemented with a batch number, serial number or date and time of production. Global Dialogue on Seafood Traceability recommends the following codes LGTIN and SGTIN. LGTIN is a unique code identifying the same lot/batch, for example cans of tuna belonging to the same production batch will have the same code. SGTIN is a Serial GTIN, in this case each can of tuna will have a globally unique code (GS1, 2017).

3.2.1.2 GRANULARITY

As explained in Borit and Olsen 2016, granularity refers to the amount of product referred to by the TRU identifier. Granularity depends on the physical size of the TRU; the smaller the TRU the smaller the granularity. Granularity plays an important role in the precision of the traceability system (Asioli et al., 2014). When implementing a traceability system, companies have to make a decision on the wanted granularity. A fish processing company can typically choose whether they assign a new production batch number every day, every shift (e.g. 2-3 times per day) or every time they change raw materials (e.g. 1-20 times per day). The lower the granularity, the more TRUs they will have, the more work will be involved, and the more accurate the traceability system will be. Granularity can be a particularly important consideration when planning for potential product recalls; the larger the granularity (i.e. coarser) the more products will have to be recalled if anything goes wrong. Finer granularity can be very costly for the FBO, resulting in the adoption of coarser granularity (Karlsen et al., 2012).

3.2.1.3 ASSOCIATION OF IDENTIFIER WITH TRACEABLE RESOURCE UNIT

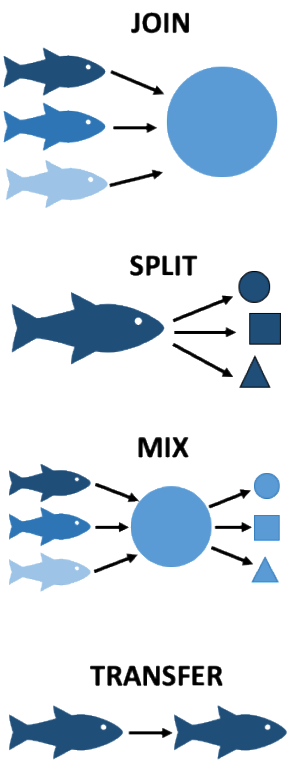
Associating the code with the TRU can be done in a number of ways. The oldest and most common practice is simply labelling or marking the product manually. Up to this day some TS are paper-based or require human intervention in capturing the data and processing it (Kemény & Ilie-Zudor, 2016, p. 50). However, the human intervention is often a source of errors and can be very time consuming. The development of optical identification technologies such as barcodes, RFID (Radio Frequency Identification) or QR (Quick Response) codes meant that the TRUs can now be identified through machine readable codes, speeding up the process and reducing the room for errors. The amount of information that is displayed on the TRU or its packaging will depend on the product itself and the stage of the supply chain.

3.2.2 DOCUMENTING TRANSFORMATIONS

Transformations are point along the supply chain situated between companies or within a single company, during which the TRU is altered in any way. In order to have full access to all the information regarding the TRU, we must document these instances at all stages of the supply chain. Transformations are often considered Critical Traceability Points (CTP). The CTPs are points along the supply chain where there is increased probability of information loss. However, information loss could also occur due to repackaging or removing and placing a new label. It is critical to maintain links between the physical trade unit and the flow of information associated with it through its entire life cycle. The processing infrastructure must record place and time to create a sequence of transformations, events and relations to other entities (Kemény & Ilie-Zudor, 2016; Monostor et al., 2010).

3.2.2.1 TYPES OF TRANSFORMATIONS

There are a few main types of transformations, joining, splitting, mixing and transferring (*Figure* 3), however, these will occur repeatedly throughout the supply chain meaning that keeping record is very important as the supply chain becomes complex.



Joining – joining happens when a number of different input TRUs are combined together into one output TRU, e.g. three species of fish are put together to create a fish cake.

Splitting – splitting occurs when one input TRU is divided into a number of outputs, e.g. one whole fish is cut into smaller pieces and packed into separate boxes

Mixing – mixing takes place when a number of input TRUs are combined together in different amounts to create a number of output TRUs. E.g different species of fish are combined and packed into separate boxes of different sizes

Transferring – transferring happens when one input TRU stays in one piece and becomes an output TRU, e.g. a fish is sold to a buyer without being processed

Figure 3 Types of transformations, From (Donnelly et al., 2009, p. 69; Olsen & Borit, 2018, p. 146)

One product can go through a large number of transformations before making it to the consumer. *Figure 4* represents a simplified traceability tree, where we can see the journey of TRU 1A through four stages of the supply chain. At stage one TRU 1A is **split** into two equal parts, one part creates TRU 2A while the second part is **joined** together with TRU 1C to create TRU 2AC. TRU 2A is then directly **transferred** to TRU 3AC and joined together with TRU 2AC. As TRU 1A travels through the chain, it eventually ends up in all four of the final TRUs. An important driver for recording the transformations is food safety. For example, in the event of mislabelling TRU 1A and not mentioning that it contains an allergen such as lactose, all TRUs with any amount of 1A need to be either recalled or the FBOs must be informed about the error and should mention lactose in the list of ingredients. In terms of food safety, the most important aspect of the TS is the knowledge of the ancestors and progeny of the TRUs. For example, at any point in the supply chain we need to have access to information about how the TRU came into existence, tracing back to the beginning of the supply chain, and what TRUs were produced out of the TRU in question, tracking all the way forward to the end of the supply chain. Despite the simplified representation of the tree (*Figure 4*), mapping of all the connections may not be possible. Current traceability systems tend to work on a one-link and one-link basis making it hard to achieve transparency throughout the whole chain. Skoglund & Dejmek (2007) emphasize the importance of fuzzy traceability, meaning that one has to recognize the possibility that an unintended ingredient being present in the output TRU and must adapt to such instances. A common way of dealing with such uncertainties is simply labelling the product in a way that will minimize the risk, e.g. “This product may contain milk”.

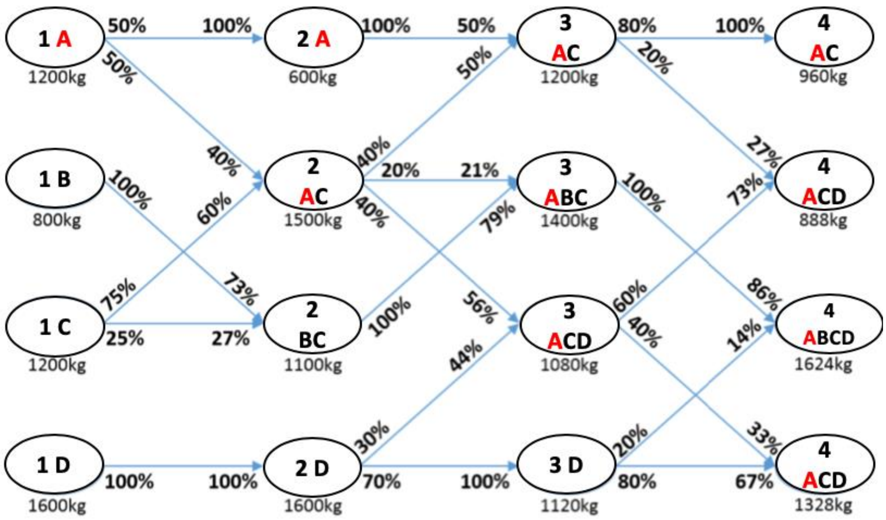


Figure 4. An example of a simplified traceability tree modified from (Olsen & Borit, 2018)

3.2.2.2 DIRECT OR INDIRECT TRANSFORMATIONS

It is important to understand the difference between direct and indirect recording of transformations. In an ideal world all transformations would be recorder directly where we know exactly what were the input TRUs identifiers, and the output TRUs identifiers (Olsen & Borit, 2018, p. 146). However, a common practice in the food industry when dealing with large amounts of products, especially of liquid nature, is that many input TRUs are added into one big container and in the meantime many output TRUs are created. What remains unclear is the amount and type of transformation that took place over this period of time. Therefore, the transformation is recorded indirectly once the container is emptied and cleaned, and a new process of mixing starts. Indirect recording of transformations leaves a lot of room for error.

3.2.2.3 RECORDING OF WEIGHTS AND/OR PERCENTAGES

Systematic recording of weights and/or percentages can be beneficial for the FBO. Knowing what goes into each TU can help to uncover relationships and dependencies (Storoy et al., 2013, p. 44). For example, in *Figure 4*, one can see that TRU 2D is composed of only one ingredient TRU 1D. This would suggest a high dependency, meaning that if the supply of 1D is discontinued the FBO will be unable to produce 2D. Discovering such dependencies can help protecting the business. Furthermore, as weights and/or percentages are recorded it will be possible to create industrial statistics. Having access to such information will help to better understand and optimize the production processes (Olsen & Borit, 2018, p. 47).

3.2.2.4 TRANSFORMATIONS METADATA

Recording of the transformations requires collection of data. Such data is referred to as metadata and it aims to provide a full description of what happened to the TRU, how, where, when it happened and duration of the transformation. An example of a "what" would be transportation of ingredient from supplier or reception of ingredient (Olsen & Aschan, 2010). Metadata can also include environmental factors such as temperature or pressure, location, duration of the transformation.

3.2.3 ACCESS TO THE TRACEABLE RESOURCE UNIT'S ATTRIBUTES

Successful identification of the TRU facilitates the ability to document transformation and record all necessary attributes. Attributes represent important characteristics of the TRU, examples of attributes can be found in *Figure 5.* Collecting data about the TRU attributes and the ability to share and access these is of most interest to the FBO. The TS carries various types of data required for regulatory, commercial and food safety/quality purposes (Epelbaum & Martinez, 2014). The attributes are often referred to as Key Data Elements (KDE) (Future of Fish, p. 12). It is important to emphasize, that all of the attributes recorded through the traceability system cannot be treated as facts. The traceability system ensures the access to information, however, whether this information is true is another issue. Therefore, each attribute must be treated as a claim rather than a fact.

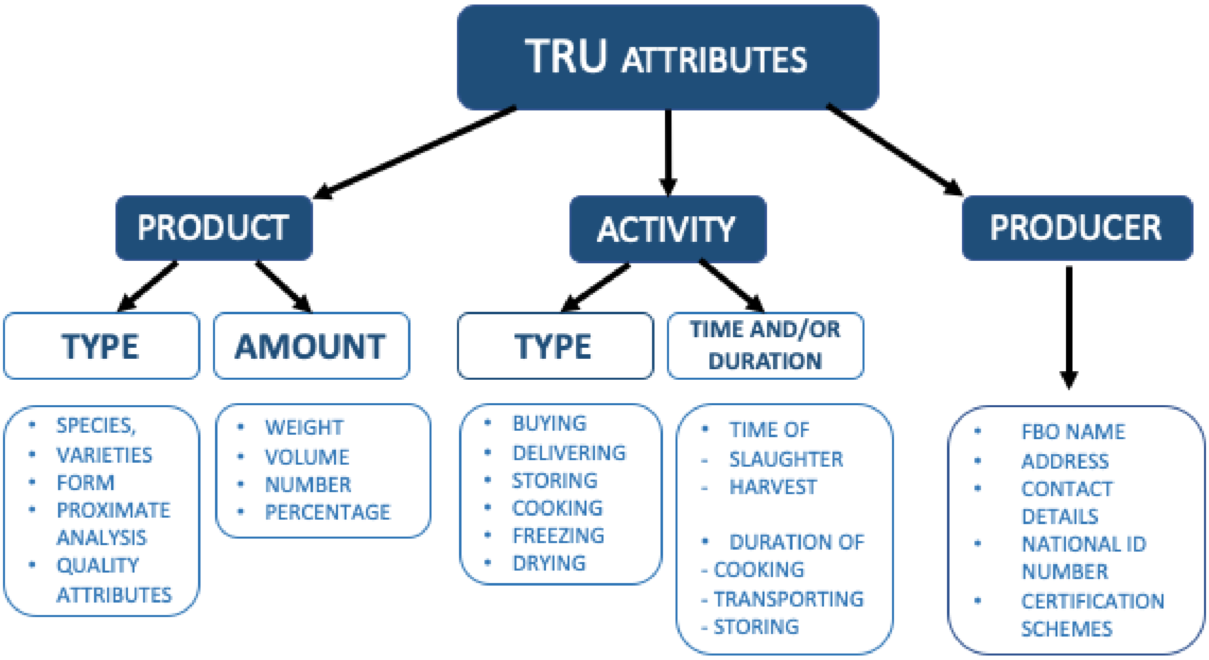


Figure 5 Traceable Resource Unit (TRU) attributes

3.3 TRACEABILITY TECHNOLOGY

3.3.1 DATA STREAM AND KEY PROCESSES

Additionally to the components of a traceability system it is important to describe the key processes that influence the data stream. The data stream is the actual flow of information within the traceability system and the key processes define what happens to that information. Different key processes are associated with different components of the TS. For example, the addition of data will be associated with the "Identification of the TRU" and "Documentation of the Transformation" components. It considers new or additional data that is added to the product as it moves along the supply chain. (Bhatt et al., 2016) came up with a list of eight key processes that take place in a TS (*Table 3*). Recognising these will aid the process of risks and challenges identification in the TS.

Table 3 Key data processes found in a traceability system (TS), compiled from (Bhatt et al., 2016, p. 396)

Key process	Description
Product identification	Linking of products to identifier
Data addition	Linking additional info to the product as it moves along the supply chain
Data partition	Dividing the data into internal or external streams
Data storage	How is the data kept and organised
Data transmission	Transfer of information along the supply chain
Data security and access	Security mechanisms, user specification, and permissions
Data collection and measurement	Creation and recording of data
Data validation	Checking the authenticity of the data elements and claims found in TS

3.3.2 SEAFOOD PRODUCTS TRACEABILITY TECHNOLOGY

There are many technologies enabling and supporting the implementation of food traceability. This section focuses on technologies that enable collection, storage and sharing of data. It does not consider technologies designed to verify the claims registered by the TS, such as spectroscopy or magnetic resonance. Different technologies are relevant and applicable for different parts of the traceability system, it is, therefore, important to acknowledge the current state in each of these groups. Technologies that are currently applied in traceability systems can be divided into four groups: identification technologies, data collection technologies, data storing technologies, and data sharing technologies. Following the diagram of TS components proposed by (Olsen & Borit, 2018), the technologies are exemplified in *Figure 6.*

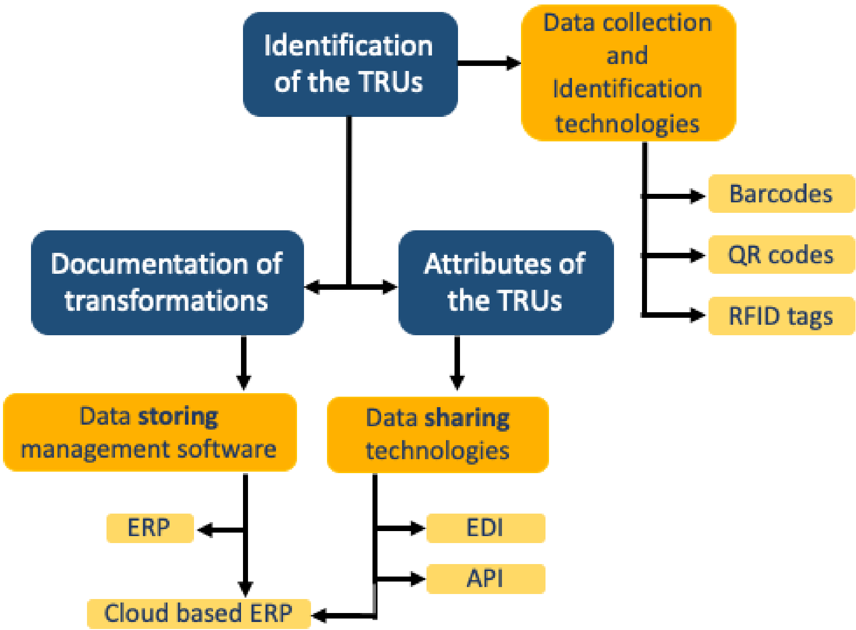


Figure 6 Traceability components and corresponding technologies and software (QR – Quick Response, RFID – Radio Frequency Identification, ERP – Enterprise Resource Planning, EDI – Electronic Data Interchange, API – Application Program Interface) Source: (Hardt et al., 2017; Kemény & Ilie-Zudor, 2016)

3.3.2.1 IDENTIFICATION AND DATA COLLECTION TECHNOLOGIES

Identification technologies and data collection technologies can be grouped together as the identification technologies are unable to fulfil their purpose without being connected to a data collection technology. An example would be an RFID tag (ID technology) and transceiver (data collection technology). In this instance the technologies are linked together, however, there are several other ways of collecting data such as manual input into a computer or a paper form. After the product has been identified, a number of different Information Technology (IT) systems provide the necessary infrastructure for storing and sharing traceability data.

3.3.2.1.1 Barcodes and quick response (QR) codes

The barcodes and QR codes are two types of optical identifiers. The standard barcodes are still one of the commonly used identification techniques, the barcodes store information in a 1-dimensional horizontal manner and are often accompanied by a code created from numbers, an example of this being an EAN13 *(Figure 7a).* Such barcodes are mostly used at to transmit information between businesses (B2B) and due to a limited amount of information that these codes can carry, some FBOs have moved towards the use to Quick Response (QR) Codes *(Figure 7b).* QR codes have the ability to store information both horizontally and vertically (2D), meaning that more information can be parsed in a single reading. Furthermore, the QR codes do not require sophisticated readers as they can also be read by smartphones. Scanning the QR code can take anyone to the website with product information, however, it does not necessarily provide direct access to all product attributes, only those chosen to be displayed by the producer. Both types of codes can be susceptible to environmental damage, such from water or ice, which means our ability to read them may be compromised. Furthermore, reading of the codes can be quite slow, as the products have to be positioned in a way that enables the optical automatic reading (Kemény & Ilie-Zudor, 2016).

Figure 7 (a) Example of an EAN 13 barcode (b) Quick Response (QR) Code

3.3.2.1.2 Radio frequency identification tags (RFID)

RFID tags are another type of identification technology, the tags work based on electromagnetic waves (series of pulses), which allow for the transmission of data between the transponder (the tag) and the transceiver (the reading device). Comparing to the optical identifiers, which are limited by the use of space, RFID tags are limited in time (Kemény & Ilie-Zudor, 2016).

There are 3 types of RFID tags:

- Passive tags, which rely on reflecting the energy emitted by the transceiver. They are long lasting due to their low energy usage; however, their storage capacity is quite low comparing to the other two types.
- Semi-passive tags or battery assisted, allow for an inclusion of a sensor, which enables real time tracking and environmental monitoring, given that the tag remains within a reading distance, which is comparable to the passive tag.
- Active tags have both the battery and a transmitter, which sends energy directly to the

transceiver rather than reflecting it. Such tags are much more sophisticated as they have a bigger memory, which can be rewritable, and they have a much wider range (Dabbene et al., 2016).

RFID tags work based on electromagnetic waves that allow for automatic identification. They do not need to be visible and can be placed inside the packages, which will protect them from environmental impact. Furthermore, the tags do not have to be placed in a certain position to enable the reading, meaning the identification process can be faster (Kemény & Ilie-Zudor, 2016). Despite the many benefits, the RFID tags, especially the active type, are not commonly used in food traceability. The cost of active or semi active tags often outweighs the cost of the product they are associated with.

3.3.2.2 DATA MANAGEMENT SOFTWARE AND DATA SHARING TECHNOLOGIES

3.3.2.2.1 Enterprise resource planning (ERP) / cloud based ERP

An ERP system is a business management software system that integrates all of the most important business’s functions and processes. Information with regards to logistics, sales, manufacturing, accounting, sales, auditing and many more can be kept in one ERP database. The system enables the FBO to collect, manage and analyse the data in one place while being able to customize the ERP system to their own needs. Nevertheless, customization can be very time consuming and problematic as businesses have to revaluate all their existing practices and potentially replace them with new ones. Furthermore, implementation, technical support and maintenance of the ERP requires advanced technical knowledge (Osnes et al., 2018). For the system to function smoothly all employees must be fully trained to operate the system, which could additionally increase costs. This means that once the ERP system has been established and running for years, the FBOs can be reluctant to upgrade to a newer and better system. The cost of customizing the system from scratch may outweigh the perceived benefits.

Cloud ERP provided to end users (businesses) is delivered through a Software as a Service (SaaS) model. The user does not need to install or configure the system as it can be accessed via an internet browser (Abd Elmonem et al., 2016). Cloud based ERP can be helpful in establishing chain traceability, where multiple partners can store data and provide each other with access to specific information. This can be done through a permission-based sharing, where each partner decides what data they would like to share and what to conceal (Future of Fish). Abd Elmonem and others (2016) carried out a systematic literature review of cloud ERP benefits and challenges. Security risk is the biggest challenge, as users feel they can lose control over their sensitive data as it is not stored on premises. Cloud ERP is a fairly new technology, which does not have widely accepted standards, which increases the barriers to successful implementation. Furthermore, cloud service providers currently offer relatively fixed solution packages, meaning there is little room for customization and integration with other technologies. Moreover, as the cloud ERP relies on internet connection there is a risk of network failure, which can affect the performance of the system.

3.3.2.2.2 Electronic data interchange (EDI)

Electronic Data Interchange (EDI) allows for a structured interorganizational exchange and transfer of data between different systems. This form of communication dates back to 1960. Initially documents such as invoices or purchase orders were sent through fax or mail, meaning that the communication was less efficient and left a lot of room for error. EDI has the ability to create chain traceability and it strongly relies on the agreements between partners to use common standards. There are a number of components that work together to create an IT infrastructure necessary for successful EDI.

Transfer of data: There are a number of EDI solutions; Point to Point, Value Added Network (VAN) or web-based EDI. In some cases, many companies opt out for a hybrid of these, often also including paper-based communication (Vrbová et al., 2018).

Processing of data: in other words, the data received in an EDI standard must be translated into a format readable to humans.

Data mapping: this involves managing and organizing the data properly so that all parties involved are able to access, understand, and analyse the data.

There are two common ways of formatting data for the purpose of sharing it through EDI. The first alternative is the use of eXtensible Mark-up Language (XML). XML is a structured set of rules, which enable exchange of data between different applications by encoding all type of documents into a format readable both by machines and humans. XML deals with the syntactic interpretation of documents, meaning it analyses the structure of the language. However, it is not sufficient in interpreting the semantics, which refer to the meaning of the language (Füzesi et al., 2016). The second alternative is the use of EDI standards such as EDIFACT or ANSI x12, which dictate strict rules with regards to the positioning of data. The use of standards is much less flexible; however, it supports the creation of interoperability and the files tend to be smaller than in the XML format.

3.3.2.2.3 Application program interface (API)

API is a software interface that enables electronic communication between two or more separate systems. API is not based on end-to-end interoperability standards; however, it has an ability to embed standards. This mean it can be established across the whole supply chain, and it can be used to enable chain traceability. However, once the API has been established it becomes limited to those systems it was designed for (Hardt et al., 2017, p. A4). This means that establishing new partnerships or entering another supply chain would require designing a new API.

3.4 RISKS AND CHALLENGES WITHIN CURRENT TRACEABILITY SYSTEMS

There are a number of risks and challenges associated with the current traceability systems and the key processed that take place within each of the components. The identification of the limitations within the TS follows the conceptual framework of the TS proposed by (Olsen & Borit, 2018). Linking the risks and challenges to specific parts of the TS allows for a detailed analysis *Figure 8*. Providing this overview addresses research question (1).

(1) What are the risks and challenges within food/seafood product traceability systems?

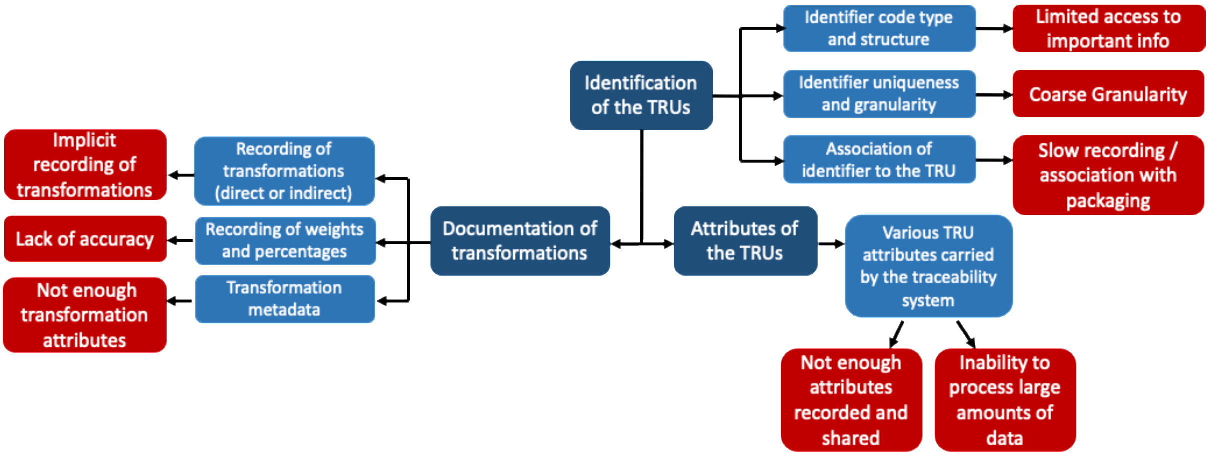


Figure 8 Traceability system components and their risks modified from (Olsen & Borit, 2018).

3.4.1 LIMITED ACCESS TO IMPORTANT INFORMATION

Currently there is no optimum way to covert important information between businesses. Identifiers have the potential to incorporate some information in their structure, however, the currently used barcodes and labels have a limited capacity to convey big amounts of data. Furthermore, barcodes and QR codes do not have the ability to incorporate environmental information such as temperature or location (Kumperščak et al., 2019, p. 471). Until the code is read and processed, one does not have access to important information.

3.4.2 COARSE GRANULARITY AND LACK OF ACCURACY

Due to high costs associated with identifying many TRUs, it is common practice to associate a big TRU (e.g. 1000 kg fish labelled as one product) with one identifier. In the case of contamination many products will have to be recalled, which increases the costs for the FBO as well as puts more consumers at risk. Furthermore, there is room for error if some attributes are recorded manually (Bhatt et al., 2016, p. 413). This leads to the loss of important data and knowledge with regards to industrial and FBO performance.

3.4.3 SLOW RECORDING / ASSOCIATION WITH PACKAGING

Reading of codes happens relatively slowly, barcodes need to be visible to the reader/scanner and they can only be read one at a time (Kumperščak et al., 2019, p. 571). An alternative would be a RFID tag, however, they are considerably more expensive (Bouzembrak et al., 2019, p. 62), and in the case of seafood the cost of the tag may outweigh the product price. Many TS are partly manual as smaller companies cannot afford full electronic TS (Borit & Olsen, 2016). Furthermore, most of the identifiers are associated with the packaging of the TRU rather than the physical product. Such practices are very common in the seafood industry, as normally it is only the "big catches", which are directly labelled or tagged. For example, a whole tuna. This could lead to potential fraud as the information flow throughout the supply chain could follow the identifier rather than the product itself, which makes it is hard to monitor the authenticity of the product.

3.4.4 IMPLICIT RECORDING OF TRANSFORMATIONS

Implicit recording of the transformations means that circumstances of the transformation are not stated clearly. For example, a fish factory receives products from a number of sources at the same time and it is not uncommon that these catches are then combined together in a single box X. A fish cake is produced from a mix of fishes found in box X at time Y, one does not know exactly the proportions of each fish found in this fish cake, but one knows what went into box X before time Y. Such practices leave a lot of room for mistakes and could lead to undocumented mixing and the loss of important information with regards to the TRU attributes.

3.4.5 NOT ENOUGH TRANSFORMATION ATTRIBUTES

It would be beneficial to include more transformations metadata, which would allow to identify attributes directly related to the transformation, and analyse and evaluate the relationships between the transformations and factors such as location and duration (Olsen & Borit, 2018, p. 148). It can be challenging to add new product attributes in a supply chain of fast moving fresh produce (Bhatt et al., 2016, p. 412). The ability to discover patterns and shed light on existing restrictions is therefore limited.

3.4.6 NOT ENOUGH ATTRIBUTES / INABILITY TO PROCESS LARGE AMOUNTS OF DATA

Recording of attributes is often carried out manually, meaning that the process can be time consuming and leaves a lot of room for error. Furthermore, the input of recorded data is often slower than real time (Bhatt et al., 2016, p. 412). Nevertheless, there is a need to know more about the TRU in question, however, current TS are unable to process such large amounts of data. This creates a situation where the collection of additional data may be seen as an inefficient use of time, because until one is able to process it the data is unusable.

3.4.7 INFORMATION LOSS

One important purpose of the TS is to systematically link all recorded information to unique identification codes. It would be beneficial if the initial implementation of a TS identified Critical Traceability Points (CTP) and Key data elements (KDE) to record and share. CTP are often at the transformation points and recording of these is important to the functioning of the TS. CTP are often the points where information loss can occur (Karlsen et al., 2012), and this can be caused by the implicit recording of transformation or repackaging and removing a label. (Olsen & Aschan, 2010) have found that many companies are quite good at recording the data, with some improvement necessary in data sending. Many companies tend to include their internal batch number, which has no meaning at further links in the chain. Batch number is ignored by the receiving party and not passed on further.

3.4.8 INTEROPERABILITY ISSUES & LACK OF UNIVERSAL STANDARDS

The key to successful traceability system is consistency of collecting, managing and sharing the data. However, it is often that FBOs along the supply chain do not agree on what the shared information means. Furthermore, the information about the product must travel separately from the product, which is often not linked to a unique identifier, making it difficult to confidently match data to the product it describes. Standards are imposed by a number of actors such as the government, industry or NGOs. Each of these groups have their own goals and agendas meaning that there are many different standards. In order to achieve a true interoperability a standardized data collection and communication between the systems is required. There are two types of standards that must be considered; semantic standards and syntactic standards. Semantic standards refers to how the shared information is understood, it requires standardized vocabulary to ensure the information is interpreted in the exactly same manner by all parties (Future of Fish). For example, it is important to establish a common name for a species of fish as the same fish will be called differently in several countries. Furthermore, the list of attributes collected often differs between countries, which could cause gaps in the data or loss of information as the receiver may be unable to process it. Syntactic interoperability ensures communication between systems. In order for it to be achieved, there must be standards in place, which will dictate data formatting and communication protocols. The ability to collect and share different types of data is limited by the lack of universal standardization of these processes.

True interoperability is achieved through the combination of syntactic and semantic interoperability. Interoperability issues are caused by a number of factors and prove to be the biggest challenge in achieving chain traceability. European Union General Food Law requires the establishment of traceability practices for all food products (Dabbene et al., 2014, p. 67). However, there are no clear guidelines with regards to how the system should be implemented (Asioli et al., 2011). The methods and techniques are not specified by the law meaning that each FBO can customize their TS and decide on matters such as the size of the batch or when and how the transformations are recorded. This degree of freedom means that the information shared throughout the chain may be hard to process. Furthermore, both internal and chain electronic traceability systems require a number of different technologies in order to function. Some of these technologies have a number of alternatives depending on the companies' needs and financial capabilities. For example, in a situation where a company has many trading partners and relies on Point to Point EDI, this can become very costly and complex if the partners use a number of different communication protocols (Namtek, n.d.). Moreover, having a compatible EDI can be the deciding factor whether companies will trade.

Interoperability issues may impact the businesses in a number of ways. Additional labour and production costs may arise from re-punching the data, this could decrease the speed of operations and competitiveness. Furthermore, lack of interoperability could prevent a fast response in the event of an emergencies related to recalls (GDST, n.d.). Despite the efforts from international organizations such as Food and Agriculture Organization (FAO), World Health Organization (WHO) or GS1 to define and provide standards for traceability, it has been recognized by the Codex Alimentarius Commission that these standards are not harmonized across borders often leading to a barrier in international trade (FAO & WHO, 2003).

3.5 GENERAL TRACEABILITY CHALLENGES

3.5.1 FRAUD AND AUTHENTICITY OF THE PRODUCT AND ITS ATTRIBUTES

A traceability system collects information relating to the TRU for the purpose of sharing this information with other links in the chain. However, the TS does not ensure the authenticity of the product and its attributes. Data found in the TS must be, therefore, treated as a claim and subjected to verification techniques such as, for example, DNA sampling. However, such verification techniques are not a part of the TS itself. Seafood is among one of the three most commonly mislabelled foods in the world, along with olive oil and honey (INTERPOL, n.d.). Seafood fraud can take place at any point in the supply chain and once the fraudulent action took place it can be really hard to find its origin. A very common seafood fraud is the substitution of one specie for another similar, cheaper one (Haynes et al., 2019). The motivation behind this is often financial and takes place in the supply chains of highly valuable seafood species, for example the tunas. Furthermore, seafood fraud is greatly associated with IUU fishing practices, where species often come from unsustainable stocks. Oceana, an international organization that works on protecting and restoring the oceans carries out regular investigations into seafood fraud. In their latest nationwide study of Canadian fisheries, an astonishing 44% of tested seafood products were found to be mislabelled (Oceana, 2019, p. 20). Such studies highlight the amplitude of the seafood fraud, however, despite the worrying results one cannot be sure whether the mislabelling was intentional or accidental. Nevertheless, mislabelling of seafood product may not only enable IUU practices but it can compromise the health and safety of consumers.

3.5.2 LACK OF AWARENESS

Awareness and understanding of the whole concept of traceability is limited both with the consumer and FBOs. In a recent study on consumer perspective, it has been found that over 50% of 216 participants[2] were either unable to define traceability or had misconceptions about the term (Rodriguez-Salvador & Dopico, 2020, p. 3). Furthermore, most of the participants who tried to define traceability associated the term primarily with the origin of the product. Nevertheless, after being presented with the definition of traceability and educated on the concept most agreed that traceability is necessary. The lack of awareness can be further reflected in the confusion between traceability systems and other concepts such as certification schemes, catch documentation or chain of custody. Borit & Olsen (2016, p. 22) have argued that even at legislator levels there is a lack of understanding of the difference between chain traceability and internal traceability. As long as this misconception exists, firms will continue to focus on internal traceability and true chain traceability will remain unattainable. Traceability systems can be used as a tool to obtain certification labels, simultaneously the prospect of certification can serve as a motivating driver for the implementation

[2] 139 women – 57 men, aged 19-81, different levels of education, different family sizes

of the TS. Despite the close relationship between the two, it is important to distinguish the difference between these concepts. Furthermore, Sterling & Chiasson (2014, p. 12) suggest that corporate leadership lacks the understanding with regards to how traceability systems could help to develop new more efficient processes and improve their financial performance.

3.5.3 SLOW TAKE UP OF TRACEABILITY SYSTEMS

Take up and engagement in the TS will in a large extend depend on the reasons why the FBO decided to implement such a system. Drivers of traceability imposed from the outside, such as the legislation or commercial requirements, may be seen as sources of additional costs rather than an opportunity (for a summary of traceability drivers see Appendix 1). The company already faces cost associated with the physical flow of the products. As these costs are inevitable for the producers, they are more likely to cut back on costs associated with information logistics as long as they meet the minimum requirements. Furthermore, it is essential to acknowledge that the reasons for a slow take-up of new technologies is often deeply rooted in the organizational and institutional frameworks (Sterling & Chiasson, 2014, p. 12). Lack of awareness plays a big part in this as implementation of TS requires a good level of technology literacy. Low understanding of technology combined with security concerns and the lack of compelling evidence on the return of investment creates huge barriers to adoption of new technologies (Future of Fish, 2014, p. 7). In order for a traceability system to serve its purpose it has to be implemented across the entire supply chain. However, each part of the chain will deal with totally different issues, which means the TS must be able to operate under different circumstances as well as provide a common platform for sharing the information.

3.5.4 A GUARDED CULTURE

In some cases, seafood industry is, in large proportion, made up of family run business, where trust between companies is built through years of collaboration (Future of Fish, 2014). It is imprinted into the business culture that companies are ought to protect their data from competitors. Furthermore, the lack of understanding of new technologies often leads to concerns with regards to data security. Companies are resistant to sharing their data across the whole supply chain, as this could mean a loss of competitive advantage. Therefore, traceability based on one-link up and one-link down information exchange remains the most popular alternative. In the recent years, there has been a significant increase in the adoption of traceability technologies, however, there is tendency to focus on internal traceability (Hardt et al., 2017, p. A3). This alone does not provide supply chain transparency.

SUMMARY OF SECTION 3.4 AND 3.5

In order to provide a good overview of Chapter 3, the traceability system components, key processes, technologies and limitations have been summarized in **Table 4**.

Table 4 Summary of traceability system components, key processes, technologies, risks and challenges*. (TS – Traceability System, TRU – Traceable Resource Unit, QR – Quick Response, RFID – Radio Frequency Identification, ERP – Enterprise Resource Planning, EDI – Electronic Data Interchange, API – Application Program Interface, IUU – Illegal, Unregulated, Unreported)*

<table>
<tr><th>TS COMPONENTS</th><th colspan="3">Identification of the TRU</th><th colspan="2">Documentation of transformations</th><th colspan="2">Attributes of the TRU</th></tr>
<tr><td rowspan="4">KEY PROCESSES</td><td colspan="5">Data collection and measurement</td><td colspan="2">Data partition</td></tr>
<tr><td colspan="5">Data addition</td><td colspan="2">Data transmission</td></tr>
<tr><td colspan="3" rowspan="2">Product identification</td><td colspan="4">Data storage</td></tr>
<tr><td colspan="4">Data security and access</td></tr>
<tr><td>TECHNOLOGY</td><td>Bar Code</td><td>QR codes</td><td>RFID Tag</td><td>ERP</td><td>Cloud based ERP</td><td>EDI</td><td>API</td></tr>
<tr><td rowspan="5">TECHNOLOGY RISKS and CHALLENGES</td><td colspan="2">Association with packaging</td><td rowspan="3">Short life cycle (active)</td><td rowspan="2">Requires advanced technical knowledge</td><td rowspan="2">Performance risk / network failure</td><td>Expensive</td><td>Security risk</td></tr>
<tr><td colspan="2">Susceptible to environmental changes</td><td>Too many standards</td><td>High maintain. costs</td></tr>
<tr><td colspan="2">Slow reading: must be positioned</td><td>Time consuming implementation</td><td>Security and control concerns</td><td rowspan="2">Constant revisions of standards</td><td rowspan="2">Requires advanced tech knowledge</td></tr>
<tr><td colspan="2">Does not record environmental parameters (location)</td><td rowspan="2">Expensive</td><td>High maintenance costs</td><td rowspan="2">Customization and integration limitation</td></tr>
<tr><td colspan="2">Limited information</td><td>High initial costs</td><td colspan="2">Limits trading partners</td></tr>
<tr><td rowspan="3">PROCESS LIMITATION</td><td colspan="3">Coarse granularity</td><td>Undocumented mixing</td><td colspan="3">Loss of information</td></tr>
<tr><td colspan="7">Inability to process large amount of data</td></tr>
<tr><td colspan="7">Not enough attributes recorded</td></tr>
<tr><td rowspan="5">GENERAL CHALLENGES</td><td colspan="7">Lack of uniform standards + Interoperability issues</td></tr>
<tr><td colspan="7">Lack of trust: guarded culture</td></tr>
<tr><td colspan="7">Awareness gap - consumer and user</td></tr>
<tr><td colspan="7">Fraud/Product Authenticity: Mislabelling + IUU</td></tr>
<tr><td colspan="7">Slow take up</td></tr>
</table>

4. EMERGING TECHNOLOGIES

4.1 DEFINITIONS

Emerging technologies (ET) are a type of technologies that are coming into existence and due to their newness they lack refinement. Rotolo and others (2015, p. 13) define emerging technologies as *"a radically novel and relatively fast growing technology characterised by a certain degree of coherence persisting over time and with the potential to exert a considerable impact on the socio-economic domain(s) which is observed in terms of the composition of actors, institutions and patterns of interactions among those, along with the associated knowledge production processes. Its most prominent impact, however, lies in the future and so in the emergence phase is still somewhat uncertain and ambiguous."* Through the identification of the five characteristics of ET (radical novelty, relatively fast growth, coherence, prominent impact, and uncertainty & ambiguity), Rotolo and others (2015) created a conceptual framework of ET *(Figure 9).*

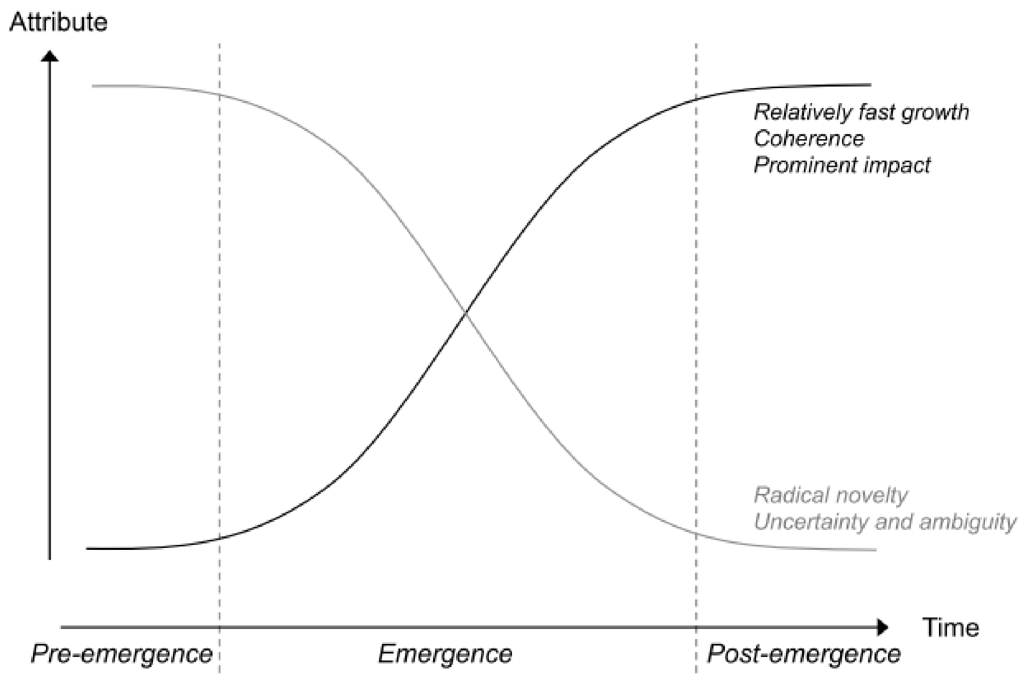


Figure 9 Pre-emergence, emergence and post-emergence attributes and trends (Rotolo et al., 2015, p. 15)

As visualized in *Figure 9*, emergence is a continuous process, which can happen over a long period of time. The evolving attributes of emergence can serve as an indication of the current state of a given technology. For instance, when uncertainty is high, we are safe to assume the technology is at the early stage of emergence. In the post emergence phase, it is expected to see these technologies become ubiquitous, meaning they can be found everywhere. "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." (Weiser, 1991, p. 94).

In this context, it is important to mention also the concept of disruptive technology (DT). The concept of DT has been introduced in 1990s, and the most influential work in this area comes from Clayton Christensen. The author has later reconstructed the term into “disruptive innovation” (DI) in order to provide a more holistic view of what we can consider as disruptive (Christensen & Raynor, 2003). The terms of disruptive innovation and disruptive technology are used in both synonymous and hierarchal manners, which causes some uncertainty among researchers (Li et al., 2018, p. 286). However, the main difference is that DT does not restrict itself to new markets. Disruptive innovation can be defined as “one *that changes the performance metrics, or consumer expectations, of a market by providing radically new functionality, discontinuous technical standards, or new forms of ownership.”* (Nagy et al., 2016, p. 122). Technology has the potential to transform lives and economies, however, the process does not happen overnight even if the technology is considered disruptive. A disruptive technology introduces new ways of doing things, which overthrows old methods by making them irrelevant or unattractive. Despite effort to detect whether the technology is disruptive, the study of disruptive technologies tends to work in retrospective manner where the disruption is examined only after it has taken place.

The concepts of DT and ET have been closely examined by Li et al (2018). The authors have found that DT and ET belong to two separate literature clusters. DT is often associated with business management and corporate strategy implications of DT, whereas ET work concerns itself with the socio-economic systems and how they could be influenced by ET. Despite these differences, the two concepts share three district similarities: **novelty**, **uncertainty,** and **indication of impact**. Novelty is a fundamental feature of ET and a large degree of novelty is also expected in DT. Uncertainly in ET is associated with different technology options, whereas, in DT, uncertainty comes from technology capabilities; is the technology able to surpass expectations and overthrow an existing technology? Both types of technologies are expected to bring about changes and impact people’s lives in one way or another.

4.2 IDENTIFICATION OF EMERGING DATA DRIVEN TECHNOLOGIES AND THEIR ANALYSIS

The Western society is presently in the middle of a 4th industrial revolution led by the speed of technological development. Currently there are hundreds of new technologies brought to life on regular basis, however, it is beyond the scope of this thesis to address all of them. This part of the thesis aims to provide an overview of emerging data driven technologies, many of which share three distinctive characteristics: convergence, data driven and cross scale (Thomas, 2019). This will allow to answer research question (2).

(2) What are the latest emerging technologies relevant to food/seafood industry?

Due to an enormous amount of information being produced with regards to technologies and the debates that take place concerning their emerging state or disruptive capabilities, this thesis relies on one credible source that has helped to identify the data driven technologies discussed in this thesis. Thus, emerging data driven technologies considered in this thesis were sourced from the latest Technology Outlook - 2030 published by (DNV GL, 2020). Det Norske Veritas Germanischer Lloyd (DNV GL) is a global accreditation and classification society that carries out extensive research with regards to technology and share their knowledge through open source articles, outlooks, and reports. In their 2030 Technology Outlook, DNV GL identified a number of data driven technologies that are currently important or could become important in the next few years. They have identified three categories of technologies: enabling, transforming, and sustaining. Despite the three distinctive groups, a number of technologies addressed in the report can fall under all three categories depending on their application. For example, the Autonomous Systems are presented as enabling - in a general sense, transformative - when applied in autonomous vehicles and vessels, and sustaining - when applied in mapping and monitoring of the oceans. Technologies reviewed in this thesis belong to the group of "Enabling technologies", however given the right application they have the ability to transform industries and sustain ecosystems. Technologies chosen for further exploration have the ability to accelerate digitization, and enable virtualization and automation across the life cycle (DNV GL, 2020). Technologies explored in this chapter are:

- Artificial Intelligence
- Autonomous systems
- Extended reality
- Internet of Things
- Digital Twin
- Blockchain
- 5G
- Quantum Computing

For the purpose of providing a good understanding and a solid basis for analysis, a structured approach was used to describe each of the technologies.

Technologies explored in this chapter were examined based on the following aspects:

(1) **Functionality and application** –What are the core functions and applications of the technology?

(2) **Components and architecture** – What are the main components of the technology? How are the components assembled?

(3) **Implementation** - What is the cost of implementation and maintenance? What skills are required? What are the implementation challenges?

(4) **Ownership** – Who does the technology belong to? Who owns the data?

(5) **Impact** – What is the expected impact of the technology?

4.3 ARTIFICIAL INTELLIGENCE

FUNCTIONALITY and APPLICATION

The goal of Artificial intelligence (AI) is to simulate human intelligence without the human input. The initial concept is meant to duplicate human learning, reasoning and problem-solving abilities to arrive at rational decisions. AI can be defined as "..software and hardware systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information.." (EC, 2019, p. 6). A big subsection of AI is machine learning, where the machines have the ability to derive meaning from data that is either organized to enhance the learning, or undefined, leaving the machine to learn by itself and recognize patterns. It is worth mentioning that AI and machine learning thrives with a lot of data (Martens, 2018, p. 4). That is why Big Data is extremely beneficial for the enhancement of AI. Also, AI can benefit the data acquisition for Big Data through better analysis of inputs and vision. Artificial intelligence is described as weak and strong, which is related to the amount of jobs the system is able to fulfil. Weak AI is often related to singular jobs such as taking one input and proposing different options (a good example is Apple Siri assistant). The strong AI will be able to carry out tasks with own initiative suggesting the AI has consciousness and genuine understanding rather than simply recognizing patterns (Pinel et al., 2015, p. 44). This is often referred to as Artificial Super Intelligence and as of today it is a subject of futuristic fantasies (Asun et al., 2019, p. 10). The learning skill of AI once implemented can be utilised to jobs ranging from big-data analysis to self-modification of the code, which is one of the ultimate aims of ambitious AI projects. It means that the AI system can get more data from Big Data to base the decision on, as well as enhance its own functions and procedures to become more efficient. AI can be applied in all aspects of our lives, a simple example from a food industry would be sorting the fresh produce such as potatoes (Garver, 2018). Where the AI utilized optical recognition and machine learning to recognize the shape and colour of potatoes that are destined for different purposes.

COMPONENTS and ARCHITECTURE

The AI has evolved tremendously over the years. The 'bar' for the definition of AI is increasing with its development. Text recognition and functions calculations were once considered AI, as of today they are a simple programming function. There are a number of important components that fall under the umbrella of AI simultaneously enabling its functions *(Figure 10)*.

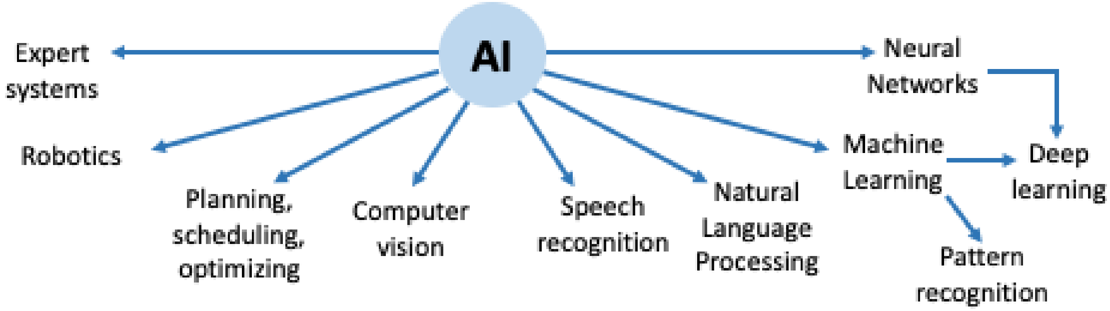


Figure 10 Components of Artificial Intelligence

Machine learning is an automated analysis giving computers the ability to learn and derive meaning from often very large datasets. The purpose of machine learning is to identify patterns through classification and prediction and improve the functions of the system.

There are three machine learning methods:

Supervised learning requires the use of pre-defined input such as historical data and patterns in order to train the machine (Tiwari et al., 2018, p. 3). The machine then applies the learned algorithm to a new set of data in order to discover patterns, predict errors and adapt the model.

Unsupervised learning relies on the machines ability to discover patterns in unlabelled, unorganized data. This technique is able to process large amounts of data through clustering, mapping and self-organization (Ongsulee, 2017, p. 4).

Reinforced learning uses an algorithm that learns on trial and error basis, with the objective to reach the goal as soon as possible. An example of this is gaming or navigation (Ongsulee, 2017, p. 4).

Neural network has an explicit focus on the simulation of biological neural network and conversion of neural decisions into a programmed code (EC, 2019, p. 4). The networks are usually connected through weighted units that transfer information between each other, trying to simulate neurons and analysing the connections and meaning of the data. **Deep learning** is a more advanced approach to artificial neural networks. The use of most-modern computers for the most computing power possible employs deep learning in order to analyse the undefined data and derive the meaning from the several layers of learning between the input and output (EC, 2019, p. 4). Deep learning and neural networks are currently used in social media or e-commerce where they are able to discover internet browsing patterns and suggest personalized advertisement. **Natural language processing** is a sub-category of AI focused entirely on the aspects of human language with the purpose of translation, classification information extraction (Kumar et al., 2019, p. 137). For instance, it can be used in listening and responding to simple tasks in personal assistants like Siri. **Speech recognition** has the ability to detect and interpret spoken words and phrases and transcribe them into text**.** Speech recognition can be used in situations where you are unable to use your hands, a good example from the food industry would be the physical inventory counting. As you walk through the factory or storage facilities you may need to both move the inventory around and register the amounts at the same time. For efficiency purposes this would normally require two people, however, with speech recognition all you have to do it carry the device in your pocket and dictate the amounts. This leaves no room for human misinterpretation or bias. **Computer vision** has a focus on pattern recognition, often linked with another sub-category of deep learning in order to effectively 'recognize' the shapes and content of an image or object (Guo et al., 2016). Computer vision can be applied in situations where the human eye or normal cameras are not enough. For instance, computer vision can be used to recognize the species of the fish swimming in the waters before a decision is made to harvest that fish. It has a supremacy over normal cameras as it is able to process the data while collecting it rather than waiting for human interpretation. **Robotics** refers to physical part of AI, which deal with movement and motor skills. A robot is a mechanical device, which can be either automated through programming or controlled by a human (Kumar et al., 2019, p. 137). Robotics can be used in labour intensive settings such as farming. For example, digging the earth up around in a circular motion making it ready to plant the seeds. **Expert system** is a computer program with a user interface that simulates the behaviours of a human expert (Ranschaert et al., 2019, p. 354). It has the ability to create knowledge base solutions, provide advice and make decisions. A most commonly used expert system is an ATM (Automated Teller Machine), which acts as a human banker.

A simple representation of the AI architecture is presented in *Figure 11*. Environmental data is collected through multiple channels including sensors, websites, microphones, cameras or already existing databases. The data is processed into information, which is understandable for the next step of reasoning and decision making. Once the decision has been made, actuators/robotics are employed to perform the instructed action. However, the actions do not always require a moving physical actuator they could be carried out through software e.g. a chat-bot (EC, 2019, p. 3).

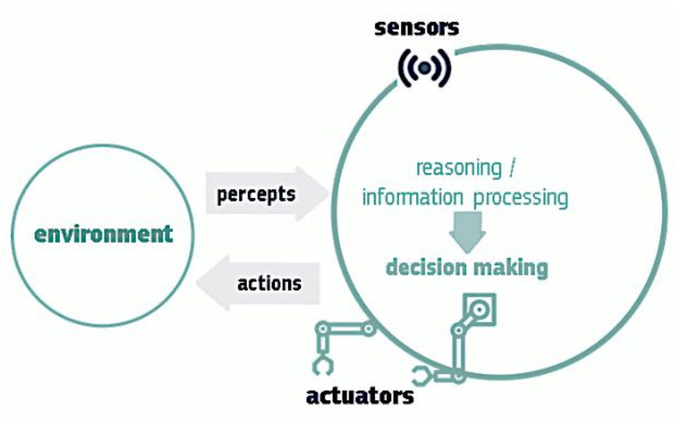


Figure 11 Architecture of AI taken from (EC, 2019, p. 2)

IMPLEMENTATION

The cost and skills required for the implementation of AI will depend on its application. A weak AI system could be a customer chat-bot or a decision system for a database. The development of AI is not different to any other programming. The implementation is as easy as development and design of a software. The possibilities to use ready systems, which require data to become functional is also an option. With an increasing number of AI programmers in the market, AI implementation is within a range of even small cost-saving businesses. However, the more advanced the AI system the higher the costs of implementation. The incredibly fast growth of AI requires an up to date infrastructure of both software and hardware. Costs of a high performance system of machine learning algorithms can be as high as $10.000 (Fuller et al., 2019, p. 5). Nevertheless, in a long term perspective machine learning can in fact reduce the costs through the improvement of decision making processes (Martens, 2018, p. 5). There are multiple challenges to the implementation of AI that are often concerning the topic of ethics and morality. Aspects such as transparency; justice and fairness; non-maleficence; responsibility; and privacy are the subjects of international debate (Asun et al., 2019, p. 20). Currently these challenges are further emphasized by the lack of regulation that is far behind the technology development.

OWNERSHIP

Further development of AI and machine learning requires access to large amounts of data. The collection and storage of data can be costly, however due to a non-rivalry nature of data it allows for multiple simultaneous users. This can increase the societal benefits gained from data collection. Nevertheless, users of data require a monetary incentive and an open access data can diminish its value (Martens, 2018, p. 11). The EU Database Directive (Directive 96/9/EC – 11 March 1996) allows for ownership rights to entire databases. However, single data points, which can be linked to a natural person fall under the requirements of General Data Protection Regulation (GDPR) meaning that the owner of the database does not have exclusive ownership (Martens, 2018, p. 17). Database Directive further supports the data ownership of any entity who has carried out a “substantial investment in obtaining, verifying or presenting the concepts” (Martens, 2018, p. 17). Simply put, an AI owner also owns the data.

IMPACT

There is a need for constant decision making in all aspects of life. If these decisions could be based on instant access to AI, which ideally has access to more data than the human decision maker, we would save time and avoid unnecessary mistakes. As of today, AI application range from finance, industry, automotive, healthcare to customer service. However, there are a number of concerns surrounding the topic of AI. AI will lead to displacement in the labour market, it is predicted that 75 mln jobs will be displaced and 133 mln new highly skilled roles may emerge (WEF, 2018). Ethics of AI have been at the forefront of the discussion, concerning both the technology properties and its application in socio-technical systems (Asun et al., 2019, p. 24). The pre-programming of AI can be problematic, as morality is often a subjective matter.

4.4 AUTOMATION / AUTONOMOUS SYSTEMS

FUNCTIONALITY and APPLICATION

Automation is a process designed to have minimum human input and assistance, while in autonomous systems the process or procedure does not require external intervention and is able to perform and make decisions in uncertain environments and potentially unexpected situations (DNV GL, 2020, p. 16). Categorizing the autonomy level can be done in many different ways. For example, in the automotive industry the autonomy levels have been predefined on the scale from 0 to 5, where 0-2 means increased automation, 3-4 means minimal control and 5 means full autonomy (Eisinger, 2020). All the levels have a different safety requirement to ensure that the system is operational and safe for the user. High level of automation is often applied in setting where the risk to human life could be high. For example, high levels of automation with help from Internet of Things and machine learning are starting to revolutionize the aquaculture industry in tasks such as feeding of the fish and environmental monitoring (DNV GL, 2020, p. 42).

COMPONENTS and ARCHITECTURE

The performance of autonomous systems is often dependent on the inputs provided by its environment. The system must be aware of the situation, thus the use of sensing technologies or AI for image recognition is crucial to ensure the sufficient connection of the control system with its environment (Eisinger, 2020). It is inevitable to mention the connection between autonomous systems and AI. While automation requires rule-based programming, the higher we go in the level of autonomy the closer the more AI is incorporated into the system. Full autonomous systems are largely based on the components of AI, such as machine learning and neural networks. These enable the autonomous system to take advantage of AI functions while remaining a self-governing system.

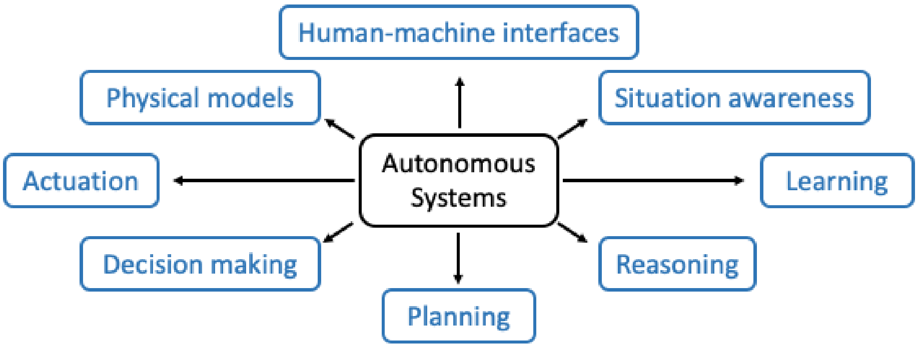


Figure 12 Components of Autonomous Systems (NFA, 2014, p. 6)

The ability of the system to process and store the data is also a requirement – fast processing and accessible storage of its data is corelated with the system efficiency in general. Through practice of observing the situation, the system is able to learn and use this knowledge to generate conclusions (NFA, 2014, p. 6). Moreover, as the system reasons with available information it is able to create a plan of action and take decision having considered alternative scenarios. The system is then able to interact with the environment through the use of actuators (NFA, 2014, p. 6). For example, in the case of an autonomous fishing farm the system collects environmental information such as temperature, the acidity of the water, the amount of pollution in the water or high and low tide. It can monitor the concentration of sea lice or the amount of feed that has fallen to the bottom meaning the fish has stopped eating. The system can the decide to move the cage down a few meters to avoid the lice and stop the feeding in order to minimize the waste of food. Depending on the level out autonomy some degree of human intervention may be required. For that reason, systems must be built in a way that is accessible and operational for human beings through the use of human-machine interfaces.

IMPLEMENTATION

The cost of autonomous system development is still high and above the budget of a small-medium enterprise, although the advancements of linked technologies – sensors, data storage, edge computing, may make the implementation of the autonomous control affordable to more users. Implementation of autonomous systems is most beneficial in environments where the risk of human failure is too high or there is danger to human lives (NFA, 2014, p. 4). The automated systems with low autonomy are easy to develop and may be done in a standard programming approach, potentially using in-house developer, with usual development skills. The least advanced implementation would require a server and a dataset to work with, potentially a sensor for the system to work with. Although a simple solution could be developed within a day with minimum infrastructure, utilising small computing units such as Raspberry Pie or Arduino (Reisinger, 2018).

OWNERSHIP

The data generated by autonomous systems possess similar challenges to those of AI. There is a lot of data generated, not all of it stored, although most of it is processed and analysed (Boberg et al., 2018, p. 3). The users must be aware of it and extra precautions for security hardening must be taken. The data usually belongs to the system owner or its user, depending on the application.

IMPACT

The first applications of fully autonomous systems are becoming popular in niche industries such as mining and food delivery (Eisinger, 2020). The automated processes on the other hand are popular in nearly all aspects of life already – it is possible to automate simple, repetitive tasks. The easiest examples may be automated invoice payment or automated thermostat behaviour at home. The most advanced could be autonomous shipping or self-driving vehicles (DNV GL, 2020, p. 25). As mentioned earlier, the complexity and costs are corelated and depend on the requirements of the system. It is expected automation will disrupt the labour market, initially affecting the unskilled workers then moving up in the 'skill chain' with the technology maturity. Although, it should not be used against the development of autonomous and automated systems, the shift in job nature will be quicker than anticipated and the society must find ways to adapt. The important aspect of adaption is the increase in minimum-education level to decrease the percentage of unskilled workers (Pham et al., 2018, p. 128). The other socioeconomic solution proposed to overcome the negative effects of increased automation is universal basic income, which was already tested in several countries such as Finland or Canada, although at such an early stage of autonomy adoption in the society, it is often seen as too soon to try. The taxation of robot work-force is considered as the standardised solution to slow down the socioeconomic impacts (Delaney, 2017).

4.5 EXTENDED REALITY

FUNCTIONALITY and APPLICATION

Extended reality is an umbrella term used for computer-generated environments merging either virtual and physical reality or generate a new virtual reality. There are three subcategories of extended reality (XR): Virtual Reality, Mixed Reality and Augmented Reality. The differentiation is the ration of virtual environment embedded in the physical world layer respectively from the lowest to the highest *(Figure* 13*).*

Augmented Reality (AR) adds a virtual layer on top of the physical world, in most cases to deliver more data to the AR user. AR aligns real and augmented objects in a real-time perspective. A popular example is a Snapchat and Instagram filter modifying the user camera image in the real-world display, where the virtual object sits on top of the physical world. In AR the augumentation is not directly tied to the physical object, which means when you point the camera in a different direction the virtual object will also move. AR could be used in a supermarket, a consumer could walk around and scan products with their phone, which could display the product in a virtual version with important information such as allergens.

Mixed Reality (MR) combines the physical world with virtual world in a way that interactions in both are linked "where the virtual augments the real and the real augments the virtual" (Fast-Berglund et al., 2018, p. 32). In MR the virtual object is locked to the physical object, which makes it possible to walk around the object and see it from different angles. Manipulation of digital objects in the physical space and vice versa is an ultimate goal of MR. MR can be used in educational settings allowing students to interact with the object, for example dive into the world of anatomy, while still being able to be aware of the classroom setting.

Virtual Reality (VR) tend to use headsets to create an immersive user experience in a computer-generated reality. The user is able to move around and interact with the environment in a virtual, three-dimensional (3D), 360 degrees world. VR can be a cost-effective alternative to training staff in jobs that are associated with high risk or high cost scenarios.

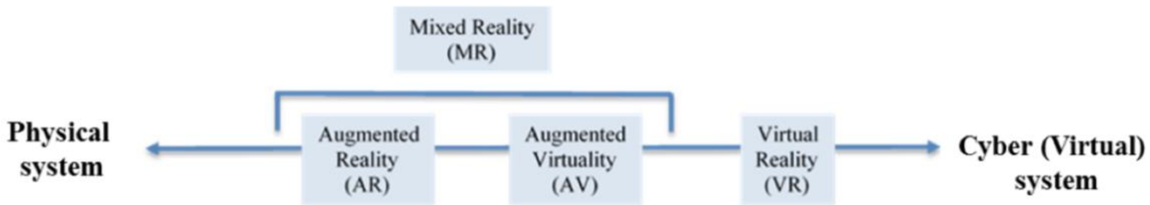


Figure 13 Relation between XR technologies and environment (Fast-Berglund et al., 2018, p. 32)

The industries adapt the uses of XR and begin to see the benefits, especially in the training of employees, collaboration and prototyping stages of the enterprises (Hadwick, 2020, p. 20). The biggest obstacle to wider adoption seems to be head-mounted display (HMD) usability, comfort and wider-adoption by business sector, as the product is relatively novel and perceived as odd by sectors other than consumer leisure and entertainment.

COMPONENTS and ARCHITECTURE

Extended reality is composed of two key components, hardware and software. XR components and their examples are illustrated in *Figure 14*. Simulation engine is responsible for modelling an environment to be reproduced in the virtual setting (D'Andrea et al., 2013, p. 1). Input/output devices create the user interface, which enriches the user experience. A device most commonly associated with XR is a head mounted device (HMD), which delivers a higher level of immersion through head mounted display, stereo sound and motion tracking (Fast-Berglund et al., 2018). Additionally, in a XR setting a user is able to interact with the environment through the use of haptic devices. Haptic devices encourage movement, an interesting application of this can be found in the use of XR in rehabilitation and physiotherapy, where patients perform different movement while the haptic device collects quantitative data of the physio session (D'Andrea et al., 2013, p. 1).

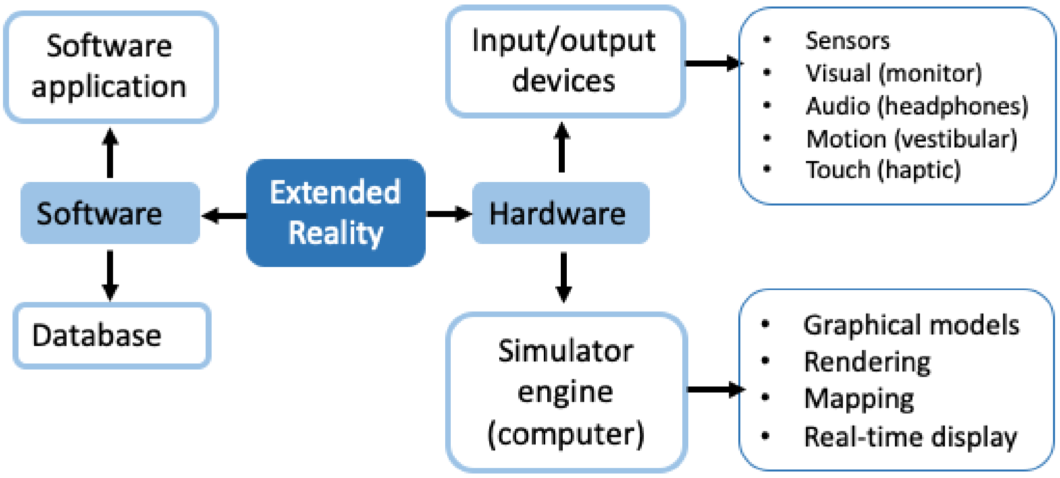


Figure 14 Components of Extended Reality systems (adopted from (Bamodu & Ye, 2013, p. 2)

IMPLEMENTATION

As of today, the XR implementation is out of the scope of in-house development of a non-technological firm or a non-technological user. The developments in XR require a specialistic programming approach, linked with 3D design elements. It costs around 20,000 USD to develop a very simple 3D environment in XR (Watson & Johnston, 2019). The implementation usually requires a team of developers and can cost hundreds of thousands USD for fully interactive implementations. The technical challenges of combining and synchronizing of the two worlds are usually the amount of rendering processes required to achieve a smooth experience (Ethirajulu, 2020). Thus, a successful implementation is not simply a case of programming, but also a sufficient infrastructure, usually related to edge computing technologies or edge cloud. The concept of split rendering (rendering in the cloud) is often utilised, although it requires 5G ready infrastructure. Nevertheless, development and implementation costs will be much lower for AR application as it requires less design of the virtual world and can focus on single 3D objects.

OWNERSHIP

The ownership of data generated by XR is unclear, as the amount of data collected, analysed and generated is not comparable or categorised in the current data privacy acts. The usage, protection and data privacy areas need clarification in a big-scale public project (LLP, 2017, p. 7). Considering the private or limited scope of use of XR, such as the one inside the business or private network, the data is owned by the XR owner and needs sufficient data usage regulations signed by the users.

IMPACT

Extended reality industry is expected to reach a value of 200 billion dollars by 2022 (Fade, 2019). The market is expected to grow rapidly over the next few years, although the consumer and business adoption is limited to only innovators and few early adopters. As of 2020, the adaption is the highest in the consumer sector, while the education and healthcare are catching up very quickly. According to Ericsson reports (Ethirajulu, 2020), the XR is expected to grow exponentially across all industries, enabling better design processes, user training, data presentation and scientific work. Once the benefits of XR and the potential in cost saving is fully understood, some of our physical world may move into a virtual layer for good.

4.6 INTERNET OF THINGS & SENSORS

FUNCTIONALITY and APPLICATION

Internet of Things (IoT) is an increasingly growing network of intelligent devices. Such devices have the ability to collect data through the use of multiple sensors and communicate the data with each other using the internet. The purpose of IoT is the ability to monitor, analyse and remotely control the connected devices. IoT can be defined as "An open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data and resources, reacting and acting in face of situations and changes in the environment" (Madakam et al., 2015, p. 165). IoT builds upon the concept of machine-to-machine communication, which relies on customized communication solutions. IoT is an interoperable platform which integrates machines, technologies, products and people (Leminen et al., 2020, p. 300). IoT is becoming increasingly popular across both consumer related applications and industrial application. One of the significantly increasing industrial application of IoT can be found in aquaculture. The introduction of IoT has facilitated the move toward precision fish farming (PFF), a concept, which has the potential to optimize seafood production while reducing environmental impact and financial costs (DNV GL, 2020, p. 42). Through real time monitoring and information exchange IoT provides a reliable framework for decision making.

COMPONENTS and ARCHITECTURE

The architectural implementation of an IoT system involves a number of fundamental requirements. The "things" must have a unique identity, ability to communicate as well as sense their surroundings. Combination of those three factors will allow "things" to be remotely controlled, opening for informed decision making. Architectural composition of the IoT will highly depend on the area of use, the network can be very complex with hundreds of interconnected devices. Nevertheless, a typical IoT will be composed of 4 distinctive components or layers: physical, networks, platform and application *(Figure 15).*

1) **Physical layer** is the collection of devices/things with embedded sensors and actuators. Sensors have the ability to collect and share environmental data, such as location, motion, temperature or air quality. On the other hand, actuators are able to receive information in the form of commands and carry out required tasks. Each devices in IoT must have the ability to collect and send data as well as receive commands and perform tasks (Leverage, 2018, p. 10).
2) **Network layer** enables communication between all things connected. This can be achieved through the use of gateways, which "sit" on the edge of the network and enable data flow between them. The main function of gateways is the support of multiple interfaces, this

enables the communication of devices connected through different methods such as Bluetooth, ZigBee or WiFi. Furthermore, a gateway enables protocol conversion meaning it translates the data exchanged between incompatible devices and networks (ITU, 2012). The framework for network capabilities is based on internet protocol (IP) application of authentication, authorization and accounting (AAA).

3) **Platform layer** takes place at a level where data processing software is employed. Large amount of data is collected within the IoT network. Constant processing and analysis must be performed to extract valuable information. For that reason, data processing has moved closer to the device or gateway level in the form of edge or fog computing respectively. Edge and fog computing increase the security and privacy of data, lower the cost of data transmission and allow for faster transmission speed (Klonoff, 2017). While edge computing takes place at the edge of the device, fog computing happens at local area network. Both allow for instantaneous data analysis, which can result in initiation of commands.

4) **Application layer** builds upon the platform layer, once the data has been pre-processed in edge and fog computing it is sent to the cloud for further processing, analysis, management and storage. Application layer provides valuable knowledge, which allows informed decision making. The layer serves as a user interface, where data can be visualized. At this level the user is able to remotely control and monitor the system as well as create predefined rules, which can form automatic responses to new information and changes within the system (Leverage, 2018, p. 21).

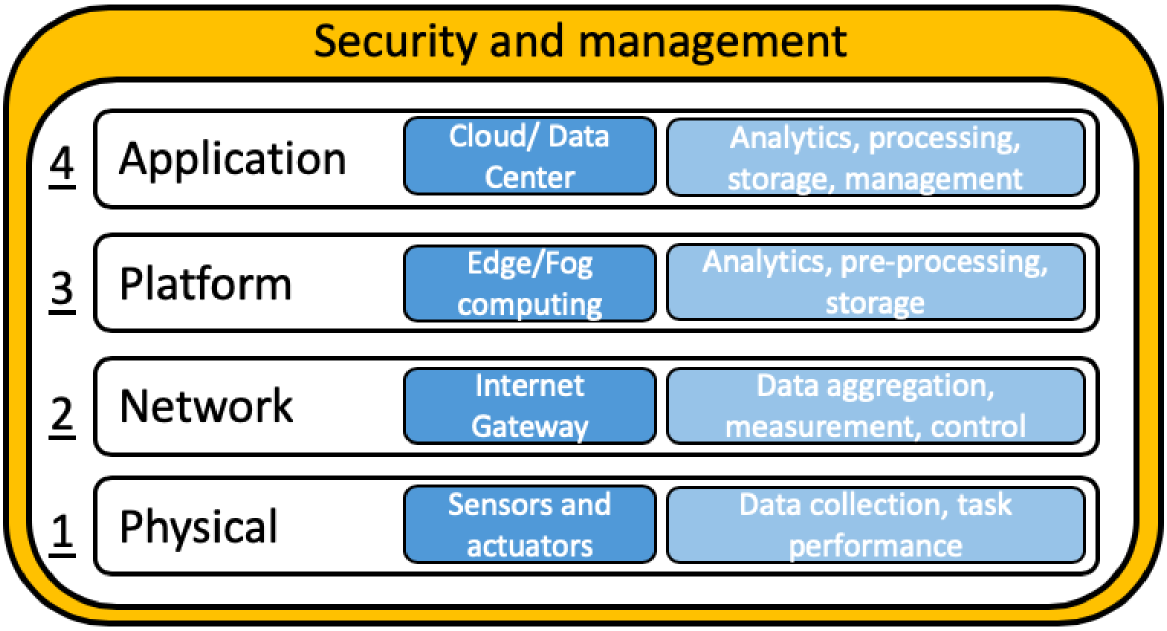


Figure 15 Architectural framework of IoT components

The overarching security and management framework embodies (1) data privacy, confidentiality, and integrity; (2) authentication, authorization and accounting; (3) availability of services; and (4) energy efficiency (Jamali et al., 2019, p. 34).

IMPLEMENTATION

The process of an IoT adoption can be very challenging and time consuming, as each business will require a unique customization of the IoT network. Furthermore, implementation of IoT requires interoperability between the things found in the network and a secure connection between the devices and the outside world. Most IoTs are implemented within a single company, as implementation across multiple businesses remains just as difficult as with current technologies. A concept of "Thing Description" proposed by the World Wide Web Consortium (W3C) introduces an open description format, which enables the semantic and syntactic interoperability between devices found in multiple networks (Korkan et al., 2018, p. 47). A fully compatible system ensures security, efficiency, reliability, and controllability. In an industrial setting a number of organizational conditions must be in place for a successful implementation. It requires a high level of technical knowledge and skills, which could often lead to changes in labour needs and organizational structures (Brous et al., 2020, p. 14).

OWNERSHIP

The ownership of data generated within an IoT will depend on the context. Throughout the lifecycle of machine generated data, it is subjected to a number of different stages. Data capture, acquisition, processing and publication can all be performed by different entities. Due to the large amount of data produced within IoT, data ownership is subject to the provision of the Database Directive. Essentially any entity who has incurred costs handing the data at any stage of data journey has the rights to ownership, the exception is personal data which is a subject to GDPR (Martens, 2018, p. 17).

IMPACT

Currently there are approximately 20 billion devices connected to the internet, it is predicted that this number will increase to 500 billion by 2030 (DNV GL, 2020, p. 11). Internet has revolutionized our lives and economies through the convenient access to information. IoT is expected to be the next great wave of disruption affecting almost all aspects of our lives. IoT application in the health sector will enable personalization of healthcare services. The real-time information sharing will be a key element in the prevention of life threatening diseases and efficiency of treatment (DNV GL, 2020). IoT has the ability to optimize our energy consumption, advance manufacturing practices and improve business processes (Jamali et al., 2019, p. 2).

4.7 DIGITAL TWIN

FUNCTIONALITY and APPLICATION

Digital twin is a virtual, living model of a physical object, process, system, product or service. A digital twin can be defined as "an evolving digital profile of the historical and current behaviour of a physical object or process that helps optimize business performance" (Raj & Lin, 2020, p. 37). When talking about digital twins, it is essential to understand the role of a digital thread. Digital thread is a continuous, unbroken pipeline of data. Digital thread can be considered as the starting point and a fundamental concept, which enables the digital twin to achieve its purpose (Parrott & Warshaw, 2017, p. 10). As the digital twin processes and analyses the data in a near real-time dimension, it requires a constant stream of new data. Life cycle data of the object, its design, physical elements, software elements and historical data is provided through the digital thread. Real-time processing and analysis of data creates a detailed feedback, which can provide insightful understanding of element composition and dynamics of the physical twin. Constant feedback and ability execute commands, either autonomously or with human supervision, creates opportunities for continuous engineering. In an industry context, feedback facilitates recalibration of manufacturing processes and operations. Such functions allow to predict failures, obstructions, and provide recommendations based on simulations of all plausible outcomes. The application of digital twin can aid the manufacturing process. For example, manufacturing of a new airplane can be aided with a parallel digital representation of the plane. Starting at the point of design where the digital twin, given access to an endless amount of information of similar airplanes, can summarize the problems faced by those airplanes and provide improved design solutions. As the construction begins the digital twin can monitor all processes and recommend the best alternatives of materials and predict their life span. Once the full physical version of the airplane comes to life, the digital twin, knowing the whole history of the plane and current usage is able to predict fault a schedule in maintenance. Another application of digital twin can take place in the aftersales care, where consumers can be assured of the lifetime of their product. The development of digital twin can be assigned to advancement in AI and IoT, as the three technologies are highly connected (Fuller et al., 2019, p. 4).

COMPONENTS and ARCHITECTURE

A digital twin is more than just a mirror imagine of its physical twin. As shown in *Figure 16*, each of the twins carries separate roles in the form of three distinctive components. The physical twin collects the operational and environmental data by capturing it through multiple sensors. Operational data refer to the physical functioning of the device such as movement, rotational force or material resistance (Parrott & Warshaw, 2017, p. 8). Whereas, the environmental data denote aspects such as temperature, pressure or moisture level. Initial processing take place on the edge, which significantly reduces the amount of data needed to be communicated through the network. Data communicated from all sensors is then aggregated and further processed on the premises (the edge) or in the cloud. This prepares data for analysis where algorithms are engaged to run multiple simulations and create insight. Insights can be presented in the form of visualizations and performance predictions. If any abnormalities are discovered the digital twin provides a number of optimizing solutions. The solutions can be derived as direct commands, in the case of an autonomous system, or subjected to human intervention. As soon as the solution is approved by either the digital twin or a human, actions can be taken through the use of actuators.

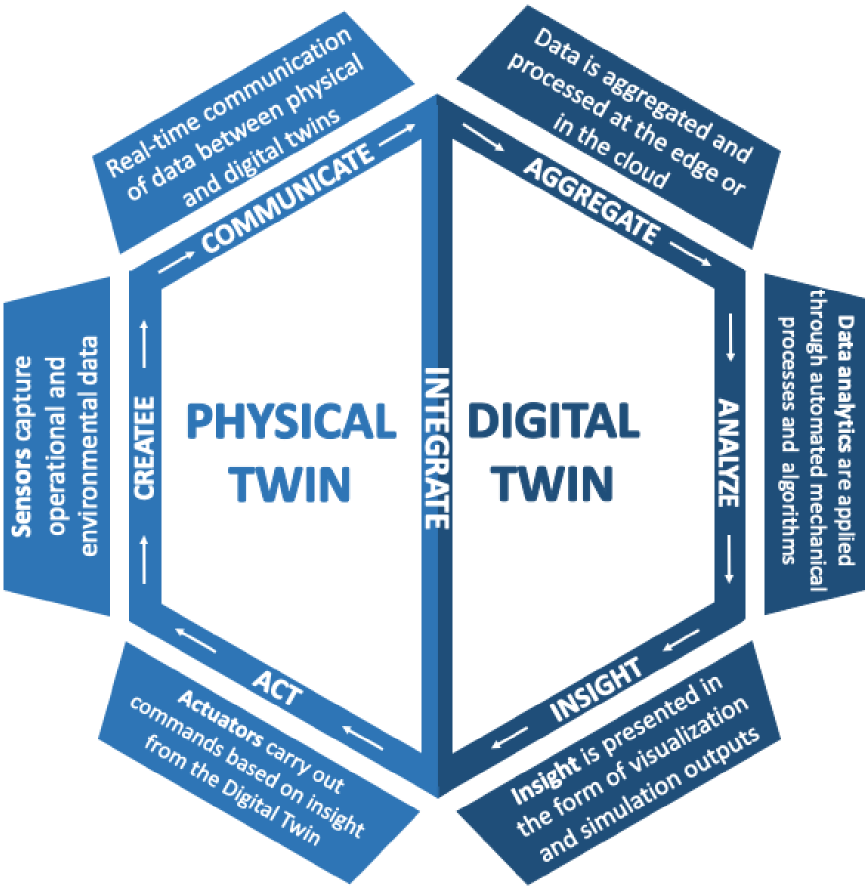


Figure 16 Conceptual framework of the Digital Twin, shape adopted from (Parrott & Warshaw, 2017, p. 5)*, description boxes – own design*

IMPLEMENTATION

Implementation of a digital twin can be a lengthy and costly process; thus, it is important to ensure that the physical object or process are worth the investment. Its connection to AI and IoT means that the technologies will also share some challenges. The concept is still in an infancy stage with a very few real-life applications. Only a handful of world top data companies are currently experimenting with the real case models of the digital twin (Melesse et al., 2020, p. 271). However, as data storage capabilities continue to improve and the costs of computing becomes lower, there are significant chances of increased implementation of digital twins (Parrott & Warshaw, 2017, p. 11).

OWNERSHIP

The infancy stage of digital twin means that issues relating to the ownership, privacy and security of data created by are yet to be decided (Fuller et al., 2019, p. 5). It can only be assumed that the owner of the physical product will also be the owner of the digital twin and the data associated with it. However, in the case of after sale services, which can be provided to the consumers the ownership of data is most likely to fall under the GDPR.

IMPACT

Currently the use of digital twin is most popular in areas where the risk of failure would outweigh the costs associated with the implementation of the digital twin. A sector, which particularly stands out is the aerospace and defence. It is predicted that the digital twin market will be value at 35billion dollar by 2025 (Markets&Markets, 2019). Top three industries, which will adopt the new technology are the automotive and transportation, healthcare, and energy and utilities. As the number of connected devices grow within the IoT, we are likely to see an increased adoption of the digital twin technology.

4.8 BLOCKCHAIN

FUNCTIONALITY and APPLICATION

In order to explore the functionalities of blockchain, one must touch upon the concept of centralized, decentralized and distributed databases or networks. A traditional, centralized database is stored in a single location. Control over the database is given to one entity. A single administrator who is able to control write and read permissions, and alter the records stored in the database. Such databases are relatively easy to establish; however, they are highly prone to failures and potentially hard to maintain. The data integrity and redundancy are easy to keep (Singh, 2009, p. 32), but it's hard to access the same data by multiple users and it is potentially prone to bottlenecks in high traffic.

Blockchain can be defined as "distributed digital ledgers of cryptographically signed transactions that are grouped into blocks" (Yaga et al., 2018, p. 49). Blockchain differs to a traditional database, there is no single server for storage of the data. Depending on the application, the database can be either decentralized or distributed. In a decentralised system, there are multiple servers, which are independent of each other. The database is controlled by multiple permission holders, which make sure that the activity within the network is valid. The most commonly known decentralised blockchain is Bitcoin cryptocurrency (Zheng et al., 2017). In a distributed network there is not a single entity who has full control over the database, the control is distributed across all users (nodes). The goal of blockchain is to distribute and store the information in a database, which is tamper proof and transparent. Tamper proofing the database refers to the immutability of the data.

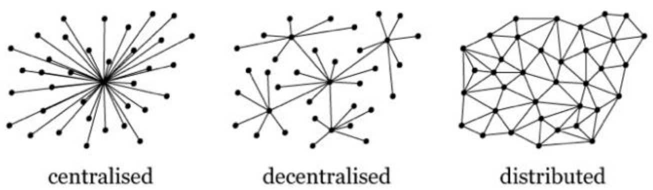


Figure 17 Centralized, decentralized and distributed databases (Future of Fish, p. 16)

Blockchain is becoming increasingly popular across many industries. Areas, which previously relied on third parties to establish a degree of trust will find blockchain very practical (Nofer et al., 2017, p. 186). It has been adopted in the use of smart contracts, satisfying contractual conditions and minimizing the need for trusted intermediaries (Yaga et al., 2018, p. 32). Besides the widespread use of blockchain in the financial sector, blockchain applications are often found within a field of record keeping (medical records, historical records, property records). Currently it is becoming very popular in supply chains where the end product aims to receive a certification. Blockchain enabled documentation of sustainable practices, fair trade or organic sourcing.

COMPONENTS and ARCHITECTURE

Blockchain is a complex technology, thus it is important to understand its components and their interaction (Table 5).

Components	Definition
Consensus model	A way to validate a transaction in a distributed system through a previously agreed process
Cryptographic hash functions/algorithms	Hash algorithm produces a condensed representation of an input (a message) and maps it into an output (message digest). It is a one-way function, meaning it is computationally infeasible to invert it.
Transactions	A recording of an interaction between parties. Interactions such as the transfer of assets between parties, or the creation of new assets.
Asymmetric-key cryptography	It is a pair of mathematically related keys (one private, one public). "Users can digitally sign data with their private key and the resulting signature can be verified by anyone using the corresponding public key" (Yaga et al., 2018, p. 49).
Addresses	"A short, alphanumeric string derived from a user's public key using a hash function, with additional data to detect errors. Addresses are used to send and receive digital information and assets." (Yaga et al., 2018, p. 49)
Ledgers	A collection of transactions
Blocks	A data structure containing a block header (data describing the block itself) and block data (portion of a block that contains a set of validated transactions and ledger events) (Yaga et al., 2018, p. 49)
Node	An individual system within the blockchain network

Table 5 Definitions and descriptions of blockchain components (Barker, 2016; Yaga et al., 2018)

A blockchain stores the information (transactions) in blocks, which are added to the chain (multiple, previous blocks). Each transaction, once started, gets distributed in a block across the network. Multiple nodes in the network verify the transaction and add it to their chain. The block stays in the location for as long as the chain exists and can't be modified or deleted. In an encrypted chain, the location is represented by a hash. Hash is the only way to get to the location in the chain and decrypt the real value. On the other hand, blockchain is usually fully accessible to all its nodes. It means that any client can have the blockchain on their machine and read all the transaction details that are predefined in the blockchain network. This predefinition is a one-time setup of a consensus model that can't be altered, and the content is hashed. It means that the administration, access control and permissions are in the hands of all the nodes within the network to be verified constantly. The blockchain will also be stored in each node within the network, effectively duplicating the blockchain and the data as many times as there are nodes within the blockchain, making it immutable. This way it is close to impossible as of today to alter the data within a public blockchain. It would require taking over more than 51% of nodes, which in the current sizes of public blockchains becomes a task near impossible (Zheng et al., 2017, p. 561). Blockchain often utilises 'proof of work' forcing computers to compute the hashes (referred to as mining) in order to join the network.

IMPLEMENTATION

Any multi-transactional database could benefit from blockchain security, integrity and transparency, although the implementation costs may be slightly higher for a private company. This is mainly due to the relative novelty of the technology, which results in higher hourly costs of consultation in the field related to the initial platform build, maintenance and monitoring. For a private blockchain a 5 year implementation cost is estimated around 1.5million dollars, whereas for a public blockchain the costs is around 110 thousand dollars (EY, 2019, p. 10). The current transaction per second limit in standard blockchain designs makes it slower compared to traditional centralised databases. Slow performance may not make the implementation worthwhile with current computer power available for an average node (Chowdhury et al., 2018, p. 4).

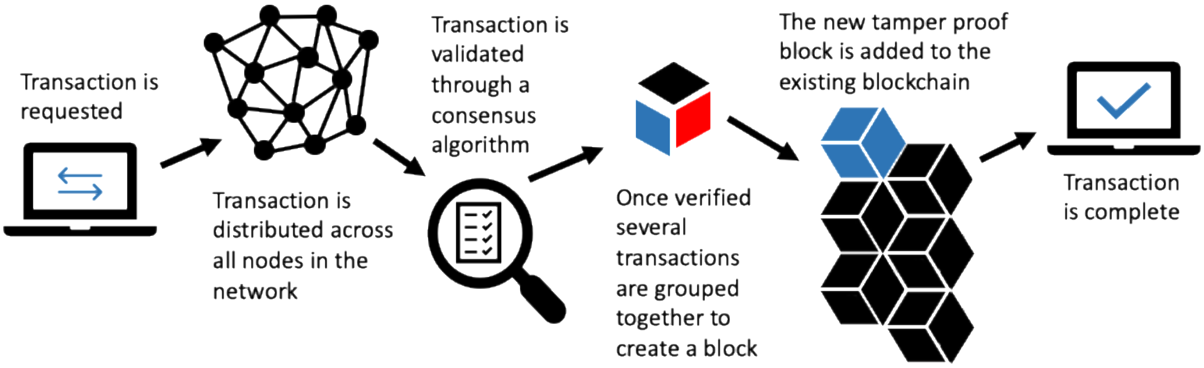


Figure 18 Conceptual framework of a blockchain adopted from (Erhan et al., 2019, p. 4)

OWNERSHIP

A decentralised or distributed approach in blockchain makes the data more secure but also available throughout the network. The data ownership will be dependent on the blockchain design. In the case of a small private network, we can control and potentially temper with the data by deleting all the nodes, so in some aspect we have ownership of the data (Zheng et al., 2017, p. 559). If the blockchain is public, anybody in the world can access the transaction information (this is to make the verification within the network possible). We have no effective control over all the instances and the blockchain can spread around the world, making the ownership and control near to impossible.

IMPACT

The blockchain market is expected to be worth 20 billion dollars annually by the end of 2024 (Mitic, 2019). The blockchain may become a standard for currency, voting, contracts, healthcare and all aspects of life that include data. Every industry will use it eventually, once the key issues of blockchain related to computational power and standardisation will be tackled effectively. There are two sides to the environmental impacts of blockchain, on one hand data centres require huge amounts of energy in order to support the blockchain network. On the other hand, blockchain application in supply chain management offers increased transparency and efficiency, leading to a more sustainable use of resources (GEF, 2019, p. 5). Furthermore, the use of smart contacts is likely to cause disruption in the labour markets in areas where there is a need for trusted third parties. The IoT is also expected to go in parallel with blockchain adoption, as IoT devices can also create the blockchain networks. As of today, the disruption is in place, although it is not visible to the public. It's the question of when, rather than whether the governments and businesses will treat blockchain as a standard technology.

Crypto anchors

Blockchain is widely recognized for its immutability, increasing trust and integrity of information, however it lacks the connection to the physical world. Crypto Anchors is a concept that is builds upon the Blockchain technology *(Figure 19).* Despite not being mentioned in the DNV GL Technology Outlook it is an important concept to mention as its functions could prove to be very beneficial in the field of traceability. Crypto Anchors are currently widely explored by IBM, in 2018 IBM Research predicted Crypto Anchors as one of the five innovations that will change our lives (IBM, 2018). However, up to today IBM remains one of the few companies exploring this concept. Nevertheless, despite its early emergence Crypto Anchoring offers interesting applications. Cryptographic Anchoring "ties a unique identifier to the physical object with a property of the object that is hard to clone, forge, and transfer to another object" (Balagurusamy et al., 2019, p. 4:2).

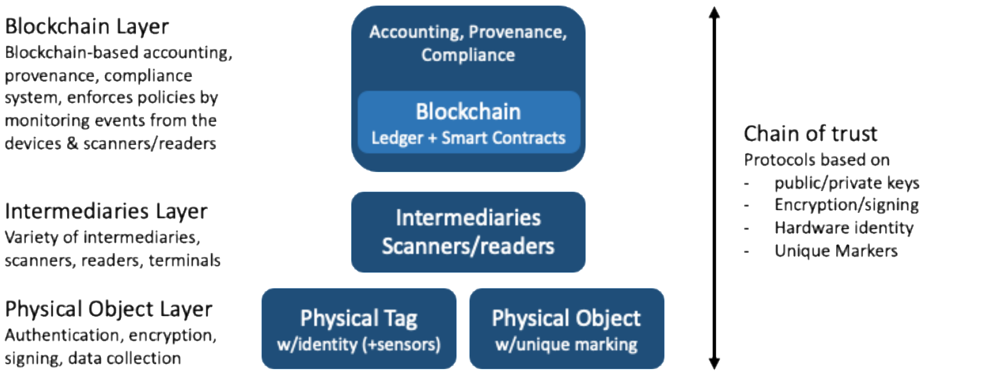


Figure 19 Three-layer architecture of the crypto-anchor concept taken from (Balagurusamy et al., 2019, p. 4:10)

There are three main sources of authenticity: configured secrets, physical fingerprint, embedded security feature (Balagurusamy et al., 2019, p. 4:2). Configured secrets can be found in cryptographic keys, where the information behind the key cannot be revealed, only the owner of the copy knows what the key stores. In physical fingerprints, the crypto anchor ties itself to one of the attributes specific to the object making it a source of its authenticity. For example, an optical characteristic of a fish such as the skin or fillet pattern. It becomes a tamper proof physical fingerprint that can be matched to the immutable digital fingerprint stored in a blockchain. Embedded security features could be printed onto the product in a form of security ink, micro-printing or hologram.

4.9 5G

FUNCTIONALITY and APPLICATION

The fifth-generation cellular network is the telecommunication technology that makes data transfers 100 times faster than the current 4G technology (Hoffman, 2020). Currently the download speed of 5G is 10Gb/s compared to 100Mb/s for the previous generation of 4G networks. The main difference between 5G and its precedents is the use of higher frequency of radio waves of shorter range (5G-ACIA, 2019, p. 14). Effectively the advantages of 5G will be experienced by the whole population, as demand for internet usage and data transfer continues to grow (Grijpink et al., 2020). Transformations will take place on an industrial, service and consumer scale. The introduction of 5G networks in major cities and technological hubs around the world creates exciting opportunities for further development and increase in efficiency of Big Data, AI, The Cloud, IoT, Blockchain and Autonomous systems.

COMPONENTS and ARCHITECTURE

The aim of the 5G network is to provide reliable communication to three distinctive types of users: consumer, service and businesses. The network has been designed in a way that will provide unique services to each group through a notion of **network slicing**. Network slicing is a concept of separated virtual networks delivered over a single network (Ordonez-Lucena et al., 2017).

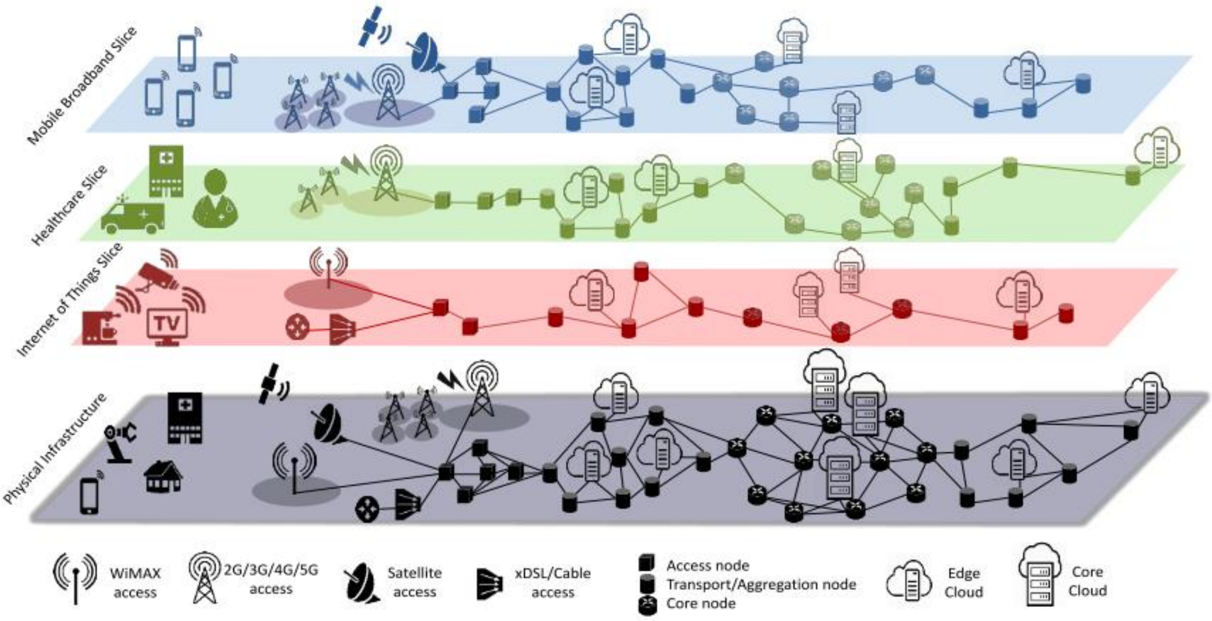


Figure 20 5G network slices build upon an underlying multi-access and multi-vendor physical infrastructure taken from (Ordonez-Lucena et al., 2017, p. 2)

The physical infrastructure requires a high density of the antennas due shorter range of the high frequency radio waves, meaning higher cost for the provider (Grijpink et al., 2020, p. 22). The positive of higher density is lower latency[3] of the network. Making it reliable and nearly a mission-critical system ready (fully ready if we consider Ultra-Reliable Low-Latency Communications (URLLC) being introduced shortly) (5G-ACIA, 2019, p. 14). URLLC enables reliable transmission of small amounts of data, it is aimed at improving critical communication points in areas such as remote surgery or autonomous system control. The 5G can be further categorised into specialistic application of Enhanced Mobile Broadband (eMBB) as a natural progression from the LTE technology of fourth generation, supporting higher capacity and wider coverage. EMBB will serve the mobile broadband slice enhancing the experience of consumers as demand for internet transfer increased due to entertainment and internet applications (Grijpink et al., 2020). The Internet of Things slice will be enabled by the Massive Machine-Type Communications (mMTC), which aims to support a large number of devices located in one area (Kavanagh, 2019).

IMPLEMENTATION

To utilise the benefits of 5G as a consumer or enterprise, all that is needed is a 5G ready device. The new data transfer speed standard makes 5G a competitive alternative to fibre-network solutions for some enterprises and projects, especially those requiring remote locations of devices. The implementation is easy and will not cost much. The network devices will change the standard from 4G and 5G, thus the users will have to update their devices – this may be the only implementation cost for the easiest uses. Concerning commercial projects, the connectivity is also not problematic, a 5G ready devices do not cost more than 4G devices, while these were introduced, thus it could be seen as a projected cost of an upgrade for most.

OWNERSHIP

The data transferred using the 5G technology is customer data and belongs to the user. Although, there are still security concerns involved in the 5G technology. The antennas are more 'intelligent' and have higher analytical capacity due to use of edge computing, thus each of the antennas will effectively save the data on trends, behaviour, performance and potentially few more anonymised inputs, which then can be stored and owned by the provider (Gamal Emara, 2019). Enterprises often see it as unnecessary risk and tend to stick to private-fibre solutions for onsite projects. Similar risk exists for the past 2 generations of telecommunication networks, although its scope increased with the advancements of the antennas. It should not stop customers from adapting, although it has had negative effects on adoption previously. The case of Huawei antennas in the US banned due to exactly these security concerns is the best-known case (NIETSCHE & RASSER, 2020).

[3] Latency is the amount of time required for data to travel from one point to another.

IMPACT

5G communication technology is predicted to be a 700 billion dollar market by 2030 (Karlsson, 2019). 5G networks have impact on the advancement of all the technologies previously described, as it increases the data transfer capacity – an essential element of each technology. The IoT are affected by mMTC, the healthcare, aviation and shipping are affected by URLLC, the eMBB supports and enhances the mobility (Ordonez-Lucena et al., 2017). The 'smart' technologies including monitoring by sensors, analysis, tracking and management are improved. The real-world examples are remote control of heavy machinery, because of low latency of 5G, the smart streetlights and smart drainage systems in cities, communicating effectively where thousands of things communicate at the same time. With the size of transceiver chips developed by Intel, the tracking application is inevitable and natural to come next (Evans, 2017).

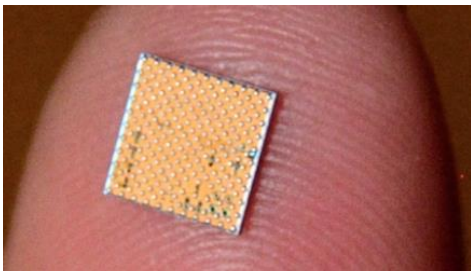


Figure 21 A tiny transceiver chip developed by Intel for the new 5G Modem (Evans, 2017)

4.10 QUANTUM COMPUTING

FUNCTIONALITY and APPLICATION

Quantum computing is a novel approach to computing calculations. The power of a quantum computer promises exponentially fast processing capabilities (Arute et al., 2019). Currently classical computers do not have the necessary power to process and analyse the huge amounts of data, which is currently being created. "Universal quantum computers leverage the quantum mechanical phenomena of superposition and entanglement to create states that scale exponentially with number of qubits, or quantum bits."(IBM, 2019). Quantum computing will offer revolutionary capabilities, however, it is believed that the technology is in a very early stage and no commercial application will take place before 2030 (DNV GL, 2020, p. 13).

COMPONENTS and ARCHITECTURE

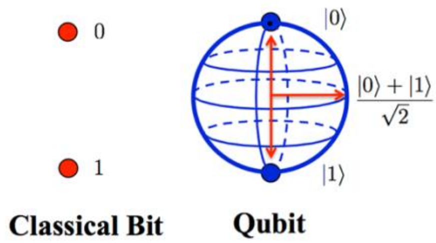


Figure 22 Classical Bit vs Qubit

In 'classical' computing bits are used to represent and process data, effectively making the computing long lists of 0s and 1s which then use logic gates for calculations, resulting in either 0 or 1. The difference between the classical approach and the quantum approach is the use of **qubits** instead of bit. QC uses quantum mechanics for calculations, based on the wave mechanical models, instead of electronic circuits (Poonia & Kalra, 2016, p. 280). Effectively, the quantum computer uses qubits, which are mixes of 0 and 1 bits in a so-called superposition[4]. **Superposition** means that a qubit can be both 1 and 0 at once (Prince, 2014, p. 156), putting it in a state of uncertainty until further processed. In effect, the processing is done to calculate multiple scenarios of each uncertainty. Whereas, the standard computing requires a solid input that is always certain due to either high or low charge (1 or 0 respectively). The uncertainty makes the quantum computing an incredible tool for simulations and predictions (including cryptography and models). Another concept explored in quantum computing is **entanglement**, where two or more particles are in the same state even if separated by larges distance meaning they are not independent (Moret-Bonillo, 2015, p. 96). Quantum computing and physics are an area which is still highly theoretical and claimed by many to be impossible to harness on a bigger scale (Moskvitch,

[4] A famous paradox explaining the concept of superposition comes from Schrodinger. An imaginary cat is placed in a sealed box with a device, which has 50% chances of killing the cat in the next hour. When the box is open after an hour, we can determine whether the cat is dead or alive. Schrodinger argued that according to quantum physics the moment before the box is opened the cat is both dead and alive at the same time. Only after the box has been opened the definite state of the cat is determined (Moring, 2001, p. 192).

2018). Quantum computing requires temperatures often below 5 Kelvins (-270C) in order to maintain the sufficient physical state and further stabilisation of the superposition of qubits (Heuck et al., 2020).

IMPLEMENTATION

The implementation is extremely hard at the moment. In a large part the technology is only theoretical and until proven otherwise on the bigger scale of more than several hundred thousand of qubits of power. Similar to the advancement of standard computing, at first it could be affordable only to the biggest corporations, although within several years it could be used by any consumer. If we achieve a state of portable quantum computers within our century, the world we know will be much different and more predictable.

OWNERSHIP

The data produced by a quantum computer will be owned by the computer owner, as it is with standard computing approach. Of course, there may be exception like cloud computing for others or working with other datasets. However, it is too early to consider these aspects of the technology.

IMPACT

IBM has developed a quantum supremacy processor with a power of 53 qubits. They claim to have processed a 10,000-year problem for a standard computing approach in 200 seconds (Arute et al., 2019, p. 505). This scale represents the power of a quantum computing, but also a danger of disruption to the previous technologies that we currently use. Quantum supremacy refers to the quantum computing ability to perform tasks, which are currently unattainable for standard classical computers (Arute et al., 2019). Effectively, the first company or individual possessing a fully operational quantum computer, may be able to crack any encrypted data within hours rather than hundreds of thousands of years – this makes the whole financial sector at risk, thus our socioeconomical fundaments. If we forget about the negative aspects, then the quantum supremacy can make the technological advancement so fast that an average human will not be able to effectively follow it. The unsolvable mathematical and physical problems could be tackled within days, the diseases could be analysed to find a cure within days, the weather models could be analysed to a degree of effective climate control (Marr, 2017). Out of all technologies described, it is the quantum computing that brings the most disruption.

Table 6 Summary of emerging technologies and their characteristics

		Artificial Intelligence	Autonomous systems	Extended Reality	Internet of Things	Digital Twin	Block chain	5G	Quantum Computing
Functionalities		- Mimicking of human behaviours - Learning - Reasoning, decision making - Pattern recognition	- Autonomous control - Decision making under uncertain circumstances	Immersive or blended experience of the virtual world	- Communication between multiple devices - Remote control - Monitoring and analysis	- Living model of a physical object/process - Real-time processing - High level risk analyses - Predictive maintenance	- Secure and transparent/ confidential way to share information among many users	Reliable and fast connectivity	Exponentially fast processing and predictive capabilities
Applications		Can be applied to all aspects of our life	- Repetitive tasks - Areas where the risk of human error or to human life is too high	- Training of employees - Prototyping new products/systems - Collaboration in the workplace	- Energy saving - Precision aquaculture - Life cycle of a product - Supply chain management	- Areas where the risk of failure is too high - Life cycle of a product - Testing new systems prior before production	- Supply chain - Financial transactions - Smart contracts - Record keeping	- Mission critical tasks - Communication between vehicles and infrastructure - All areas of our lives	QC will replace standard computing, it can be applied in all aspects of our life
Implementation	Cost	Low in Weak AI High in Strong AI	The higher the level of autonomy the higher the cost	High	High	High	- High costs for private companies - Relatively low costs for public applications	- Low for user - Very high for provider	Very high
	Technical skills required	Low in Weak AI High in Strong AI	The higher the level of autonomy the higher the skills required	High	High	High	High level of skills required	- Low for user - Very high for provider	Very high
	Challenges	- Ethics - Morality - Lack of regulations - Lack of awareness of benefits	- Ethics - Morality - Lack of regulations - Lack of awareness of benefits	Lack of awareness Lack of regulations Computational power (rendering)	- Requires interoperability - Lengthy customization process	- Lengthy process - Lack of regulations - Computational power	- Slow performance (computational power) - Complexity of integration - Lack of regulations	- Security and privacy concerns with regards to data - High density of antennas	- Sensitivity to environment - Susceptible to errors - Very complex concept
Ownership		Database owned by the entity who obtains, verifies or presents the data. Data point linked to natural persons covered by GDPR	Needs clarification in data privacy acts. However, the owned of the autonomous object is likely to own the data	Needs clarification in data privacy acts. However, the owner of the device is likely to own the data	Database owned by the entity who obtains, verifies or presents the data. Data point linked to natural persons covered by GDPR	Needs clarification in data privacy acts. However, the owner of the device is likely to own the data	Data ownership in public blockchains is hard to obtain, all nodes have equal access. In private blockchains the data is owned by the	Data belongs to the user. However, the provider will have the capacity to store anonymized performance data	Too early to consider data ownership, however, it can be assumed the data will belong to the owner of the computer
Impact	Society	Displacement of the labour force	Displacement of the labour force.	Parts of physical world will move into a virtual world for good	Changes in organizational structures and labour force	Changes in organizational structures and labour force	Disruption of labour, where there is a need for trusted third parties	Increase in the speed of changes exemplified under other technologies	Potential to disrupt the socioeconomics fundaments
	Industries	All	- Manufacturing - Mining - Maritime Automotive	- Consumer - Entertainment - Education - Marketing - Healthcare	- Manufacturing - Supply chain - Energy/utilities - Consumer - Retail - Healthcare - Food production	- Aerospace & Defence - Automotive - Transportation - Healthcare - Energy/utilities	- Supply chain - Banking/Finance - Real estate/property - Healthcare - Energy - Government (voting)	All	All
Benefits		- Better decision making - Enhance productivity - Conversion of information into knowledge - Solutions to complicated problems	- Predictability - Enhance productivity - Evade human errors - Better decision making	- Safe/controlled environment - Little risk - Increased engagement	- Increase efficiency - Reliability - Controllability	- Reduced risk - Decreased maintenance costs - Increased reliability of equipment - Improved customer service	- Transparency - Security - Integrity - Immutability	- Increased efficiency of other technologies - Improved critical communication - Higher capacity - Wider coverage	- Quantum supremacy - Enhanced machine learning - Solutions to climate change - Predictability

5. EMERGING TECHNOLOGIES AND TRACEABILITY

As exemplified in sections 3.4 and 3.5 traceability systems and the general concept of traceability are faced with several risks and challenges. There is a clear need for improvement in order to enjoy the full benefits of traceability such as transparency, trust, risk mitigation, market access or operational efficiencies. New technologies have the potential to address several risks and challenges surrounding traceability and traceability systems. Knowing the functionalities and applications of technologies exemplified in Chapter 4, I can now proceed to create this link while addressing research question nr.3.

(3) What is the potential of these technologies to address the limitations and challenges of food/seafood product traceability systems?

Several risks and challenges are directly associated with the use of current technologies and the financial capabilities of the FBOs. Implementation costs, maintenance costs or the need for highly skilled technical staff represent challenges that are faced by most companies starting or running a food business. It is important to acknowledge these challenges as they have helped to build a clearer picture of the current struggles faced by the FBOs in the field of traceability. However, the emerging data driven technologies mentioned in this study are very likely to be associated with many of the same challenges, as in particular the implementation costs are likely to be higher due to their novelty. These challenges will be most evident for small or medium FBOs, where the financial barriers will prevent them from investing in the new technologies until the technologies weave themselves into our everyday lives. I am aware that none of the data driven technologies described in this study were designed specifically to address risks or challenges of traceability systems. The aim of the analysis is to explore the potential of using these technologies for improving traceability systems (for example, the smart phone was not specifically designed as a navigation system, nevertheless, since it had the potential to simplify access to a navigation system, it started to be used as such instead of a dedicated such system).

5.1 TRACEABILITY OBJECTIVES

For the purpose of exploring the relevance and applicability of emerging technologies in seafood traceability, risk and challenges found in traceability systems have been transformed into a comprehensive list of objectives. Meeting these objectives will deliver a fully transparent and functional traceability system, that could be applied in any seafood product supply chain and potentially other supply chains in the food industry.

The following list of objectives will serve as a basis for technology assessment:

Fine granularity – achieve finer granularity, if that is beneficial for the FBO, i.e. one identifier represents a small amount of products (e.g. company can produce 1000 kg, call that "one hundred products (or units)" and use 100 codes (unit identifiers) for it instead of calling the 1000 kg "one product (or unit)" and using one code (batch identifier) for it). One has to note that companies should make a cost/risk-benefit analysis to determine what granularity is best for them. Finer granularity means more work and higher cost; the benefits of finer granularity might not justify that. In this thesis it is assumed that FBOs have as objective achieving finer granularity, as this would translate in a smaller amount of products to recall if anything should happen (Olsen & Borit, 2018)

Documented transformations – each action taken along the supply chain is registered and transformation metadata is collected

Integrity of information – key data elements are stored in the system and remain intact while flowing through the traceability system

Processing of large amounts of data (more TRU attributes) – the system is able to collect and process large amounts of data

Uniform Standards – key processes such as data collection, transmission or addition are carried out in the same way across the whole supply chain

Interoperability – both semantic and syntactic interoperability is achieved, meaning all parties are able to understand the data and communicate it between multiple systems

Increased Trust & Security – the interactions between different actors within the traceability system are secure and follow the generally agreed regulations

Product Authenticity – the product is what it claims to be

Increased awareness – increased awareness and understanding among users and consumers

Increased take up – unlocking the potential of technology, particularly for small and medium enterprises

5.2 EVALUATION OF POTENTIAL AND APPLICATION OF EMERGING TECHNOLOGIES FOR SEAFOOD PRODUCT TRACEABILITY

Each technology is evaluated based on its potential to meet a given objective, therefore, showcasing its ability to address the problem. The explanation of colour codes is included in **Table *7***. The results of the assessment of the potential of emerging data driven technologies for seafood product traceability are summarized in Table 8.

Table 7 Colour coding of results - explanation

	Technology functionality has the potential to fully meet the objective
	Technology functionality had the potential to supports the achievement of this objective given other aspects are in place
	Technology functionality might not directly impact on meeting the objective

Table 8 Results – Evaluation of the technologies' potential to meet traceability objectives

	Fine granularity	Documented transformations	Integrity of information	Uniform standards	Processing of large amounts of data	Interoperability	Trust & Security	Product Authenticity	Increased awareness	Increased take-up
Artificial Intelligence (AI)	- Ability to recognize fish species: machine learning/computer vision - Ability to read barcodes - Faster identification	Machine Learning/ pattern recognition More accurate documentation of transformations	- ML - Identification of Critical Traceability Points (CTP) - Improvement of practices	Machine learning can assess how key processes are carried out across the industry and recommend common standards	AI is capable of processing large amounts of data	Provides understanding over several systems at a time recommending the best solutions for both semantic and syntactic interoperability	Able to discover irregularities, however, a fully trustworthy system should be supplemented with Blockchain	Ability to identify seafood products as well as discover fraudulent behaviour. Can be supplemented with data collected by bio and chemical sensors	Can give insight into different processes, which increases our understanding	As understanding increases, FBO will be more inclined to invest in TS . However, high costs of implementation
Autonomous systems	- Automatic identification will enable finer granularity as identifiers can be given to smaller amount of products	- Automatized documentation of transformations - More accurate recordings	- Elimination of human error and Identification of Critical Traceability Points (CTP)	Standards can be incorporated into the set of rules automatization follows	Autonomous systems are capable of processing large amounts of data	Only at the highest level, same principles apply as in AI	Elimination of human error or possibility of fraud. However, just as AI it also requires Blockchain	Able to identify seafood product and discover fraudulent behaviour. Can be supplemented with data collected by bio and chemical sensors	Autonomous systems implemented in multiple links in the supply chain could lower the costs of labour, while minimising human error	Lowers costs of labour and offers a supply chain free of human error, however, high costs of implementation
Extended Reality (XR)	There is no direct application in creating a finer granularity.	Transformations could be visualized in a virtual platform	There is no direct application in ensuring the integrity of information	Educate users and public on importance of standards	Able to process large amounts of data, but requires fast connection when rendering	There is no direct effect of Extended Reality on interoperability	Visualization of the supply chain can increase trust among the FBO and consumers. No direct application in ensuring the security of data	Ensures product authenticity at some stages of the supply chain. E.g. live 360-degree view of a fishing operation, elimination of IUU	XR offers an opportunity in educating and training FBOs. Visualization of the supply chain for the consumers	Visualizing the benefits and uses of TS, FBO will be more inclined to participate in something they understand. However, high implementation costs
Internet of Things (IoT)	- Identification of seafood product through sensors and help of AI - Faster Identification	Automatic documentation of transformations through the use of sensors	IoT enables data transmission between devices	Improves standards with regards to data collection. Can be supplemented with AI	Due to the edge computing IoT is capable of processing large amounts of data.	IoT alone cannot ensure interoperability. Can be supplemented with the Web of Things and the concept of "Thing Description"	The level of trust and security of data collected through IoT will be reflected in the level of trust in the data stored in the TS.	IoT alone cannot guarantee the authenticity of a product	Connected devices can deliver more information, increasing the understanding of traceability and optimizing processes	IoT offers huge benefits for internal traceability, however, the take up could be slowed down by the interoperability issues
Digital Twin	Automatic identification through sensors	Automatic documentation of transformations through the use of sensors, instant creation of a digital twin	Digital thread ensures that all operational and historical are kept intact in order to enable the functioning of the Digital Twin.	As Digital Twin is highly connected with AI and IoT it can help establishing uniform standards.	Capable to process large amounts of data in a real time	Similar to IoT, It could be based on the Web of Things and the concept of "Thing Description"	The level of trust and security of data used to create the digital twin will be reflected in the level of trust in the data stored in the TS.	Able to identify products through sensors. Continous stream of information can contribute to product authenticity	Full virtual version of a physical seafood product and its journey can increase understanding of the importance of traceability	Digital Twin offers increased understanding of TS. Could lead to increased take-up. However, high implementation costs
Blockchain	Need to be supported by the use of crypto anchors	Blockchain can ensure that all metadata is recorder and securely stored. Suitable for documenting transactions	Due to immutability and recording of transactions. Blockchain is capable of ensuring data integrity	Consensus model in Blockchain can help to establish uniform standards across all nodes	Able to process large amounts of data, but slower than centralized databases. Could be enhanced by 5G	Blockchain contributes to improving interoperability through the use of a consensus model and recording of transactions	Transparency and immutability of Blockchain can increase trust and security of data	Blockchain alone cannot ensure product authenticity. Crypto anchoring could be used to support Blockchain	Public Blockchains offer a full view of product attributes/ journey to consumers. Transparency beyond the one-up/one-down dynamic	Blockchain ensures trust and security. FBOs will be more inclined to invest in TS. However, high implementation costs
5G	5G alone is unable to ensure any of the objectives. However, the fast data transmission and network slicing is able to support each of the technologies mentioned in this table									
Quantum Computing	Possibilities that can be achieved through the use of Quantum Computing are limited only by our imagination, QC has the potential to not only meet all the objectives but also completely revolutionize the whole traceability system									

Artificial Intelligence

Computer vision supported by deep learning algorithms have the ability to recognize fish species. Furthermore, it has been found that neural networks can be used to read barcodes (Fridborn, 2017, p. 33). Maybe in the near future, such networks will be preferred to barcode readers if they increase speed or accuracy. Automatizing the identification process with robotics and machine learning can speed up the process, leading to a finer granularity. Machine learning (ML) offers countless benefits for the entire seafood product traceability system. Ability to learn and recognize patterns will enable the discovery of critical traceability points (where information is usually lost), ensuring integrity of information (e.g. analysis of patterns in specific supply chain).

AI can support the establishing of more optimal common standards leading to increased interoperability. Given AI has access to information across all points in the supply chain it can analyse the ways key processes are carried out and recommend the best or most suitable standards for that specific supply chain or for the whole industry. With ML it is possible to process large amounts of valuable data that previously had no use. Doing so will improve the predictive analysis of ML making it possible to discover and predict illegal activity (NOU, 2019). AI might be able to increase trust as ML would be able to discover irregularities or fraudulent behaviour along the supply chain, improving the process of control and inspection (Probst, 2019). Increased network speed and provision of data to the AI through 5G will increase the efficiency of the AI. AI can increase our understanding of the TS components and how they interact. Giving us having a comprehensive insight into all the processes that place along the supply chain, ML can help to minimize seafood product losses and increase operational efficiency. As our understanding of the TS increases, FBO will be more inclined to invest in TS and new technologies. However, the costs of implementation may be too high for small and medium enterprises (SMEs) at this point in time.

Autonomous systems

Automatic identification might enable finer granularity and improved documentation of transformations. However, in order to enjoy the most benefits the highest level of autonomy should be taken into consideration. In fully autonomous systems there is no possibility for human error (it is not considered here the human errors from the phase of setting up and configuring the system) and information integrity can be achieved. Autonomous system can operate with a pre-defined set of rules, by incorporating standards into these rules the systems can help to harmonize the whole supply chain creating interoperability.

Fully autonomous systems would require the use of 5G (or better). Autonomous systems can increase both trust and security as it helps to eliminate human error or the possibility of fraud. Fully autonomous systems require no external intervention, this means they have the ability to correct failure of the system even in uncertain environments (Eisinger, 2020). This could be particularly useful in offshore aquaculture plants, where human intervention may not be possible. In the long run autonomous systems implemented in multiple links in the supply chain could lower the costs of labour, while minimising human error (imagine a vertically integrated FBO where an autonomous system catches the fish and processes it, while the final product is sold in an Amazon Go type of automated shop).

Extended Reality (XR)

Extended reality offers unique opportunities in the field of traceability. XR can create value for the FBO both externally and internally. Internally, XR can enable process efficiency through collaboration between FBOs in research, development and training of staff (Ro et al., 2018). Externally, it can improve the customer interactions through the engagement of FBOs and other stakeholders in virtual education and training. Furthermore, visualising the whole supply chain of a product could result in consumers making better purchasing decisions. If two similar fish products were available and one of them came with the possibility to not only see its entire journey but also meet the fisherman who caught the fish, some people would be may be willing to pay a little extra for that possibility.

XR requires large amounts of data to create an accurate virtual representation of the seafood supply chains. However, in order to reach its full capacity, it would require 5G in order to enable faster rendering. With enough data the transformations could be visualized in a virtual platform. Visualization of the supply chain can give people access to situations that usually are closed to the public eye building trust and relationship among the stakeholders. Being virtually present in a fish processing plant or a fishing vessel can bring the consumer closer and help to increase trust among the FBO and consumers. While, XR has no direct application in ensuring the security of data. XR might ensure product authenticity at some stages of the supply chain. For example, a live 360-degree view of a fishing operation would be able to help eliminate IUU fishing practices. The perceived safety of the technology, organizational readiness, environment and external pressure are among the factors that will determine the adoption of XR (Chuah, 2019).

Internet of Things

The multiple sensors found within IoT enable automatic registration of seafood products. With the help of AI, it will be able to recognize species/barcodes faster than standard data collection technologies such as barcode scanners. Furthermore, automatic sensors and data collection can ensure that any actions taken along the supply chain are registered, and if combined with Blockchain each this could create a suitable infrastructure for recording and documenting transformations. Number one benefit of IoT is the ability of things to communicate. As the communication between devices is enabled it is very unlikely any information loss will take place. However, this should also be supplemented with Blockchain ensuring the data is secure and visible to other FBOs in the chain. Communication between devices must be based on a uniform standard, however, IoT struggles with chain interoperability. This could be solved with the Web of Things and the concept of "Thing Description", which enables semantic and syntactic interoperability (Korkan et al., 2018).

As data recording from IoT can feed directly into Blockchain, IoT plays an important role in ensuring trust and security. Nevertheless, IoT alone cannot guarantee the authenticity of a product, however, combined with Blockchain and a concept of crypto anchoring, IoT will be able to meet this objective. Connected devices can deliver much more information than before, increasing the understanding of traceability and optimizing processes. The application of edge computing in IoT enable faster processing of large amounts of data (Klonoff, 2017). IoT offers huge benefits for both internal and chain traceability, however, the take up could be slowed down by the interoperability issues.

Digital Twin

Digital twin can use its sensors for automatic identification of the seafood products. Once the product has been scanned into the system, we are able to link its virtual form to the physical form with the help of existing identification technologies or crypto anchors. Automatizing the process will make the identification faster, allowing also for finer granularity. Furthermore, through the use of multiple sensors Digital Twin can collect all transformation metadata, process it and visualize it giving us not only the transformation itself but also an insight into industrial statistics and ways to enhance the performance. Creation of a Digital Twin requires a continuous flow of information called digital thread (Parrott & Warshaw, 2017). This ensures that all operational and historical data are kept intact in order to ensure the functioning of the Digital Twin. The integrity of information is therefore also ensured. Digital Twin collect enormous amounts of data and processes it in a real time perspective. This enables almost immediate insight into the information produced from the data.

Digital Twin requires interoperability between the physical and digital twin as well as other digital twins. It could be based on the Web of Things and the concept of "Thing Description". The data generated by the Digital Twin can be processed by AI or ML in order to uncover patterns or trends that cannot be inferred without using this combination of technologies. Full virtual version of a physical seafood product and the journey it took from the sea to plate can increase understanding of the importance of traceability and spark enthusiasm of consumers and FBOs. However, implementation costs may be too high for SMEs.

Blockchain

The process of documenting transformations in a food supply chain resembles that of recording transactions in Blockchain. This makes Blockchain a suitable technology for documenting transformations that happen across the supply chain (Olsen et al., 2019). Due to immutability of the transactions, Blockchain is capable of ensuring data integrity and transparency. Information in the Blockchain cannot be overwritten, this decreases the possibility of fraud and increases security of information and trust among the all users. Nevertheless, Blockchain alone cannot ensure the authenticity of the product as it lacks the ability to connect the information from the digital world to the physical world. However, if combined with cryptographic anchoring, the physical object can be tied to a unique identifier creating a bond between the digital and physical world (Balagurusamy et al., 2019). While the primary purpose of implementing Blockchain is trust and transparency, Blockchain has been able to positively affect the interoperability (Olsen et al., 2019). As Blockchain is based on a consensus model, each transaction within the chain follows the exact same rules. This makes it possible to create a full view of the product journey and its attributes and move beyond the one-up/one-down dynamic currently practices in food supply chains. Large amounts of data can be stored within Blockchain, however, overall it is much slower than traditional databases as additionally to storing data it needs to use cryptography to verify the transactions (Olsen et al., 2019).

The seafood industry shows increased interest in the use of Blockchain in traceability systems. One example can be found in the tuna fishery in Fiji, where World Wildlife Fund (WWF) in collaboration with a local fishing and processing company are establishing a transparent supply chain of frozen and fresh tuna (WWF, 2018). Such projects have the potential to not only ensure sustainability of the resources but also improve working conditions for those involved in the fishery. Transparent supply chains can contribute to establishing good working environments, especially in areas where slave labour is a significant issue.

5G

Out of all technologies 5G alone is unable to ensure any of the objectives. However, the fast data transmission and network slicing is able to support each of the technologies mentioned in this thesis, as well as those currently used in traceability system. Massive Machine-Type Communications (mMTC) can particularly enhance the working of IoT by providing a reliable connection in areas with large number of devices. Furthermore, 5G will enable faster exchange of data, which will enhance the capabilities of AI, Autonomous systems, Extended Reality, IoT and Digital Twin - technologies that rely on Big Data. As well as, speed up the transaction time in Blockchain. 5G will be especially important for the further development of Extended Reality, as the rendering process requires a strong and reliable internet connection. However, the range of 5G is limited by the high frequency waves, its application are particularly limited out in the sea or in areas of dispersed populations (NOU, 2019). Furthermore, this is the only technology that does not require a substantial financial investment from the users. However, it is predicted that only a quarter of the world population will have access to 5G coverage by 2030 (Grijpink et al., 2020). This is caused by extremely high costs for the providers.

Quantum Computing

Possibilities that can be achieved through the use of Quantum Computing are limited only by our imagination. Each of the objectives listed could be met, analysed and improved 100 times over. Quantum computing will enhance machine learning giving us the ability to predict outcomes of each action taken along the supply chain. A concept known as "Butterfly effect" (where the smallest action can lead to an enormous change along the chain), could be analysed and predicted within seconds. What we now consider science fiction could be made possible with Quantum Computing. This carries a huge implication for the entire society, both positive and negative. On one hand it could provide a completely transparent view of the whole supply chain. Imagine knowing what wild fish you are going to consume in three days' time from the moment an autonomous fishing vessel pulls the catch on board. On the other hand, if such powerful computers are not regulated, Quantum Computers could completely disrupt the world as we know it. Paradoxically a Quantum Computer would be the only way to predict this impact.

5.3 CONCEPTUAL FRAMEWORK OF THE TECHNOLOGIES APPLIED IN A TRACEABILITY SYSTEM

The conceptual framework illustrates a simplified supply chain of a seafood product *(Figure 23).* There are only three FBOs: the fishing company, the processing plant, and the retailer. The conceptual framework aims to illustrate how and where the emerging data-driven technologies could be applied in a traceability system.

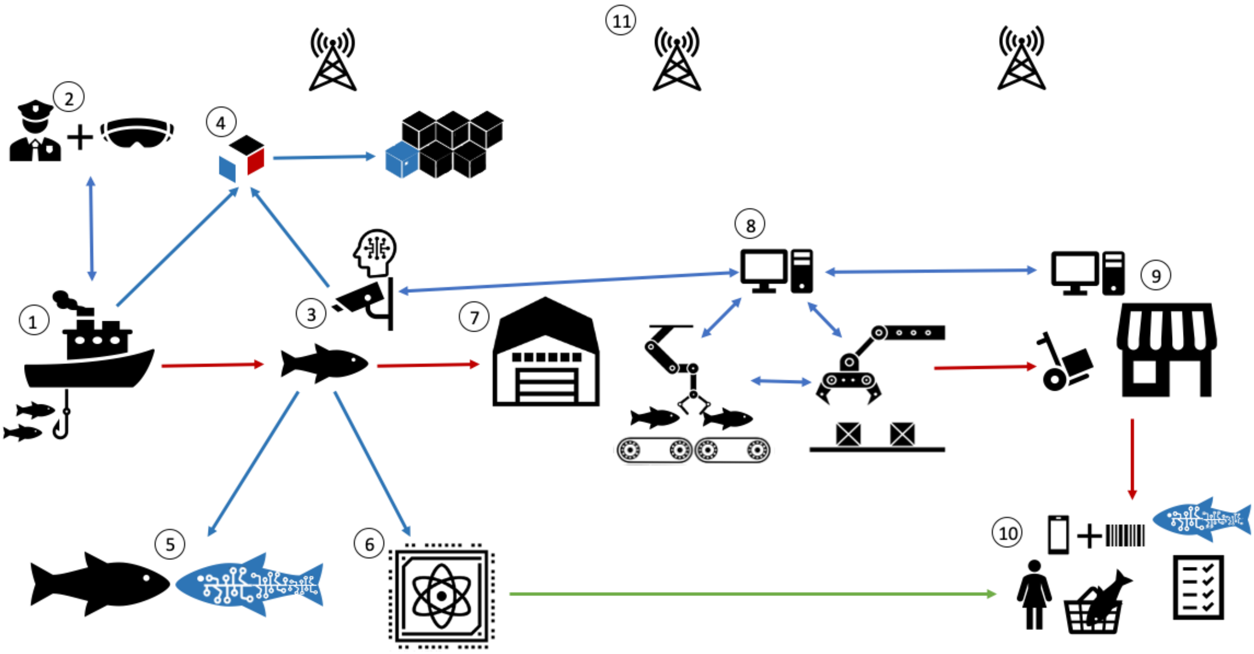


Figure 23 A conceptual framework presented in a scenario of emerging data driven technologies applied in a traceability system in a fish product supply chain (The red arrows demonstrate the physical flow of the product, the blue arrows represent the flow of information, the green arrow from point 6 to 10 demonstrates the predictive power of a Quantum Computer.) (own design)

(1) The **autonomous system** collects information with regards to the position of the fishing boat, it checks that the boat is within a fishing designated zone. The **AI** technology incorporated in the autonomous system, collected visual information of the fish in the water confirming the fish is of the correct specie and size. The environmental conditions are checked. Based on this information the autonomous system initiates the fishing activity. **Sensors** installed in the fishing equipment will notify the autonomous system when the nets are at a desired level of capacity. This could prevent fishing above the designated quota, ensuring the sustainability of the resources through elimination of wasteful practices.

(2) Authorities have been notified that a fishing activity is taking place. Through **Virtual Reality** they are able to place themselves on board of the fishing vessel and monitor the activities. The fishing activity and the attributes associated with the fish product can be verified by the authorities. Incorporating VR into the traceability system will allow for the verification of claims.

(3) Once the catch has been pulled on board, the **AI** employs machine learning and object recognition in order to sort the fish by specie and size.

(4) The information on the fishing activity and identification of the fish are combined; the transactions are merged together, and a new block is created. The block is then added to an existing **Blockchain**. This information is verified through a consensus model, and it becomes visible to all partners in the supply chain. If the Blockchain is made public, it can also be accessed by consumers. As the fish moves along the supply chain each consecutive transformation will be registered and added onto the same **Blockchain.** This means that each consecutive transaction will be verified through the consensus model, ensuring trust. However, in order to ensure the authenticity of the product one must consider the implementation of crypto anchors.

(5) The fish is identified by AI and a **digital twin** of the fish is created. As the fish moves along the supply chain, the digital twin will evolve in real time registering all changes, attributes and movement of the fish.

(6) The moment a fish is identified by AI and this information is processed by a **Quantum Computer**, QC is able to predict that this is the fish that the consumer is buying at the shop in 3 days' time.

(7) The fish is delivered at a processing plant, fish attributes are verified through **AI** and the transformation is registered as a transaction in the **Blockchain.**

(8) Devices at the processing plant communicate with each other through **Internet of Things.** As the processing takes place the packaging machine is informed about the quantity of fish and begins preparation. The whole process is **autonomous**; however, a human-machine interface is also connected through the **IoT** allowing the human to oversee the process and intervene if necessary.

(9) As the packaging takes place, the retailer is informed through **IoT** that the delivery is on its way.

(10) The consumer points her phone at the fish in the shop. Through **augmented reality** the consumer is able to access the **Digital Twin** of the fish, where all fish attributes are presented. The consumer can also make use of a **Virtual Reality** headset where the whole journey of the fish comes to life before her eyes, and she can move through each point of the supply chain. Such interactive presentations can spark curiosity and possibility lead to increased motivation to learn more about the subject of traceability.

(11) Throughout the whole supply chain **5G** ensures a reliable and fast connection between the multiple devices within the traceability system.

6. DISCUSSION

6.1 IMPLICATIONS OF FINDINGS

The evaluation of the potential of emerging data driven technologies potential to achieve traceability objectives, summarized in ***Table 8***, indicates that in some degree all of these technologies have potential to contribute to improving some aspects of the seafood traceability systems. An important observation is that not a single technology is able to do that by itself. Each of the technologies either relies on another technology to fully meet the objective or its application in traceability systems is influences by outside factors. There is a high interdependency between the technologies, meaning that ideally a number of them would have to be implemented together. Such practices are not uncommon. DNV GL refers to this as Compositional Architectures, which is the ability to combine existing and emerging technologies in order to create best solutions (DNV GL, 2020). Despite problems within some of the existing technologies, it is unlikely they will be redundant in the near future.

DNV GL predicts that all but one of the technologies mentioned in this thesis will be widely available across all industries by 2030. The only technology that is still in the very early state of emergence is the Quantum Computing and based on the complexities involved in running such a computer it will not become commercially available before 2030 (DNV GL, 2020).

A number of important benefits can be gained from the implementation of emerging technologies into the traceability systems. Many of the benefits can reach beyond a singular company or supply chain, affecting the wider society and the environment. Technological advancement in traceability systems have the potential to solve a number of major global issues such as seafood fraud, food waste, energy use, sustainability of resources and very importantly it could build trust between the stakeholders. However, in order to enjoy full benefits of the new technologies they must be implemented and interoperable across the whole supply chain enabling full chain traceability. Emerging technologies have the capacity to support the control mechanisms (Probst, 2019). Authorities such as the Norwegian Fisheries Directorate or sales organizations such as the Norwegian Fishermen's Sales Organization (Råfisklaget) can have direct access to product information that extends to the whole supply chain rather than the point of landing or the first point of sale. While Blockchain can provide this access, artificial intelligence can discover irregularities in the activities allowing for improved and targeted inspections (Probst, 2019).

Due to the novelty of these technologies, the costs of implementation and maintenance are very high. In most cases it is necessary to hire highly skilled experts to lead the implementation, customization and the training of staff. Such undertaking may not be financially feasible for small and medium FBOs. This could potentially lead to their exclusion from the supply chain. FBOs who have more market power and are driven toward meeting certain goals, such as certification or documentation of sustainability, can choose to trade only with those who have compatible traceability systems and are able to share any or all information with regards to the seafood products. With that in mind, industry leaders can exert a certain level of influence and push for a more transparent supply chain.

This means that early technology adaptors and big companies could pave the way for others. If the technology is deemed indispensable by key players in the industry it will eventually weave itself into the whole sector. Early adoption of new technologies can provide operational and competitive advantage as well as knowledge that could be shared between FBOs. The key players will benefit from bringing smaller companies on board. Afterall, in order to enjoy the full benefits of traceability systems the new technologies have to be implemented along the whole supply chain.

Recently, Microsoft launched a free, online certified course on Internet of Things that aims to teach the IT professionals the following tasks “implement the IoT solution infrastructure, provision and manage devices, implement edge, process and manage data, monitor, troubleshoot, and optimize IoT solutions, implement security” (Cruze, 2020). This is just one of the examples how big tech companies or key players in the industry could help to close technological gaps and bring the small and medium enterprises on board.

6.1.1 IS TECHNOLOGY ENOUGH?

Despite most technologies showcasing abilities to address many of the objectives, some to a greater degree than others, there were a few objectives that cannot be fully met by any of the technologies.

- Product Authenticity
- Interoperability
- Increased take-up

Technologies exemplified in this thesis were only able to meet these objectives to some extent. This means that implementation of new technologies into the traceability system does not guarantee successful achievement of the objectives, leading to two assumptions:

(1) There may be other technologies out there that could meet these objectives but were not taken into consideration.

(2) There are factors, other than technology, that determine the achievement of these objectives.

Product Authenticity

Increased capacity for collecting and processing information has the potential to increase compliance with regulations, this could lead to decreases in seafood fraud. However, none of the eight technologies evaluated in this thesis were able to fully guarantee product authenticity. While Blockchain increases trust and transparency along the supply chain (Chen et al., 2020), it lacks the ability to connect the information from the digital world to the physical world. This is where the concept of Crypto Anchors offers numerous opportunities. Cryptographic Anchoring is based on Blockchain technology, it "ties a unique identifier to the physical object with a property of the object that is hard to clone, forge, and transfer to another object" (Balagurusamy et al., 2019, p. 4:2). In the case of seafood products, physical fingerprint could be an appropriate crypto anchor. Physical attribute of the fish such as fish skin or the direction of patterns in a fish fillet could serve as a source of authenticity. A very common seafood fraud is the substitution of one specie for another similar, cheaper one (Haynes et al., 2019). Object recognition in AI would serve as a useful tool in identifying the fish, while information stored in Blockchain can confirm the authenticity of the product and its attributes. The concept of crypto anchors can be further applied to improve the granularity and achieve a one on one relationship between the TRU and the identifier, as the identifier can be directly anchored into the product. Nevertheless, the current level of development in the field indicates high implementation costs.

Interoperability

Lack of interoperability remains one of the central issues across traceability systems. The technologies assessed in this study seem to have the potential to contribute towards achieving interoperability. This is especially true for Blockchain, as all data elements are recorded as transactions and each transaction is verified based on the consensus model (Barker, 2016). Nevertheless, standards are extremely important in ensuring interoperability in a chain traceability system. But the large number of standards currently available internationally creates an effect opposite to what the standards are meant to accomplish. Demand for information comes from multiple sources, such as NGOs, governments and retailers, creating inconsistencies and increasing compliance costs (GDST, 2020). It is no surprise that many FBOs choose to opt for achieving the minimum requirements needed to meet traceability standards. Until the standards are harmonized, the interoperability gap will continue to exist, and no technology might be able to bridge this gap.

Vertical integration (VI) could be considered an alternative way of ensuring chain traceability and interoperability. VI is a "strategy frequently applied to overcome market imperfections and thus, enhance firms' performance" (Isaksen et al., 2011, p. 41). Lack of interoperability between the firms can certainly be considered a market imperfection, especially if trading of goods imposes costs that could be avoided under a scope of one company. Vertical integration not only solves the issue of interoperability but also reduces uncertainty and risk, secures supply of critical input and provides competitive advantage (Isaksen et al., 2011, p. 43). Bakkafrost, an aquaculture firm, claims to be one of the most vertically integrated companies in the world. It exercises full control over all aspects of production: fish feed, farming, processing, packaging and sales & marketing (Bakkafrost, 2019). The company emphasizes its ability to ensure quality and traceability of all its products. It would be interesting to explore the potential of emerging technologies in the context of vertical integration.

Increased take-up

None of the technologies can guarantee increased take-up of traceability systems. The lack of compelling evidence on the return of investment creates barriers to adoption (Future of Fish, 2014, p. 7). Several of the technologies lack refinement in the field of data protection and security. The laws, regulations and the general understanding on how the emerging technologies will impact our society are all lagging behind the technological development. While all of the technologies seem to offer opportunities for improvements in TS, the lack of regulations protecting the users and consumers may hinder adaption of these technologies. Not having a full understanding of how these technologies could benefit both the businesses and the consumers is one problem, however, knowing that the laws and regulations regarding the use of these technologies are not yet settled can create additional reasons to hold off the investment. In the case of Blockchain, a survey of 600 executives from 15 regions around the world has found that regulatory uncertainty is the biggest barrier preventing adoption of the technology (PwC, 2019). Furthermore, the second biggest barrier to adoption is the lack of trust among the users. A possible explanation for these results is that businesses lack awareness with regards to the functionalities of the various emerging technologies. Moreover, the boom of cryptocurrency could have created a hype of inflated expectations and the technology seems too good to be true (Fenn & Blosch, 2018).

Food industry in general remains one of the least digitally advanced industries (Gandhi et al., 2016). With regards to the seafood industry there are significant differences in technology adoption between the aquaculture industry and wild capture fisheries. Many stakeholders in the Norwegian aquaculture industry express concerns with regards to the environmental impact, technology development, ID-tagging, fish welfare or control/oversight (Bailey & Eggereide, 2020). The social pressure and an ongoing debate with regards to the environmental impacts of aquaculture are significant drivers for the aquaculture industry to invest in new technologies that document and improve their sustainability. The wild capture fisheries, which have been forever present in the Norwegian society are not faced with the same level of scepticism. Nevertheless, increasing demand from customers for sustainably sourced seafood products may force the industry to increase the adoption of emerging technologies.

The main drivers behind traceability have changed in the recent years. While initially traceability systems were implementing based on the driver of to ensuring safety and quality of food products, it is now increasingly used by governments and markets as a tool in documenting sustainability of marine resources and their origin (NOU, 2019, p. 152). This often leads to increased market access as a result of reaching a specific segment of consumers.

6.1.2 WHO CAN USE THIS THESIS AND HOW?

There is a tendency to overestimate the positive qualities of the emerging data driven technologies often leading to a peak of inflated expectations early in the technologies' life (Fenn & Blosch, 2018). While it is important that some companies join the hype and explore the limitations of those technologies, the smaller FBOs simply cannot afford to test each and every one of the emerging technologies in hope they will solve all their problems. This thesis contributes to building abasic understanding of how each of the technologies might benefit FBOs in the seafood product supply chain and what traceability challenges could be addressed. Furthermore, it suggests a way to evaluate emerging technologies against the problems found in traceability.

The thesis may be beneficial for a small/medium FBO to judge for themselves whether a given technology will benefit them or the wider society and in what ways. For example, if the company is losing money due to constant recalls as a result of human error, and insufficient ways to document transformations, then the benefits of implementing automation and IoT may outweigh the costs of implementation. However, if a retailer discovers that repeatedly many of the products they have received from their suppliers have been substituted for other species, investing in a Blockchain may not lead to the root of the problem because (1) Blockchain can only ensure authenticity of the products if the digital transactions are linked to the physical product through methods such as Crypto Anchoring (2) Blockchain would have to be implemented across the entire supply chain and not just with the retailer and the immediate supplier. Thus, information in this thesis allows the FBOs to make more informed decisions rather than fall victims to the hype.

The thesis can provide guidance for the technology providers in how they can adapt their technologies to fit the purpose of traceability. Working with a specific challenge and creating an innovative way to solve it is a lot easier than creating a new technology and seeing if it fits a purpose. Many of the technologies explored in this thesis were not created with traceability systems in mind; it is therefore no surprise that none of the technologies are able to fully meet all of the objectives. However, as the traceability system is dismantled into the different components with associated risks and challenges it is possible to see where the technology might contribute.

Furthermore, the thesis can be used by a number of stakeholders including educational institutions, high schools, and higher education establishments with specializations in (but not only) fisheries, aquaculture, innovation, and computer science. Scientists and professionals in the fields of fisheries, aquaculture, industrial economics, logistics or technology could also use the results of this thesis, if only to criticize its results. Finally, it can provide valuable information to national fisheries authorities, sales organizations, and supranational governmental and non-governmental organizations such as FAO or GDST.

6.2 COMPARISON TO OTHER STUDIES

Currently there are two technologies at the forefront of traceability discussions: IoT and Blockchain. While some studies mention artificial intelligence (Probst, 2019), this has not been explored to the same extent as IoT or Blockchain. Popularity of Blockchain may be due to its ability to address long-standing challenges associated with the complexity of supply chains (Pettey, 2019). Both technologies offer numerous improvements to the traceability systems, particularly when documenting transformations. Through the use of sensors, IoT provides the necessary infrastructure for collecting transformations' metadata, while Blockchain ensures the data is kept safe in a chronological order, ensuring immutability and transparency.

A comprehensive study on blockchain technology from (Olsen et al., 2019) offers a detailed comparison of pros and cons in traditional electronic traceability system and one that is based on blockchain. The study provides a valuable insight into the practical applications and limitations of the blockchain technology in case studies of red meat supply chain and herbs and spices supply chain. The study concluded that blockchain alone "will not solve all, or even most of the problems associated with traditional electronic traceability systems" (Olsen et al., 2019, p. 33). Despite not focusing on seafood products *per se*, the statement supports the findings of this thesis.

The growing support for the Internet of Things and a noticeable increase in academic articles and implementations of the technology, suggest that IoT has the potential to transform seafood product supply chains. Astill et al (2019) considers IoT as an overarching technology that will lead to more transparent supply chains. While there are signs that many companies are willing to implement IoT, their reasons for doing so is often rooted in seeking benefits connected to internal traceability. Of course improving internal processes can offer pronounced benefits in the form of competitive advantage, operational efficiencies and reduced costs (DNV GL, 2020, p. 42).. Data collected by IoT has significantly more value when it is used across the entire supply chain (Astill et al., 2019, p. 245). It is therefore important to understand how companies are using these technologies. FBO could implement all of the technologies mentioned in this thesis, however, if they have no intention of opening up to their partners and creating a transparent supply chain, sea to plate traceability might not be achieved.

One of the more detailed studies that connects a number of emerging technologies with fisheries comes from (Probst, 2019). The technologies (Blockchain, AI and data mining) are explored from the perspective of fisheries management, control, and surveillance. Probst argues that the technological innovations are usually two-sided, meaning that the fishermen may be hesitant to pursue them as it would mean increased control of their activities while management authorities may not be able to pursue this expenditure (Probst, 2019, p. 6). Probst argues that while emerging technologies have the potential to increase transparency and trust, they will not stop IUU. Considering the approach taken by this thesis, it can be argued that technologies have the potential to eliminate (most of) IUU given that emerging technologies are implemented in traceability system across the whole chain.

Furthermore, emerging technologies have been explored by a number of organizations in the form of white papers and reports. One white paper stands out in particular as it provides an extensive approach to some emerging technologies and their use in fisheries control. Some of the technologies included in this report were not included in this present study (non-data driven technologies) and some of the data driven technologies included in this present study were not include in the report. The report comes from the Official Norwegian Reports - Norges offentlige utredninger (NOU). NOU dedicated an entire section to digitalization and technology trends and how they can be utilized to support resource control (NOU, 2019). Overall NOU takes a similar approach with this thesis, aiming to explore the potential of numerous emerging technologies and their application in resource control. NOU categorized the technologies into three groups (1) Technologies for data collection, (2) Technologies for data analysis and availability and (3) Data communication technologies. This creates a good basis for comparison, it would be interesting to adopt this approach and redo the analysis of the technologies explored in this thesis. While the paper is a valuable contribution to our understanding of emerging technologies and their application in fisheries, the Norwegian language makes it limited to the Norwegian audience. Discovering only one study of this nature illustrates a clear gap in this research field, emphasizing just how important it is to continue exploring this topic.

6.3 LIMITATIONS OF THE STUDY

6.3.1 CREATIVITY AND KNOWLEDGE

The assessment of the emerging data driven technologies with regards to their potential in addressing traceability challenges is influenced by my own knowledge, interpretation, and creativity capacity. Both traceability and emerging technologies are concepts I started to learn about only a few months ago. My knowledge with regards to these topics is therefore limited to what has been explored in the thesis. An expert in the field of traceability or technology may deem some of the ideas far-fetched, and impossible to implement, or plainly wrong. In some cases, this may be true, as I do not have the extensive necessary knowledge to explore this field in a way that would lead to the creation of technologically advanced and 100% correct assumptions and predictions. Nevertheless, I believe that technology is such a fast-developing field of expertise that it might almost be unreasonable to assume something is impossible, considering a long enough time perspective. Imagining a new concept purely from a theoretical perspective is the first step to making it possible. 25 years ago, only a handful of people in the world could have predicted the impact internet would have on our daily lives. The novelty of emerging data driven technologies application in traceability, both in general sense and especially to my own experience could have minimized bias in interpretation. I had no pre-existing "feelings" or opinions with regards to what technology should be given more emphasis. All the technologies are explored in a structured and equal manner ensuring objectivity and fair assessment.

6.3.2 TIME

One of the biggest limitations of this study was the time constraint. Researching a new field can be very exciting and eye opening. It is tempting to contemplate on many aspects that could be important to the study and it is easy to get side-tracked, especially when exploring a completely new field. However, due to the time constraint it is inevitable to recognize that some important topics will not make it into the thesis or can only be briefly mentioned. There are a large number of topics, which I believe are important in further exploration of the relationship between traceability and emerging data driven technology.

6.3.3 OTHER TECHNOLOGIES

Technologies explored in this thesis share a major commonality; they are data driven technologies. They have the ability to accelerate digitization, and enable virtualization and automation across the life cycle (DNV GL, 2020). Nevertheless, there are a number of other technical and scientific domains that could prove to be very important in the field of traceability. For example, spectroscopy, nanotechnology, biotechnology such as DNA barcoding. All of them could be used in the development of sensors that would enhance environmental reading or verify the authenticity of seafood products. However, due to the time limit it was not feasible to consider them for this study.

6.4 SUGGESTIONS FOR FURTHER RESEARCH

As argued above, implementation of emerging technologies alone will not solve all problems surrounding the concept of traceability. In order to incentivize businesses and consumers to fully embrace the concept of traceability, it has to be examined from multiple angles.

Other technologies – this thesis is limited to data driven technologies

As mentioned above there are a number of important technologies and scientific methods that have not been explored in this study such as spectroscopy, nanotechnology and biotechnology. A recommendation for further research would be exploration of these technologies in the context of traceability.

In-depth interviews

The study builds a basic setting for further exploration of emerging technologies and their application in traceability systems. Further research would benefit from performing in depth interviews with a number of stakeholders.

- **FBOs** - in order to verify their current practices, traceability awareness, knowledge of emerging data driven technologies and technology needs.
- **Technology developers and providers** - in order to verify the technology scalability and in what ways the technologies can be tailored to fit the purpose of traceability in supply chains of different seafood products
- **Various organisations** – such as ISO, GS1 or the Global Dialogue on Seafood Traceability in order to map the current standards, achievements and plans for the future
- **Authorities/Law makers -** in order to understand when we can expect laws and regulations with regards to the data privacy and security

Organizational setting, culture, gender - (Sterling & Chiasson, 2014, p. 12) point out that it is often the organizational aspects that prevent take-up a of new technologies in traceability systems. It would be interesting to see what exactly affects this decision and whether there are differences between supply chains for different seafood types and species. Moreover, there could be cultural differences with regards to the perceived importance of traceability or the potential of emerging technologies and therefore motivation to improve practices and adopt technologies. Gender could potentially play an important role here. Are women CEOs more or less likely to invest in emerging data driven technologies than men?

Drivers – Drivers can be very important in shaping the traceability systems, predicting investments in new technologies or compliance to the traceability requirements. It would be interesting to find out the relationship between different traceability drivers and emerging data driven technologies.

Economics – In order to achieve transparency across the whole seafood industry, each and every one of the FBO must participate in creating an interoperable chain traceability system. However, not all businesses are in the positions to afford sophisticated technologies. How can these technologies become more affordable? What is the economic impact of traceability on the FBO? Should the governments subsidise small and medium enterprises in order to enable chain traceability?

7. CONCLUSION

There are multiple challenges surrounding the concept of traceability and traceability systems. While some are linked to technicalities such as data access protocols, standards and interoperability, many of them are rooted in cultural, social and organizational aspects. The implementation gap could be caused by the lack of awareness with regards to the benefits of traceability, as well as lack of understanding of existing technologies and their direct application to traceability systems. The aim of this thesis is to build an understanding of the potential of emerging data driven technologies to improve the existing seafood product traceability systems.

The continuous emergence of new technologies might offer countless opportunities in the field of traceability. Through a structured and simultaneous evaluation of multiple technologies it is possible to create a better picture of where exactly each technology could be applied and in what ways the technologies complement each other. The thesis demonstrates that each of the emerging technologies explored in this thesis has the potential to address traceability challenges to some extent. This potential is particularly evident when the technologies are combined together and implemented across the entire supply chains. It is hard to say which technology will have the biggest impact as each technology has the possibility to addresses different challenges within traceability, though many scholars are now focusing intensively on IoT and Blockchain. Furthermore, the speed of technological development makes it difficult to provide clear recommendation as to which technology should be implemented in traceability. Nevertheless, it is necessary to continue discovering and evaluating the applications of new technologies, especially in cases where their functionalities seemingly do not fit the purpose.

While technologies such a Quantum Computing may not make their way into the traceability systems anytime soon, it is important to acknowledge their potential. The current speed of technological development cannot be underestimated. Technologies such as Internet of Things, sensors, automation, Blockchain, AI or the Digital Twin are already being implemented into supply chains. It is only a matter of time before many of these technologies weave themselves into seafood product traceability. As new technologies emerge, it is essential to continue exploring their potential and building the necessary fundament that can later serve as guidance to implementation.

Transparent and trustworthy seafood product supply chains, improved data collection, increasing data processing capabilities, predictive algorithms, better decision making, reliable connection and virtualization of the product life cycle are just a few among the possible benefits of emerging data driven technologies. Nevertheless, it is important to see the technology for what it is, as there is a tendency to overinflate positive qualities of emerging technologies to fit a desired purpose. The potential impact of these technologies must be understood before they weave themselves into everyday life. Technologies can change our lives irreversibly and both positive and negative impacts must be anticipated and understood (Mulder, 2013). For that reason, theoretical and exploratory inquiries into the social, ethical, cultural, environmental and legal impacts of technology are just as (or even more) important than the development of these technologies. This calls for a more interdisciplinary approach, it is no longer sufficient to be an expert in one area due to the interactions that take place between the different disciplines.

The potential of emerging technologies to improve existing seafood product traceability systems seems to be there, however there is a long road ahead until this potential is met. Technologies alone will not be able to solve all traceability problems. There are several forces at play, other than the newest technologies, that will determine the future of traceability systems.

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9. APPENDIX

APPENDIX 1. DRIVERS BEHIND TRACEABILITY

Traceability drivers or motivational factors will in a large extent shape how the traceability systems are implemented and to what extent the food business operators (FBO) are willing to invest in new technologies. Drivers can be defined as “the resources, processes and conditions that are vital for the implementation of a traceability system” (Haleem et al., 2019, p. 337). Traceability drivers imposed from outside through the legislation, regulation and food safety standards may not provide enough incentive for FBO to adapt new technologies. Due to the compulsory nature of those drivers, they can be perceived as a financial and an organizational burden, resulting in a poor implementation of the system. It has been found that in the case of fish and fishery products the European Commission regulations of traceability are in fact ineffective, as the traceable resource units are not uniquely identifiable (Borit & Santos, 2015, p. 18). However, as companies recognize that establishing efficient traceability systems may in fact give them a competitive advantage, they will be more inclined to invest in new and better technologies. It is possible that perceived benefits alone can act as a driver for the implementation of a Traceability System (TS). It is, therefore, important to understand the drivers behind traceability and the perceived benefits as they may indicate how the systems are implemented. Traceability drivers have their underlying concerns, these concerns have been categorized by Bosona & Gebresenbet (2013, p. 37) into five different groups: regulatory, safety and quality, social, economic, and technological.

Table 9 Traceability drivers – description and examples

Notes: (R) regulatory, (SQ) safety/quality, (S) social, (E) economic, (T) technological, (ENV) environmental
Sources: (Bosona & Gebresenbet, 2013),(Borit & Olsen, 2016), (Haleem et al., 2019, p. 339)

Driver	Description	Examples
Animal Welfare (S)	Increased awareness with regards to the welfare of animals, consumers are willing to pay more for animal products which came from less intensive farming	Free range
Certification (S, ENV)	Certification schemes require detailed documentation of practices and resource origin.	MSC, organic, fair trade
Chain communication (T)	Scheduling of production through better cooperation, optimization of data collection, decreased recording of unnecessary data	IBM Food Trust – block chain
Commercial Requirements (SQ, E)	Meeting the commercial requirements with regards to food standards allows the FBO to enter the market, therefore, they are able to sell their products. These are often associated with traceability requirements	ISO
Competitive advantage (E)	Implementation of TS enables a system integration and documentation of good manufacturing practices	Industrial statistics
Documentation of Sustainability (S, ENV)	Social – increase in consumer awareness and demand for sustainable products and transparency. Increased pressure from NGOs to document sustainability Environmental – reduction of food waste, proof of product origin	EU IUU Regulation MSC Certification Food miles, resource use, emissions

Food safety and quality (SQ)	Protecting the consumer and the business by ensuring the safety and quality of food	HACCP
Information communication technology (ICT) systems (T)	ICT generate data necessary for the establishment of the TS	Simple or complex ICT systems
Legislation (R)	Food law lays down an overarching framework to establish further requirements and principles.	General Food Law Labelling laws

Special attention must be given to the documentation of sustainability, as in the recent years it has become a very important driver. Climate change, pollution, environmental concern and sustainability of marine resources have become an underlying force behind many other drivers such as legislation, commercial requirements and certification. Increased legislative attention is paid to the sustainability of natural resource products, such as fish, that come from both inside and outside of the European Union (Borit & Santos, 2015, p. 16). However, as mentioned above the European Commission regulations with regards to traceability of fish has proved to be ineffective. It has been found that TS implementation driven by regulations with underlying sustainability goals are less effective than those driven by the health and safety of humans (Borit & Santos, 2015, p. 17). A recent study from Rodriguez-Salvador & Dopico (2020), with regards to understanding the value of traceability from a consumer perspective, showed that the most important factor for more than 90% of 216 participants was knowing the origin of the product, whereas sustainability of the product was considered important by only almost 70% of the participants.

APPENDIX 2. BENEFITS OF IMPLEMENTING TRACEABILITY SYSTEMS

The benefits of traceability system implementation are closely tied with its drivers. It is expected that drivers push toward the implementation of a TS, while the benefits are a result of the implementation. However, as mentioned above a perceived benefit of implementing the TS can act as a driver. Such drivers can be seen as positive drivers, where the FBO takes an active part in improving the TS in the pursuit of the benefits. A good example of this is a Norwegian fishing company Hermes[5], who place quality, safety and sustainability at the forefront of the company by implementing a full TS from fishing grounds to the market. In return for their transparency the company enjoys a great reputation, trust of the consumers and increased market access. Such examples may provide extra incentives for the FBO to invest in implementing a TS. Sterling et al (2015) have summarized the key benefits into 3 different areas *(Figure 24)*

Figure 24 Key benefits of traceability (Sterling et al, 2015), p. 213

Risk mitigation is strongly associated with ensuring the safety and quality of products. By doing so FBOs are able to protect the potential buyers from consuming hazardous food products and in cases when bad products make it to the market, the recall procedure is more effective and less costly. It therefore acts as a mechanism to mitigate food safety crises (Haleem et al., 2019, p. 339), which simultaneously benefits the consumer and the FBO. Ensuring compliance with legal and commercial regulations not only guarantees the safety and quality of food products but also gives the FBO **market access,** confirming their ability to sell their products safely and legally. In the recent years proof of origin or documentation of sustainably has become a very important driver, being able to document the products came from sustainable sources offers a great benefit of competitive advantage. Increasing consumer awareness and preferences shifting towards sustainably sourced foods incentivises FBOs to engage in certification schemes. In the presence of increasing pressure on marine resources, such certifications often have an overarching goal, for instance protection of vulnerable species and elimination of Illegal, Unreported and Unregulated (IUU) fishing practices. One example would be the Marine Stewardship Council (MSC), which an internationally recognized certification scheme of sustainably managed fisheries. Implementation of TS can also deliver **operational efficiencies,** through lowering the production and labour costs.

[5] Norwegian fishing company dating back to 1917. Hermes operates a freezer trawler. https://www.hermesas.no

Furthermore, a TS can help to minimize food losses. Keeping accurate records of business practices can help in identification of critical food loss points, which exist along the supply chain. This can provide a good basis for introducing better practices (FAO, 2019). It has been found that it is the precision of the TS that will determine how strong the benefits are (Asioli et al., 2014, p. 12). Precision refers to the granularity of the traceable unit, meaning the size of a unit that is uniquely identified. Furthermore, chain traceability specifically has the ability of improving cooperation between businesses, increasing transparency and control. Chain traceability is the ability to share information across several companies in the supply chain. Many of the benefits of traceability are in fact intangible and they can be hard to measure due to their qualitative nature (Mai et al, 2010). An attempt to measure these has been carried out by (van Rijswijk et al., 2008) in their cross-national comparative study of consumer perceptions regarding traceability. They have found that many of the perceptions of benefits are related, and that health, safety and quality aspects were all associated with each other. Knowing everything about product provided a sense of control, building the consumer trust and confidence.