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A study on adapting advanced traceability system between feed manufacturer and salmon farmer in a farmed salmon supply chain

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Abstract

Adopting an advanced traceability system in a supply chain is crucial to solve food safety issue. It is certainly important for firms to improve their traceability to deal with potential recalls but it is up to the firms' choice 'How much traceability' they want and on 'What level of granularity'. The purpose of this thesis is to investigate how different actors in a real farmed salmon supply chain perceive benefits of implementing the advanced traceability system and how to design optimal chain traceability systems to reduce the product recalls, e.g. reduce recall scale. We investigated the presence or absence of internal and chain traceability between the two different actors, a feed manufacturer and a salmon farmer, in the farmed salmon supply chain. What the current optimal ID technology and granularity level of the two parties and what the ideal ID technology and granularity level of the two parties to achieve the chain traceability are studied. Cost-Benefit analysis of implementing different degree of traceability system is conducted to derive how costs and benefits are distributed between these two parties. Traceability's critical importance, from a recall liability perspective, decreases as we move from the salmon farmer to the feed manufacturer in the supply chain. When there is a choice among implementing the different traceability levels in the supply network, the salmon farmer has higher incentives to invest in the advanced traceability system. When the salmon farmer's interests in improving chain traceability system are not perfectly aligned with the interests of the feed manufacturer, how the salmon farmer can motivate the feed manufacturer to participate in improving the chain traceability by exploiting interest-sharing mechanism is studied. Our analysis shows that it would be difficult for whole supply chain to achieve a chain traceability, if 1) Each party has their own optimized internal traceability system, 2) The costs of implementing an advanced traceability is larger than its benefits, 3) Proper incentives is not given to improve it.

1. Introduction

In the context of a rapid globalization, a seafood supply chain is prone to be extremely complex and interconnected, which makes all parties within the supply chain difficult in coordination and operation in more accurate ways (Dai, et al., 2015). A food recall has become a considerable challenging issue for seafood supply chain when the supply chain is not able to cope with the recall immediately. Once a seafood crisis happens, products with unclear origins have to be removed for a safety reason, even though most of them are actually in good conditions. This may cause unnecessary recalls and lead the whole supply chain to fault.

It is essential that companies in a supply chain take prompt action to prepare for an emergent recall and to implement an effective strategy. Traceability system which is a systematic way of improving documentation of product information and the process has been introduced to help the seafood companies 1) isolate a source of contamination 2) control quality problems 3) meet legislation requirements 4) allocate a right recall liability to each party in the seafood supply chain.

According to Olsen (2015), traceability system in seafood industry can divide into three generations. In the first wave of the traceability, companies start using computers and recording internal data. In the second wave, they started exchanging data in the supply chain through EDI, and now most of the technical challenges have been solved. We should realize that we are now in the 'Third wave' of electronic traceability implementation in the seafood industry. That is, if a company wants a good traceability system the firm can have one; the hardware, software, standards and practices are all there. It is certainly crucial for the firms to improve their traceability to deal with potential recalls but it is up to firms choice 'How much traceability' they want and on 'What level of granularity' (Olsen, 2015).

Granularity plays a key role in a context of the food traceability. The granularity can be at different levels depending on the degree of information applied by companies and the level of granularity affects the precision of product traceability (Karisen, et al., 2010). The more precise tracing system a firm has, the faster the firm can identify and resolve food safety or quality problems (Golan, et al., 2004). There has been a growing interest in using an advanced traceability system to track and trace the products in a seafood supply chain to cope with food recalls (Aung & Chang, 2014). When a food recall happens, adopting an advanced traceability system in a supply chain is crucial to solve unclear liability costs between different parties by allocating the recall costs in fair way.

In this paper, we will study a farmed salmon supply chain presented in Karlsen, et al (2010). The aim of their study was to identify a critical traceability points of fish feed and farmed salmon in general, and to identify different granularity levels of the fish feed and the farmed salmon in particular. The results from their study can provide us valuable inputs when we are designing an electronic traceability system for the farmed salmon supply chain. Based on their inputs, we developed new settings of the farmed salmon supply chain, which consists of three parties in our case study; Feed Manufacturer (FeedM), Salmon Farmer (SalmF) and Salmon farmer's customer (Market). Many published research papers presume that each party in a supply chain will voluntarily joins an advanced traceability system once it is in place, with little or no attention paid to an incentive mechanism (Dai, et al., 2011). The purpose of this thesis is to investigate how the farmed salmon supply chain perceives benefits of implementing an advanced traceability system and how to design traceability system to reduce costs associated with product recalls. Cost-Benefit analyses of implementing different degree of the traceability system are conducted for two companies, feed manufacturer and salmon farmer to derive how costs and benefits are distributed between these two parties. For example, implementing the finer granularity will provide more precise information to trace the questionable products but requires higher investment on the traceability system. On the other hand, implementing the coarser granularity level is cheaper but the benefits are also lower. Either way, there exist trade-off between implementing the finer and the coarser granularity level.

Firstly, we will study the following question:

1) What is an optimal ID technology and granularity level of two different parties to achieve chain traceability in a farmed salmon supply chain.

Attaining chain traceability, where the target is to get rid of or reduce the information loss that happens between the links in the supply chain, has emerged as a major interest in a seafood industry. Not being able to take immediate action to a food recall due to the lack of chain traceability, a supply chain cannot avoid difficulties in 1) identifying or isolating sources of the contamination 2) recalling the contaminated products 3) allocating right recall liability to each party in the seafood supply chain. It is important to design an optimal traceability system and granularity level in a way that offers the right degree of information at a reasonable cost for both the FeedM and the SalmF in the supply chain. To attain an ideal supply chain traceability, the cost-benefit analysis is necessary before deciding which granularity level one should apply and how much traceability system is needed.

Next, we will study the second question:

2) How does interest-sharing mechanism impact the investment decisions of the FeedM and the SalmF.

Naturally, parties in a supply chain prone to shift the liability toward the other parties. Especially, the upstream parties tend to prefer the cheaper and the less precise traceability system and shift their liability to the downstream parties. We need to consider that the FeedM may not be willing to participate in improving the traceability system due to high costs of investment and liability costs afterwards. It is important to know how one party can motivate another party in a supply chain to participate in improving chain traceability when one party's interests in improving chain traceability system are not perfectly aligned with the interests of another party in the supply chain. The aim of this is to discover a right incentive-mechanism between the FeedM and the SalmF and investigate how the SalmF can properly motivate the FeedM to achieve better chain traceability.

To answer these research questions, our study is structured in following chapters. In chapter 2, we will present our two main research questions and describe previous works by other researchers, theories and our new research perspectives. In chapter 3, we will introduce methodology for our study including how we were collecting data and analyze them. Credibility and validity of our study are also discussed in this chapter. In chapter 4, we will present a specific case of a farmed salmon supply chain. Firstly, we will explain material and information flow of the supply chain. A discussion about granularity level, including a comparison of RFID and barcode, liability cost and interesting sharing mechanism are given. In chapter 5, we will summarize the main problems of the current traceability system in our case and suggest solutions to mitigate these problems. By building mathematical model we will demonstrat how the salmon farmer can motivate the feed manufacturer to implement better traceability system. In chapter 6, we will summarize the most important findings of our study and discussed limitations and possible direction of the future research.

2. Theory

2.1 Research question

1) What is an optimal ID technology and granularity level of two different parties in a farmed salmon supply chain.
2) How does interest-sharing mechanism impact the investment decisions of the FeedM and the SalmF.

2.2 Recall from food contamination

Product recalls and a preservation of living resources have gained an increased importance among food companies and governmental authorities in recent years (Ringsberg, 2014). In general, there are three causes of the product recall: (1) failures in food products' manufacturing practices (2) misleading in labeling and packaging of the food products (3) problems in controlling of contamination in raw foods.

There are three aspects of results in the contaminated food recall. (1) Individuals such as consumers face severe health-issues by consuming the contaminated food. (2) Organizations such as firms will confront substantial financial loss as well as get destroyed firms' reputations. (3) Societies will face public health problem. Millions of people around the world become ill every year as the result of unsafe food (Thomsen & McKenzie, 2001).

The Product recalls would lead decreased consumer confidence and increased logistics costs when recalled products are linked to a contaminated batch of the products or the materials (Kumar & Budin, 2006). Fonterra dairy recall in 2013, for example, shakes China consumers' confidence due to the possible presence of Clostridium, which is often regarded as harmless bacteria (Simon, 2015). Manufacturers, three food companies, two beverage companies, and three animal-feed producers in China, New Zealand, Australia, Malaysia, Saudi Arabia, Vietnam and Thailand were involved in a huge international food scandal. Some of the food recalls that stem from foodborne illnesses deal a firm a fatal blow financially. For example, the shell egg recall due to Salmonella Enteritidis in 2010, caused an estimated loss of $100 million to the industry in a single month (Shane, 2010).

The concerns regarding the food safety issues influence consumer behavior (Wilcock, et al., 2004). Brand sales on average decline almost one-quarter after one product recall take places, and the brand sales recovery does not come to the near original levels until almost 4–5 months after the recall (Thomsen, et al., 2006).

Recalls can be quite costly to uninvolved growers and firms (Peake, et al., 2014). For example, in 2008, the tomato industry was mistakenly blamed for sickening consumers with Salmonella Saintpaul. When jalapeño peppers was discovered as the actual cause of the problem, the tomato industry had already estimated losses of approximately $250 million from lost sales, costs associated with the recall, and crops left in the fields (Enis, 2008). These outcomes explain that those companies targeted in the recall, as well as uninvolved firms in the industry, may suffer long-lasting sales decline against the product recall (Thomsen, et al., 2006).

Serious actions are generally taken when a food contamination occurs, such as identifying the cause and source of contamination and subsequently recalling the contaminated products (Piramuthu, et al., 2013). Applying proper identification to trace backward to the potentially deficient batches and trace forward to the potential deficient product in a timely manner is crucial in the management of product recalls (Fritz & Schiefer, 2009).

The ramification of food safety crisis could be decreased with a proper traceability system that constantly keep on tracking of food trades and documenting of information along the food supply chain (Saltini & Akkerman, 2011). Adopting the proper traceability, for example, allows a cilantro firm to limit the scope of the recall to just 12 percent of the total recall cases in stores. Before the traceability, the firm would have had no choice but to pull 100 percent of all cases (Gates, 2010).

2.3 Traceability system and granularity level

Generally, the majority economic literatures discuss regarding traceability system in the following three aspects (1) the role of traceability system, especially in a multiingredient supply chain (2) implication of traceability system, the balance of granularity level and investment cost (3) consumers' willingness to pay for a traceable food.

There are two major reasons why the food firm should implement traceability system: (1) The ability to trace the origin of a product (2) The capability to detect and minimize the risk in timely manner when the food crises occur (Frederiksen, et al., 2007). The recorded information could be used to inspect the cause of the product recall or withdrawal. The more accurate process information that is linked to the identities, the better and faster analysis could be done to reduce the recall. The traceability system can be also helpful 1) to optimize production planning and scheduling 2) to ensure optimal use of raw materials (Wang & Li, 2006) 3) to use as a part of a competitive strategy (Canavari, et al., 2010) and 4) to increase company coordination in the supply chains (Banterle & Stranieri, 2008).

There are two types of traceability system: 1) Internal traceability; the ability to trace a resource within a company 2) Chain traceability; the ability to trace a resource through a supply chain (Moe, 1998). Traditionally, the traceability mainly managed the documentation of information relating to company's in-house processes and products. However, a survey conducted in 2002 discovered that many fish farmers met challenges to improve their traceability in the period of 2003-2004 (Forås, et al., 2004). One of the challenges was customers' complaining on product quality caused by factors from the upstream in a supply chain. That is, tracing back to the causal factors and tracing forward to all the batches that were influenced was described as problematical by many of the farmers (Frederiksen, et al., 2007). Previous studies have shown that information about food products and production processes can be lost internally within the firms, as well as between the firms in the supply chains (Donnelly, et al., 2012). This is mainly due to an increase in the global food trade and its complexity of the food supply chain, so it is important for the companies to coordinate the internal and the external management processes to ensure the food safety and to reduce the recall. Saltini and Akkerman (2011) state that the focus has been on chain traceability, where the target is to get rid of or to reduce the information loss that happens between the links in a supply chain. To achieve chain traceability, internal traceability data from all firms in a supply chain must be linked together, ideally through electronic systems (Frederiksen, et al., 2007).

Improving traceability at supply chain level can potentially reduce the costs to the downstream actors (e.g. retailers or processors) of monitoring the activities of the upstream steps (e.g. raw material supply) (Can-Trace, 2007).

In order to trace foodstuffs, it is important to define what traceable resource units are (Bertolini, et al., 2006). The Traceable Resource Unit (TRUs) are entities with similar characteristics and that have gone through the same process (Karlsen, et al., 2013). A granularity level is determined by the size of the TRUs (Karlsen, et al., 2012). The granularity level can be divided by three possible levels; item-level, batch-level and type-level. The item-level represents the finest level of granularity while the type-level deals with the other extreme. The batch-level represent a level of granularity that is in-between ”item” and ”type” level (Dai, et al., 2015). The finer granularity level needs better technology to support. Usually, RFID can fully support the item-granularity level.

Table 1 shows comparison between Radio-Frequency identification (RFID) systems and barcode (SCDigest, 2008). The barcode is a line-of-sight technology, which requires scanner to read it. It can only identify the manufacturer and product, not the unique items. The RFID tags can record the multi-dimension information, which means it is able to record more information about the product. The RFID system has already been adopted for the traceability purposes in many food supply chains (Nambiar, 2010). Higher traceability degree can be achieved by implementing the RFID compared to the barcode as it enables the recording of more accurate and complete information.

Table 1 Comparison between RFID and Barcode (SCDigest, 2008)

	RFID	Barcode
Read rate	High, multiple(>100) tags can be read simultaneously	Low, tages can only be read manually, one at a time
Human captial	None, ststem is completely automated	Large requirements, laborers must scan each tag
Read/Write capability	Ability to read, write, modify and update	Read only
Durability	High, better protected, can be internally attached	Low, easily damaged or removed
Event triggering	Capable, can be used to trigger alarm, etc	Not capable

Findings in Resende-Filho at el. (2012) paper shows that government regulation based on mandatory traceability with sanctions may not necessarily lead to safer food, while increasing food processor's costs. The traceability itself does not directly impact production systems to improve the food safety like Hazard Anlysis and Critical Control Point (HACCP) system. But, accumulated information generated by traceability system could facilitate contractual arrangements between firms in a supply chain to promote food safety (Resende-Filho & Hurley, 2012).

2.4 Liability cost

In supply chains today, there are many different parties get involved. Insufficient traceability in a supply chain could lead to difficulties in allocating liabilities (define in this context as the responsibilities to pay for costs of defects and products with unclear origins) to different parties in the product recall (Dai, et al., 2015). Not being able to trace defects back to their source discourage various parties to take effort to improve its traceability, which possibly can cause free-rider problem (Dai, et al., 2015).

Most of literature assumes that each party in a supply chain will voluntarily joins advanced traceability system once it is in place, paying no attention to the incentive mechanism (Dai, et al., 2011). But, the extent to which firms might voluntarily adopt traceability to improve food safety is less clear (Resende-Filho & Hurley, 2012). Each parties has their own self-interests, so those free-riders with the inferior traceability may escape from their liabilities if the liability is misallocated due to the lack of the traceability. Dai, et al. (2015)focus on how to avoid this free-rider problem by correcting the liability misallocation and motivating the supply chain to improve the traceability.

Piramuthu (2013) studied recall dynamics in a three-stage perishable food supply network through three different visibility levels in the presence of contamination. They consider allocation of liability among the different players in a perishable supply network based on the accuracy with which the contamination source is identified. Their results indicate that the recall liability shared by the perishable food supply network increases with decreasing levels of traceability. Also, the effects of visibility is especially salient at the lowest level downstream. Traceability’s critical importance, from a recall liability perspective, decreases as they move from the lowest to the highest level in the supply network. The marginal difference in recall cost decreases as they go from finer level to coarser level.

2.5 Motivation, incentive and interest sharing mechanism

Motivation is a significant factor for an individual to invest in the advanced traceability system. In order to make a decision to invest in this better traceability system, one must believe that it is reasonable and beneficial to one by doing so. For example, competitiveness of the food firms in national and global markets depends on their ability to implement production process in which food safety and quality requirements are fulfilled (Holleran, et al., 1999). If food firms believe that they can increase their competitiveness by adopting the better traceability system, this can be one of motivation to do so.

There are some impediments for implementing an advanced traceability system voluntarily. Dai, et al. (2015) studies the recall dynamics in a two-stage supply chain with a manufacturer and two suppliers. It shows that the suppliers would reject in improving traceability system if incentives is misallocated. Consequently, this would cause the diminishing traceability of the whole supply chain and the high product recall liabilities for the manufacturer. An interest-sharing mechanism to address this issue is therefore crucial. Reduction in the recall liability of the manufacturer can be achieved by inducing the suppliers to improve their traceability effort. By doing so, the manufacturer can share the liability cost with the suppliers afterwards.

2.6 Summary

Traceability system has been regarded as an important tool for the companies in the supply chains. Some literatures presume that each party in a supply chain will voluntarily joins an advanced traceability system once it is in place, with little or no attention paid to the incentive mechanism. Implementing an advanced traceability at the supply chain level is restricted by the uneven distribution of costs and benefits among the different actors of the chain. As we mentioned above in 2.4 and 2.5 sections, findings from the works done by Dai, et al (2011) and Piramuthu, et al (2013) are helpful for us to build concrete theoretical knowledge and give us insights on how to deal with this issue. 1) Appropriate incentive mechanisms need to be crafted to achieve full potential of chain traceability 2) The recall liability shared by the supply chain increase with decreasing levels of the traceability 3) Traceability's critical importance, from a recall liability perspective, decreases as we move from the lowest to the highest level in a supply chain. When there is a choice among the different levels in a supply network, the downstream has higher incentives to invest in advanced traceability systems first and then move upward in the supply chain.

However, their studies has few connections to a real practical case. The aim of this thesis is to investigate how actors in a real farmed salmon supply chain perceives benefits of implementing an advanced traceability system and how to design an optimal chain traceability system to reduce costs associated with product recalls. To answer our research question, we will study the real farmed salmon supply chain presented in Karlsen, et al (2010). The results from their study can provide input when we are designing an electronic traceability system for the farmed salmon supply chain and practical implementation of the traceability system. Based on their inputs, we will develop new settings of the farmed salmon supply chain and apply our theoretical knowledge gained from Dai and Piramuthu papers. We will investigate the presence or absence of internal and chain traceability between the two different actors, FeedM and SalmF, in the farmed salmon supply chain. What the current optimal ID technology and granularity level of the two different parties with internal traceability point of view and what the ideal ID technology and granularity level of two parties to achieve chain traceability are studied. Cost-Benefit analysis of implementing different degree of traceability system is conducted to derive how costs and benefits are distributed between these two parties. We wish to show unfairly distributed liability cost can act as a tool for motivating firm to invest in better traceability system in a supply chain. We will demonstrate that a better chain traceability system can reduce unnecessary recalls and liability costs. When the SalmF's interests in improving chain traceability system are not perfectly aligned with the interests of the FeedM, how the SalmF can motivates the FeedM to participate in improving chain traceability is studied. How interest-sharing mechanism can motivate each party's investment decision on the better chain traceability system and the cost interaction between the two parties to achieve chain traceability system are studied.

3. Methodology

In this chapter, we discuss which research method we used in order to answer our research questions. According to Lewis and Thornhill, the research method refers to the techniques and procedures, which are used for data collection and analyzation (Saunders, et al., 2009). First, we describe our research design for research question. Second, we describe our research approach and purpose. Lastly, we present how we collected data and analyzed them.

3.1 Research design

“Research design is the general plan of how one will go about answering your research question” (Saunders, et al., 2009). It contains clear objectives, which is derived from research question, specify source from which we plan to collect data and consider the constraints and discuss ethical issues (2009). The research design is a detailed and structured overall plan of the entire research process and the choice of research design will depend on research question and how we are going to answer it. We choose to collect data about a real farmed salmon supply chain presented in Karlsen, et al (2010) to answer our research questions. The results from their study can provide us valuable inputs when we are designing an electronic traceability system for the farmed salmon supply chain. Based on their inputs, we will develop new settings of the farmed salmon supply chain and apply our theoretical knowledge gained from Dai and Piramuthu papers. More detailed and structured overall study plan have already provided in summary section 2.6.

3.2 Research approach

“Traditional social science differentiates between a deductive and an inductive approach when doing research” (Alvesson & Karreman, 2011). The difference between deductive and inductive approach is the order of empirical information and theory. In inductive approach, information and data is first collected. Theories are built up base on it afterwards. Thus, we call it building theory. Research using an inductive approach is likely to be particularly concerned with the context in which such events were taking place. Deductive approach involves the development of a theory that is subjected to a rigorous test. In deductive approach, a hypothesis is deducted from the theory first and then test the operational hypothesis. Thus, we call it testing theory.

Our goal is to figure out how does liability cost and interest-sharing mechanism impact on the optimal ID technology and granularity level in fish feed supply chain and discuss different parties' decision when implementing traceability system. To answer this, we will collect data about a farmed salmon supply chain presented in Karlsen's study. Based on their inputs, we developed new settings of the farmed salmon supply chain, then theories will be built afterwards. Thus, inductive approach is used.

3.3 Research purpose

The classification of research purpose most often used in research methods' literature is the threefold one of exploratory, descriptive and explanatory. An exploratory study is a valuable means of finding out "what is happening; to seek new insights; to ask questions and to assess phenomena in a new light" (Robson, 2002). It is particularly useful if research wish to clarify understanding of a problem. There are three principal ways of conducting exploratory research: a search of literature, interviewing experts in subject and conducting focus group interviews. One characteristic and a major advantage of the methodology of an exploratory study is high degree of flexibility, as well as being adaptable to change (Saunders, et al., 2009). Descriptive study is to "portray an accurate profile of persons, events or situations" (Robson, 2002). Studies that establish causal relationships between variables may be termed explanatory research. The emphasis here is on studying a situation or a problem in order to explain the relationships between variables.

Our study was based on one fish feed supply chain with different parties such as three ingredient suppliers, one feed manufacturer, one salmon farmer and market. Our purpose of this study was to explore and discuss new finding to answer how much traceability should parties in supply chain implement? How does interest sharing and liability cost would influence their decisions? What is the optimal ID technology and granularity level? Thus, to reasonably explain and answer those questions, an exploratory study is performed.

3.4 Data approach

There are two main data approaches to choose when we want analyze and answer our research question: quantitative method or the qualitative method. The qualitative method does not use numerical data but rather uses data from interviews, documents, observations etc. The approach provides in-depth information about a case. Quantitative is predominantly used as a synonym of any data collection techniques or data analysis procedure that generates or uses numerical data. Mixed methods approach is the general term of when both quantitative and qualitative data collection techniques and analysis procedures are used in a research design. Triangulation means the use of two or more independent sources of data or data collection methods to corroborate research findings within a study (Saunders, et al., 2009).

In our study, we use mixed methods approach to collect and analysis data. By combining quantitative and qualitative method, we can better answer our research question. In order to answer our research question, we need first to be clear with how liability costs and interest-sharing mechanism will impact on different actors' decision. Therefore, having a clear picture of supply chain is important. We collect qualitative data and analyze it to get insight and understanding of fish feed supply chain. The source of qualitative data is secondary data from relevant publications from Norwegian Institute of Fisheries and Aquaculture Research, especially publications from Karlsen and Olsen. Based on qualitative data, we will draw material and information flow figures of fish feed supply chain to find out current problems. After coming up with theoretical solution, we will build mathematical model for quantitative analysis and verify our model. In numerical study part, we will use data for calculation to get further explanation of model. Quantitative method mainly describes the trade off and profit of each actor in supply chain.

3.5 Secondary data

Secondary data is data that have already been collected for some other purpose, perhaps processed and subsequently stored (Saunders, et al., 2009). There are three main types of secondary date: documentary, survey and those from multiple sources. Secondary data include both raw data and published summaries; both quantitative and qualitative data are included. The main advantages of using secondary data is the enormous saving in resources, in particular time and money. At the same time, it can be useful to compare data that we collected with secondary data. Re-analysing secondary data can also lead to unexpended new discoveries.

In our study, we use secondary data collected from relevant publications from Norwegian Institute of Fisheries and Aquaculture Research (Nofima), especially publications from Kine Mari Karlsen and Petter Olsen. During 2009 to 2013, Kine Mari Karlsen and Petter Olsen have published 11 publications relevant to fish feed supply chain in Norway. Nofima has conducted a series of interviews and investigations on fish feed supply chain. We also contact Nofima to get updated information. Based on those publications and information from Nofima, we can analyze material and information flow of fish feed supply chain as well as how traceability system does work in the supply chain. By re-analyzing secondary data, we found new discoveries and come up with the research question that we are studying here. Secondary data from Nofima are reliable and complete. It also help us save time and resource giving us more time to use modeling framework to answer our research questions.

3.6 Data analysis

The process of analyzing data contains organizing and sorting the data "in light of increasingly sophisticated judgments and interpretation" (Swanson & Holton III, 2005). The nature of qualitative data collected has implications for it analysis. "During analysis, the non-standardized and complex nature of the data that you have collected will probably need to be summarized, categorized or restructured as a narrative to support meaningful analysis" (Saunders, et al., 2009). As for quantitative, analysis conducted through the use of diagrams and statistics.

In order to better answer our research question, we need to summarize and restructure qualitative data to draw material and information flow of supply chain and have better understanding of fish feed supply chain traceability system. Quantitative data analyze is used in modeling framework. We use table and diagrams to express our data.

3.7 The credibility of research findings

When it comes to address issues of the credibility of research findings, Raimond, (1993) suggested to conduct the 'how do I know?' test and ask ourselves 'will the evidence and my conclusions stand up to the closest scrutiny?'

In our case, for example, how do we know the liability cost and interest-sharing mechanism impact on the optimal ID technology and granularity level in fish feed supply chain and impact on different actors' choice when implementing traceability system? How do we know improvement chain traceability has resulted in reduction of unnecessary recall? The short and clear answer, of course, in the literal sense of the question, is seemingly impossible. All we can do is reduce the possibility of driving the wrong answer. To reduce the possibility of driving the wrong answer, reliability and validity test play key role in the research design.

3.7.1 Reliability

Saunders, et al. (2009) state reliability refers to 'the extent to which your data collection techniques or analysis procedures will yield consistent findings.' According to Esterby-Smith, et al (2008), it can be assessed by '1) Will the measures yield the same results on other occasions? 2) Will similar observations be reached by other observers? 3) Is there transparency in how sense was made from the raw data'. Producing consistent findings in a qualitative study can be difficult due to the fact that the context in a qualitative study often is very specific, and thus can be hard to recreate (2009). In qualitative studies, due to variations in factors, it is almost impossible to get entirely same conclusion and result for other researchers. But just because of this, a lot of hidden information can be brought to the surface and contribute to better describe and explain the underlying causes behind a phenomenon.

In our study, we based on Nofima's secondary data to analyze fish feed supply chain. Nofima, especially Karlsen and Olsen, have conducted many interviews and investigations before and already have analysed them. Thus, the data that we re-analyze could have some bias and may different from original information. To avoid this bias, therefore, we conduct cross check: we mainly based on Olsen.P's finding (Nofima), but we refer to other researcher's publications to check and try to revert the original information if necessary.

3.7.2 Validity

According to Saunders, et al. (2009), 'validity is concerned with whether the findings are really about what they appear to be about. Is the relationship between two variables a causal relationship? Potential lack of validity in the conclusions can be minimized by a right research design. 'Validity is usually divided into internal and external validity. Internal validity is the extent to which the findings can be attributed to the interventions rather than any flaws in your research design. External validity refers to the extent of generalizability of the research results, that is, if the research results are proportionately relevant in other situations (Saunders, et al., 2009).

In our study, the information we collected from secondary data is based on Nofima's research and the building model is based on our assumptions. Thus, this could be limitation of our study. Our study is focused on implementation of better traceability system in a fish feed supply chain, therefore, this could incur external validity problem if we try to generalize to other supply chain. However, the purpose of this study is not to generalize the result but mainly to study the specific case. Thus, it will be more important to ensure the internal validity.

4. The farmed salmon supply chain

4.1 Fish feed supply chain

Several studies have reported elevated levels of environmental pollutants in aqua feeds and farmed Atlantic salmon. Ingredients for the marine feed, traditional used in commercial fish feeds, can be the source of these pollutants in a farmed fish (Berntssen, et al., 2010). Some researchers speculate that all the fish feeds contain measurable levels of some contaminants (Maule, et al., 2007). From previous study we can conclude that fish feed safety is vulnerable. In 2007, a Canadian distributor of fish feed has recalled melamine-tainted fish food from 198 U.S. fish farms and hatcheries and 57 Canadian fish farms and hatcheries. The fish feed was used as a starter diet for the salmon. The U.S. Food and Drug Administration was working to determine the extent of the fish feed distribution and whether any of the fish that were fed the melamine-containing product have been released into the environment or consumed by humans. In 2012, Land O' Lakes Purina Feed LLC has initiated a recall of fish feed due to elevated vitamin D levels. Elevated vitamin D levels may cause death or harmful to fish. Traceability system plays an important role in the case of this seafood crisis. Fish feeds can indirectly affect the consumers' health. If a healthy farmed salmon was fed by contaminated feeds, this will eventually affect the final consumers' health. Adopting the proper traceability can minimize the health risk in a timely manner and reduce costs associated with recalls.

In this part, we will study a farmed salmon supply chain presented in Karlsen, et al (2010). The results from their study can provide input when we designing an electronic traceability system for the farmed salmon supply chain and in practical implementation of the traceability system. Based on their inputs, we developed new settings of the farmed salmon supply chain, which consists of three parties in our case study as picture shown in Figure 1; Feed Manufacturer (FeedM), Salmon Farmer (SalmF) and Salmon farmer's customer (Market).

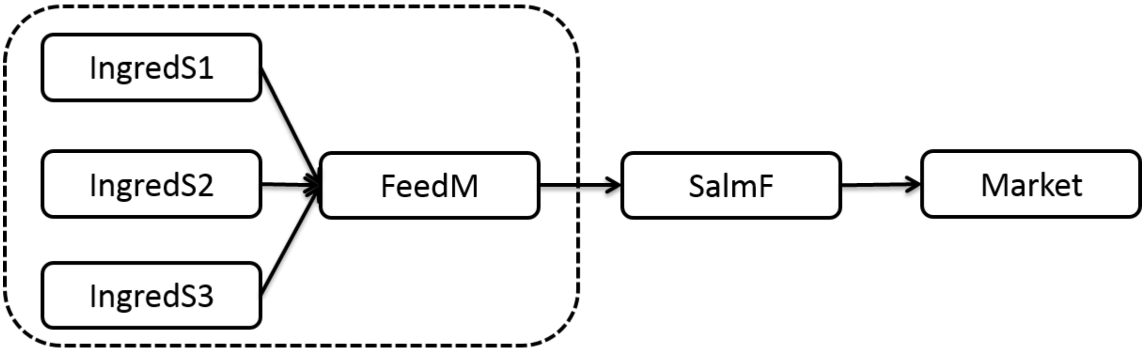

Figure 1 Description of a farmed salmon supply chain

The three ingredient suppliers and the feed manufacturer are regarded as united corporation. We assume that there already has been a mechanism between the ingredient supplier and the feed manufacturer to transfer all responsibility regarding contamination to the feed manufacturer. Due to the production processes using silos, the FeedM has higher responsibility to prove the source of the contamination. The feed manufacturer need a right compensation in order to be able to take this responsibility in case of the recall. We assume that the feed manufacturer pays lower price to the ingredient suppliers as the compensation of taking full responsibility for the recall. This assumption allow us to make the supply chain more simple way and to solve the main problem between the FeedM, the SalmF and the Market. The relationship between the united corporation and the salmon farmer as well as the SalmF and the Market are supplier-customer relationship in this model.

4.2 Information and material flow

The global captured fish industry is extremely complex, with different type of products and distribution chains (Bollen, et al., 2007). These factors indicate that implementation of electronic chain traceability is difficult (Karlsen, et al., 2011).
In this part, we start analyze material flow and information flow between different parties in the farmed salmon supply chain. Then, analysis of the presence or absence of internal traceability within a firm and chain traceability between the different parties in the farmed salmon supply chain will be followed to see the possibility of implementing of electronic chain traceability.

4.2.1 Material flow

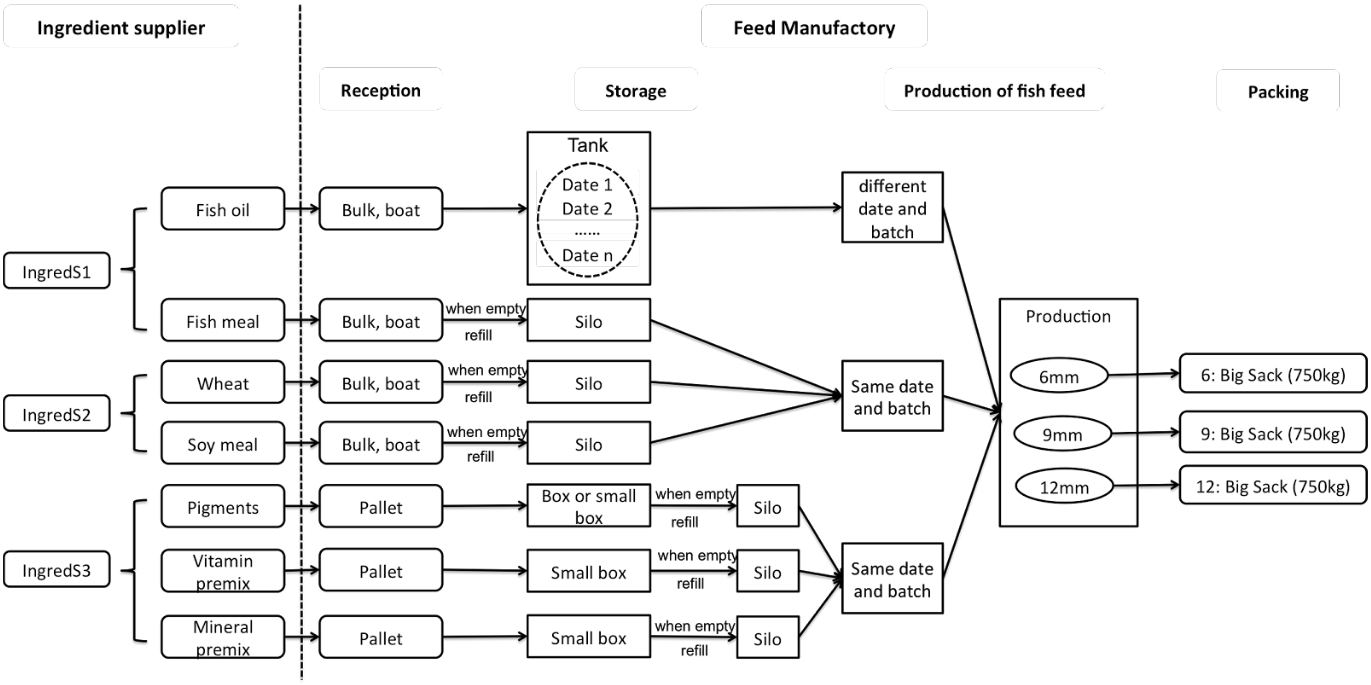

Figure 2 Material flow from the ingredient supplier to the feed manufacturer (Karisen, et al., 2010)

1) Ingredients suppliers

As shown in Figure 2, ingredients of fish feed are fishmeal, fish oil, wheat, soy meal, pigment A, pigment B, vitamin premix, and mineral premix. Fishmeal and fish oil are provided by the ingredient's supplier1. Wheat and Soymeal are provided by the ingredient's supplier2. Pigment A & B, Vitamin premix and Mineral premix are provided by the ingredient's supplier3.

2) Feed Manufacturer

Different deliveries of fish oil were continually mixed in the fish oil tank since the the FeedM had only one fish oil tank, see in Figure 2. This means that fish oil produced in the different dates (1,2,3...n) will be repeatedly mixed in one tank. All the fish meal in the one silo was often used before a new delivery of fishmeal was receive and, when it is empty it is promptly refilled in the same silo. The FeedM carried out similar procedure for wheat and soymeal. During the production, different deliveries of fishmeal, wheat, and soymeal were randomly mixed. Pigment A, Pigment B, Vitamin premix and Mineral premix stored in the different small sacks and boxes, are mixed in during the production process.

The FeedM produced different sizes (6mm, 9mm and 12mm) of feed for the farmed salmon. During this process, the FeedM used same ingredients to produce different size of feed. In other words, oil mixture produced in different date, fishmeal, wheat and soymeal produced in same date mixture are combined with Pigment A&B, Vitamin premix and Mineral premix produced in same date mixture. This means, if size 6 from production date X is contaminated, then size 9 and size 12 from production date X is also contaminated. The fish feed is packed into big sacks (750kg) classified with the size and identified by the production date.

3) Salmon Farmer

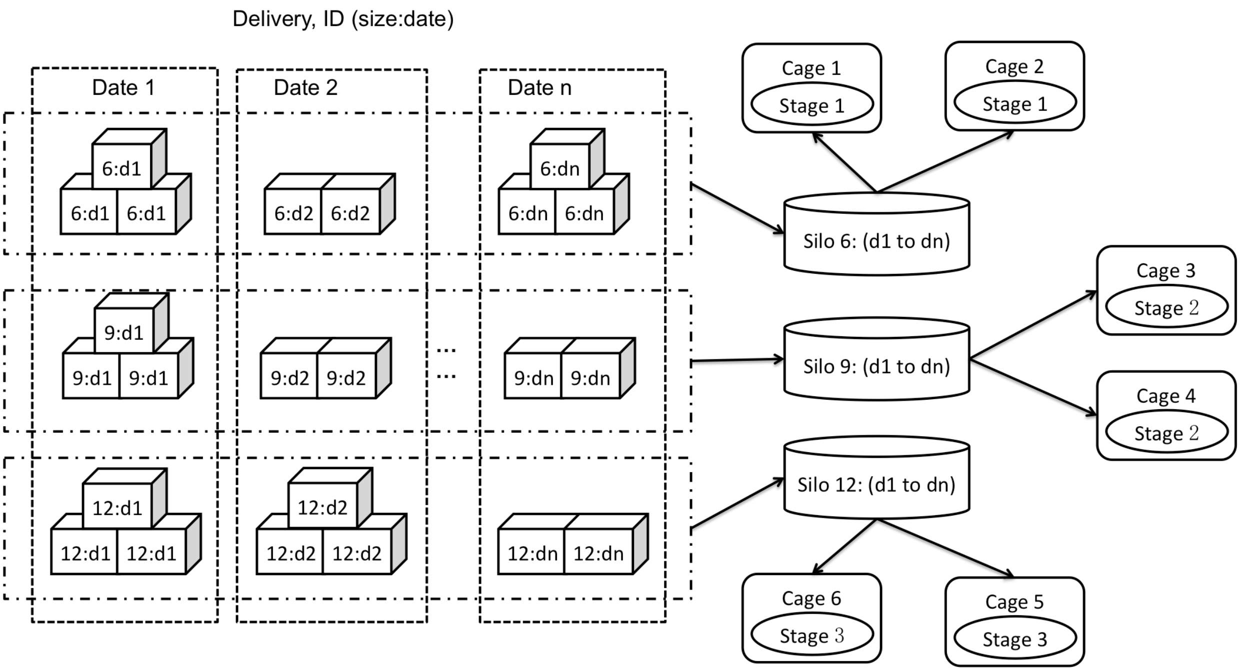

Figure 3 Material flow from the feed manufacturer to the salmon farmer

Figure 3 explains the material flow from the feed manufacturer to the salmon farmer. One delivery of the fish feed could consist of the fish feed with different production date. For example, 6mm fish feed produced in date 1 (ID number: 6:d1), date 2(ID number: 6:d2) and date n(ID number: 6:dn) can be delivered to the SalmF in a same delivery date. Once the SalmF received the fish feed from the FeedM, the same size fish feeds produced in the different production dates are mixed into one silo.

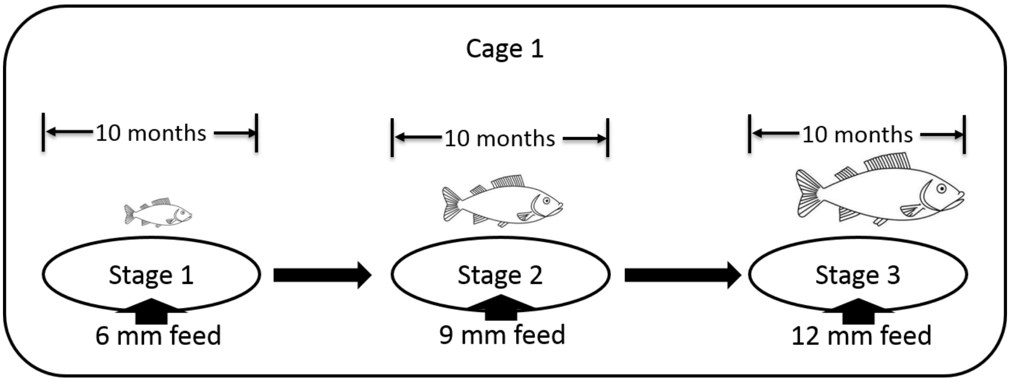

Figure 4 Fish grow flow in Cage 1

Figure 4 describes salmon's growing flow in the cage 1. Smolts are delivered by well boat to the SalmF. Then, the SalmF puts these smolts into each cage that is currently empty and raises them until they get harvested. The smolts eat only 6mm size fish feed for 10 months (Stage1). After stage 1, salmons are grown to medium size and eat only 9mm size fish feed for 10 months (Stage2). After stage 2, the salmons eat only 12mm size fish feed for 10 months until they get harvested (Stage3). Smolts will spend 30 months in one specific cage in total until they get harvested.

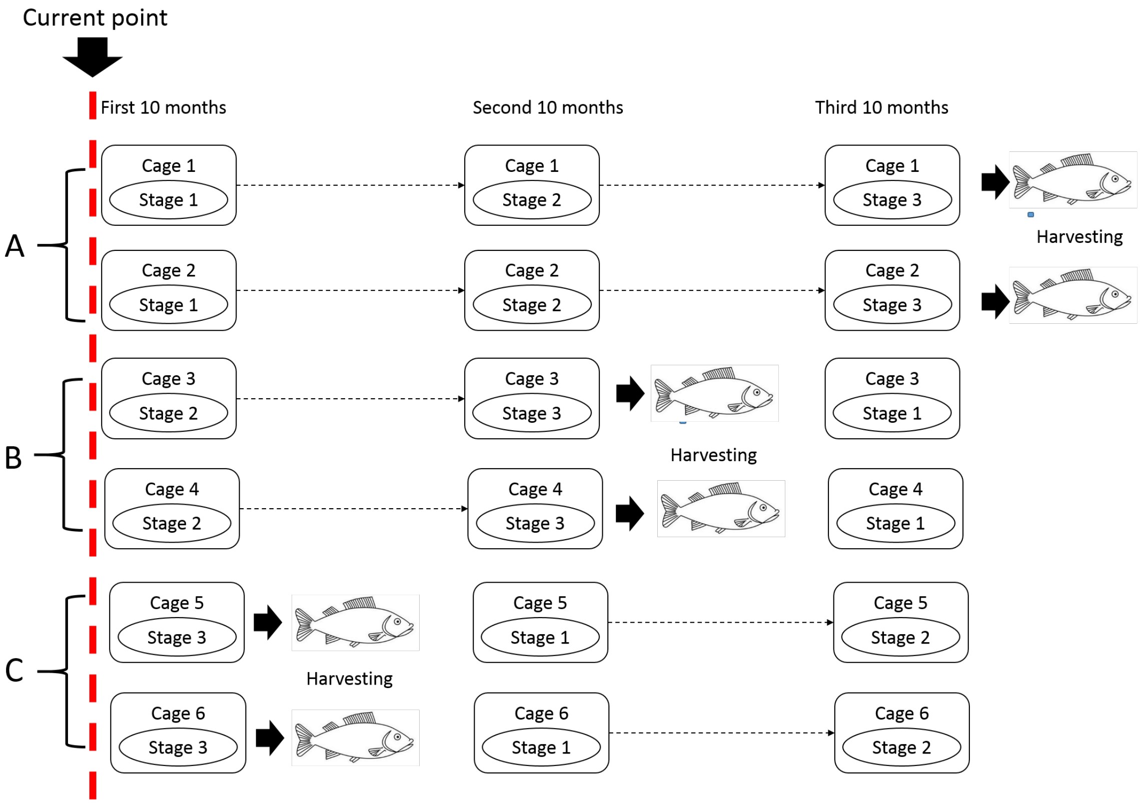

Figure 5 Thirty-month grow period of six cages in the SalmF

Let's assumed that the SalmF has six cages and just received new smolts. As shown in Figure 5, currently,

A) Cage 1 and 2 are empty so the SalmF puts new delivered smolts into these cage 1 and 2. During the stage 1, these smolts will be fed by 6mm size feed for 10months. Then, eat 9mm size feed for 10 months during the stage 2. Afterwards, eat 12mm size feed for 10 months from the stage 3 until fish in these cages get harvested.

B) Cage 3 and 4 are not empty cages and have already past first 10months period(stage1). During the stage 2, fish will be fed by 9mm size feed for 10 months. Afterwards, eat 12mm size feed for 10month from the stage 3 until fish in these cages get harvested. After that, the SalmF puts new delivered smolts into these empty cage 3,4 and raises them by feeding 6mm size feed for 10 months (stage1). Fishes in these cages continually follow the next growing cycle.

C) Fishes in Cage 5 and 6 have already past first and second 10months period(stage2). The fishes in these cage will eat 12mm size feed for 10 months from the stage 3 until the fish in these cages get harvested. Afterwards, the SalmF puts new delivered smolts into these empty cage 5 and 6 and raise them by feeding 6mm size feed for 10 months during the stage 1. After that, these fishes eat 9mm size feed for 10 months during the stage 2 and continually follow the next growing cycle.

4) Market

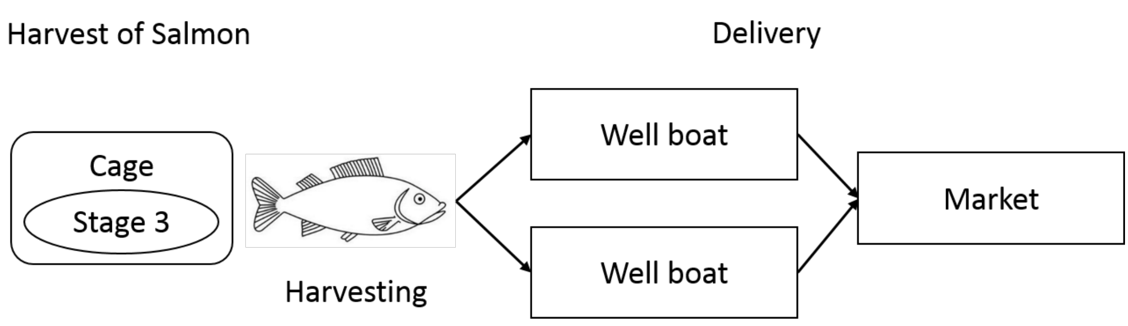

Figure 6 Material flow from salmon farmer and market

After the growth period, the farmed salmon are transported by boat to the Market. Salmon from one cage were often split into two deliveries as shown in Figure 6. Salmon from two different cages could be mixed together during transportation to utilize the capacity of the boat.

4.2.2 Information flow

Information flow describes how messages can be constructed, sent and received as well as how the data elements in the messages should be identified, measured and interpreted (Storøy, et al., 2013). A fully traceable supply chain contains chain traceability and internal traceability. Chain traceability provides the ability to trace a resource through the supply chain. That is, information could be exchanged between the different companies in the supply chain. Internal traceability provides the ability to trace a resource within a company (Karlsen, et al., 2011).

Information flow between the fish ingredient suppliers and the fish feed manufacturer.

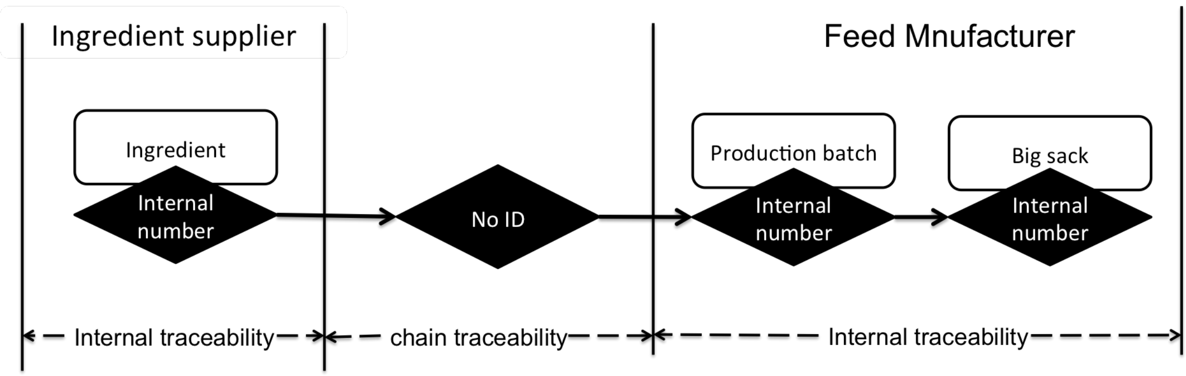

Figure 7 Information flow from the ingredient supplier to the feed manufacturer

All ingredients have internal numbers generated by the ingredient suppliers. Such internal identification is only meaningful to the ingredient suppliers. All the fish feed produced in different sizes packed into each big sack is identified by the internal-number in ERP system by the FeedM. The internal number is the production date.

When we look at Figure 7 above, chain traceability between the IngredS and the FeedM is lost. Because the FeedM didn't record the connection between ingredient identifiers and the fish feed production batches. This information must be recorded in order to be able to trace the production batch of fish feed back to the specific ingredients.

In a real case, the feed manufacturer will mix all the ingredients together to produce the feed, so it is hard for the feed manufacturer to identify which ingredient is contaminated. We here view the fish ingredient suppliers and the fish feed manufacturer as an united corporation in our study. We assume that there already has been a mechanism between the ingredient supplier and the feed manufacturer to transfer all responsibility regarding contamination to the feed manufacturer. Due to the production processes using the silos, the FeedM has higher responsibility to prove the source of the contamination. The feed manufacturer need a right compensation in order to be able to take this responsibility in case of the recall. For example, the feed manufacturer pays lower price to the ingredient suppliers as the compensation of taking full responsibility for the recall. Even though, chain traceability between the ingredient supplier and the feed manufacturer is lost, we regard them as one unit and assume the feed manufacturer pays the recall cost instead of blaming their suppliers and sharing the costs with them.

1) Information flow between the fish feed manufacturer and the salmon farmer

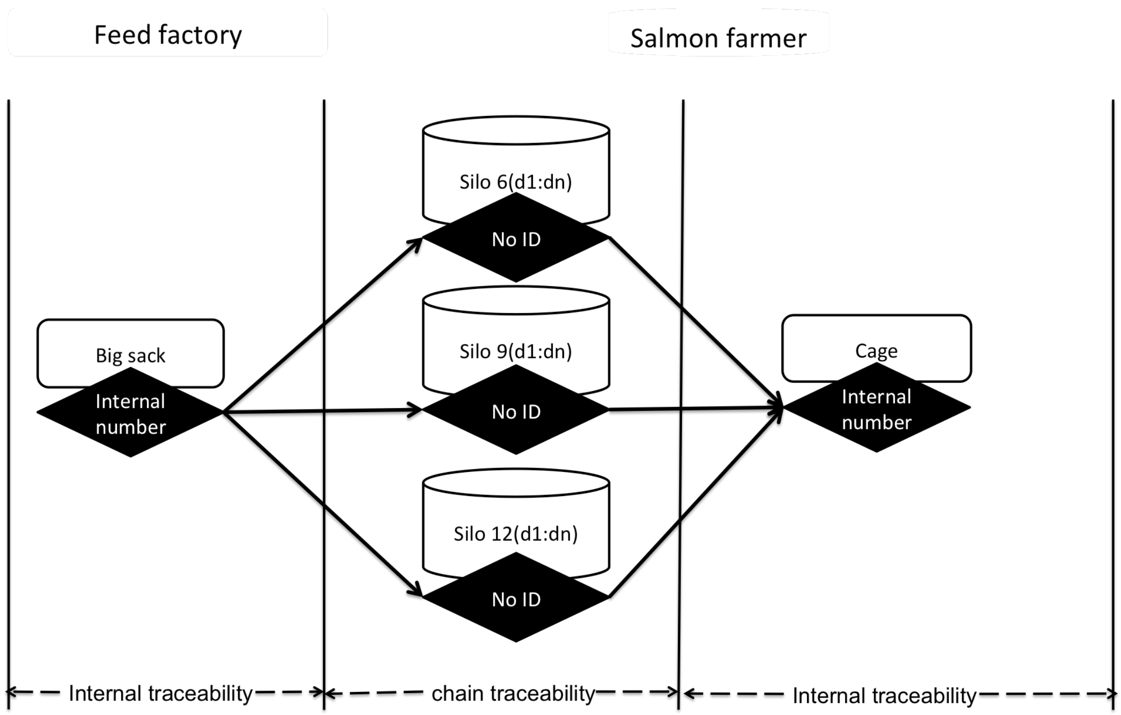

Figure 8 Information flow from the feed manufacturer to the salmon farmer

Figure 8 shows us the present or absence of the internal and chain traceability between the FeedM and the SalmF.

The SalmF will receive fish feed from the FeedM. All the fish feed produced by the FeedM in different sizes packed into each big sack is identified by an internal-number in ERP system by the FeedM. The internal code is production date and size. One delivery of the fish feed could consist of fish feed with different production date (for example, delivery (6:d1+6:d2+6dn)+(9:d1+9:d2+9dn)+(12:d1+12:d2+12:dn) same day). However, such internal identification is only meaningful to the FeedM. The SalmF cannot identify the FeedM's internal traceability information. Also, mixing the same size (d1:dn) feed in one specific silo to feed salmon, the farmer is not able to trace the feed. It is impossible to know which salmon was fed by which feed. The FeedM and the SalmF have an insufficient chain traceability.

2) Information flow between the SalmF and the Market

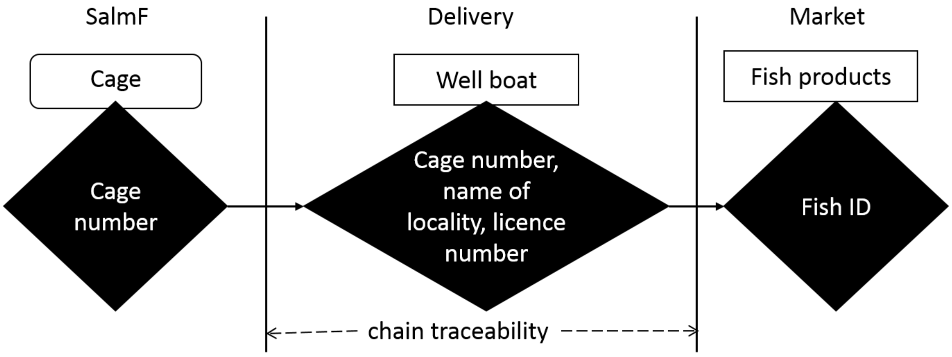

Figure 9 Information flow from the salmon farmer to the market

The SalmF and the Market are able to trace which cage the fish is from. Good chain traceability exists between the SalmF and the Market. Information about the cage number, name of the locality and the license number will be recorded during the delivery. Thus, fish products in the Market will have a cage ID. If contamination is detected in fish products, the cage number and the harvesting date is traceable.

4.3 Granularity level and ID technology

Granularity level is the smallest traceable unit distributed between two parties in the supply chain.

1) Between the FeedM and the SalmF: The granularity level for the FeedM is sack and for silo for the SalmF. In the FeedM, each sack of fish feed was identified by

size and production date. The FeedM uses barcode(internal) to record these two dimensions. This internal code language of the FeedM cannot be identified from the SalmF. Tracefish, a European Committee for Standardization Workshop Agreement (CWA), recommends using one of Global Solution One's standards to record information, a so-called Global Trade Item Number Plus (GTIN+). By using this standard, the units are identified internationally (Karlsen, et al., 2011). If the FeedM can use the barcode (GTIN+) on each sack, the SalmF is able to identify the size and the production date of the feed. In the SalmF, the feed in the silo can only be identified by size. Barcode on the silo is mainly used to connect the SalmF's ERP system to record the consumption of the fish feed.

2) Between the SalmF and the Market: Granularity level for the SalmF is each cage. The recall unit is the cage when the Market finds the contamination in fish. According to Haestein, et al (2001), labeling each individual fish would fulfill future demands for the traceability. For the SalmF, it is questionable to say that each fish as the granularity level would reduce more cost than using each cage as the granularity level in our case. There are following two reasons for this. First, salmon in one cage at the SalmF all went through the identical processes. The farmed fish received same medication, feed and environment etc. Figure 10 describes the possible granularity level choices for the farmer. A finer granularity level, each fish, will not yield any more valuable information than a courser granularity level, each cage, for the SalmF. Second, the SalmF can attain better documentation of each fish by individual labeling, but this will cause high investments and costs to the SalmF. Therefore, the SalmF should consider the benefits and costs of labeling each fish (Karisen, et al., 2010).

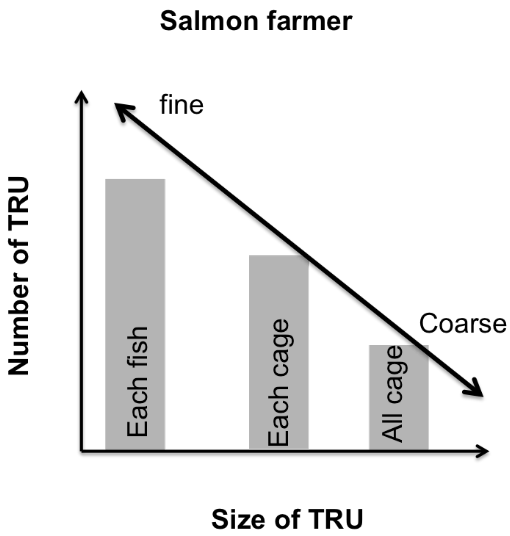

Figure 10 Possible granularity level options for the salmon farmer

4.4 Liability costs

Caswell and Johnson (1991) define the liability cost is that expected costs of being sued for a food poisoning, the amount of the potential litigation costs, and any negative impacts to the firm's reputation and sales. Dai et al (2011) define liability is the responsibility for different parties in the product recalls to pay for the costs of defects and products with unclear origins due to the lack of traceability in supply chain. We believe that that contamination can occur at the FeedM because of contaminated feed ingredients, production equipment, production process among others. There are also possibility that contamination can occur at the SalmF. The contamination source could be water or feeding process. Not only contaminated product should be recalled but also all the products with unclear origin must be removed from the market too.

Once the Market detects contamination of fish, the Market must require the SalmF to recall the contaminated fish. In order to figure out which fish needs to be recalled, the SalmF needs two dimensions to identify contamination source: size and production date of the feed. Since all cages have been fed from the same silo, the farmer cannot identify which cage is safe. The SalmF has to recall all the cages with unclear feed as well as suspicious fish in the market that have been fed by the risky feed. As different date of feed already mixed together, farmer cannot prove whether feed is contaminated or not. So, it is hard to ask the FeedM bear the liability cost. When the recall occurs, the FeedM would bear the recall liability for the products with defective feed, only if it can be traceable. The reason is that the liability cost is determined not only by the feed quality and the traceability issue from the FeedM, but also by the the SalmF's traceability deficiencies. In consequence, the rest of the liabilities of the recalled products with unclear origins move to the the SalmF. Such this liability mismatch also can be explained that the SalmF is the brand owner and it should bear the costs to maintain its reputation. In addition, once the recall occurs, the feed with unclear origins should be removed for the safety reason. With poor traceability level, non-contaminated feed cannot be differentiated from contaminated feed, therefore, all the questionable fish have to be removed from the market. In this case, brand owner (SalmF) bear most of the liability cost.

Apparently, the the SalmF prefers RFID in the whole supply chain and a finer level ID Granularity such as sack-level to aim at the defect source, but the FeedM prefer the opposite to escape from sharing the liability costs. For example, under sack-level ID Granularity, if any party invests in advanced ID technology to improve the traceability degree, the probability of sourcing the defect origin would increase. Consequently, more liability would shift from the SalmF to the FeedM. Moreover, if the traceability degrees are properly designed, the SalmF incurs no liability only if they can prove the FeedM provided defected feed to the SalmF. The Motivation for both the FeedM and the SalmF to improve the traceability system is, therefore, not perfectly aligned.

4.5 Interest sharing mechanism

Our analysis on the liability costs shows that the SalmF bears most of the liability cost if contamination is detected by the Market. If the FeedM invest in technology to improve the granularity level, the probability of sourcing the contamination origin would increase. Thus, more liability will shift from the SalmF to the FeedM. Under silo-level granularity, the SalmF will take responsible for all the liability cost. When the farmer detect the contamination of fish, there are not many evidences to prove that this issue is only from feeding contaminated feed or not. It can be from other sources such as water temperature among others. Then, the FeedM has low incentive to invest in advanced traceability system. Food safety problem become more and more serious nowadays. The

FeedM must improve its traceability system and cooperate with other supply chain parties to build a safer supply chain. Otherwise, the FeedM will gradually lose its market and be eliminated from the supply chain. Thus, it will be a win-win solution if the SalmF can accomplish an interest-sharing agreement with the FeedM and motivate one to improve its traceability that allows the SalmF to share the liability costs with the FeedM.

The cost interaction between the FeedM and the SalmF can be explain with a purchase price of feed that the SalmF pays to the FeedM. Negotiation of the purchasing price is decided by the power of two parties. If the increase in the purchase price of the fish feed can cover the extra liability cost, the SalmF will choose to provide higher purchase price to motivate the FeedM to invest in better traceability system.

In our study, we will only consider an interest-sharing mechanism if it globally pays off to increase traceability, that is if the investment cost for improved traceability is lower than the reduced recall cost due to improved traceability. We develop interest-sharing mechanism especially between the FeedM and the SalmF to find out how the SalmF can motivate the FeedM to invest in better traceability system.

4.6 Summary for the problem

4.6.1 Increased cost from unnecessary recalls

The FeedM uses its own internal code for the feeds. Internal identification is only meaningful to the FeedM but meaningless to the SalmF. One delivery of the feed from the FeedM to the SalmF could consist of the feed with the different production date. All the feed sacks with the same size but produced in different date were mixed into a silo. The main problem here is that farmer is not able to trace the feed after mixing feed (d1:dn) all together in the one silo. When the market detects contaminated fish, the farmer has to recall all the fish from all cages that could have possibly been fed by the contaminated feed. To make a differentiation between the intact and the contaminated feed is almost impossible in this case. Even though, most of fish may not be contaminated, farmer has to recall all the fish due to the safety reasons since the information of the feed is unclear. This recall amount would be tremendously huge.

4.6.2 Who has to pay?

When the recall occurred, the farmer is not able to trace which feed was contaminated after mixing feeds in one silo and cannot prove the cause of the contaminated farmed salmon is from the fish feed supplied by the feed manufacturer. Therefore, the farmer cannot share the liability cost with the feed manufacturer and has to pay all the recall costs.

4.6.3 Example of the current problem

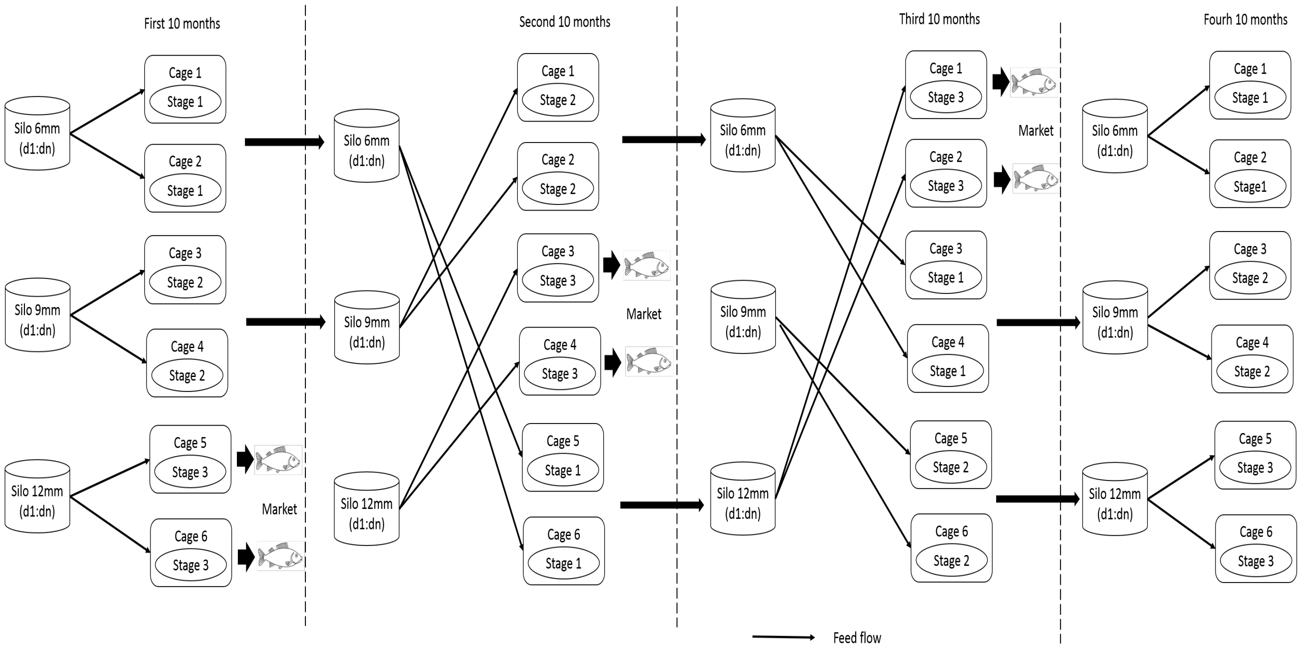

Figure 11 30 months of the salmon farming

As shown in the Figure 11, six cages of the fish will get harvesting and deliver to the market within the three 10 months growing period. For example, at the end of the third 10months, the fishes in cage 1 and 2 will get harvested and delivered to the market. The farmer will put new smolts in the cage 1 and 2 and raise them feeding 6mm feed during the fourth 10 months.

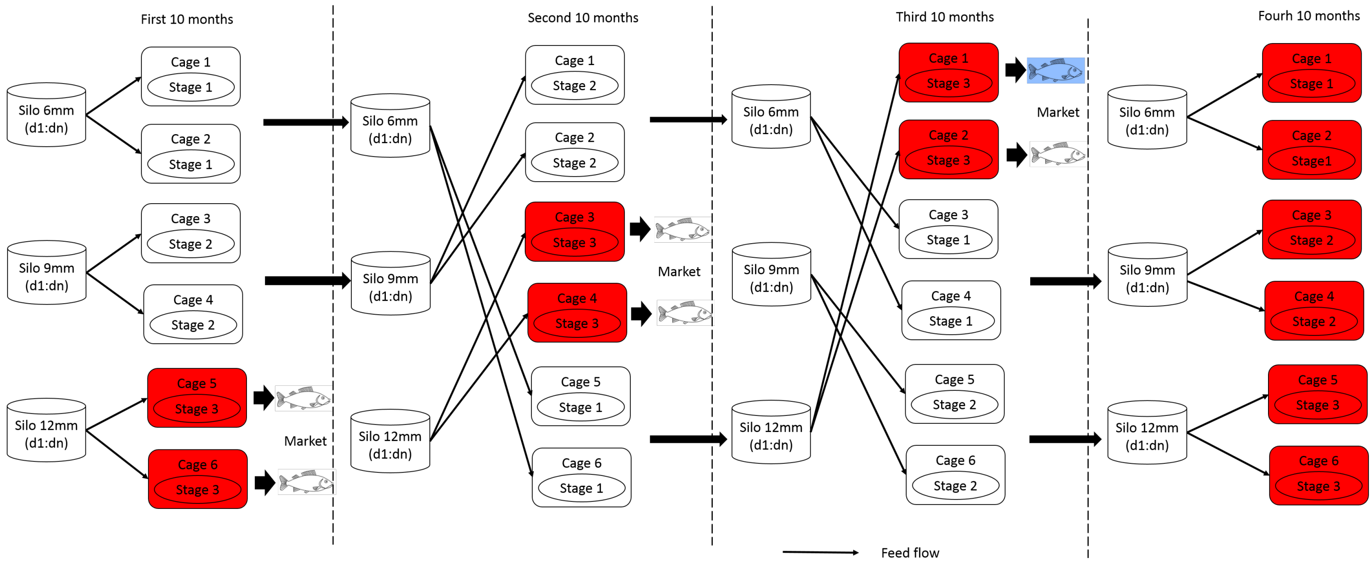

Figure 12 Recall of twelve cages when the contaminated fishes are detected

After 30 months of salmon farming, fishes in the six cages (cage 5 and cage 6 from the first 10 months, cage 3 and cage 4 from the second 10 months and cage 1 and cage 2 from the third 10 months) were delivered to the market. Let's assume that fish from cage 1(marked as blue colour in the Figure 12) is contaminated and is detected in the market in the fourth 10 months. The market will require the SalmF to recall all the questionable fish from the market. As all fish can be traced back to which cage they are from, the SalmF is able to know the contamination fish is from the cage 1 that had been harvested from third 10 months. However, the SalmF is not able to find out what the contamination source for this cage is. The SalmF has to recall all the cages that have been harvested the last 31 months and all current cages at the SalmF in fourth 10 months period.

In this situation, the SalmF need to bear all the liability cost and cannot share with the FeedM. The contamination can be happen in the FeedM, either because of the contaminated ingredient or the production equipment among others. If the SalmF wants to blame the FeedM, the SalmF must prove precisely which feed is contaminated.

5. Model

5.1 Assumption

In this part, we are going to build a mathematical model to solve the current problems in the farmed salmon supply chain. The following are assumptions for our model.

1. We have three ingredients supplier, one feed manufacturer (FeedM), one salmon farmer (SalmF) and customer of SalmF (Market). In order to simplify the supply chain and focus on the problem between the FeedM and the SalmF, we view the three ingredients' suppliers and the FeedM as united corporation. Thus, in our study, we mainly focus on decisions relevant to traceability system of the FeedM and the SalmF

2. Only Market can detect contaminated fish.

3. We assume that the fish feed will not be expired from the day of production to the day of contaminated fish recall.

4. We don't take into account delivery frequency and delivery costs in our model.

5. Depends on degree of the chain traceability between SalmF and FeedM, SalmF can either trace both size and production date of the feed or trace only size of the feed. The SalmF can keep a sample of each feed. But there is no reason for the SalmF to keep the sample if the farmer can only trace size of the feed.

Table 2 Variables, Parameters and Function list

Variables	
ID_{Tec}^{M}	ID technology of FeedM : $\{Internal\ code, GTIN\ +\}$
ID_{Gra}^{M}	ID granularity level of FeedM: $\{Silo, Batch, Sack\}$
ID_{Tec}^{F}	ID technology of SalmF : $\{Barcode, RFID\}$
ID_{Gra}^{F}	ID granularity level of SalmF: $\{Silo, Batch, Sack\}$
T_s	If size dimension of feed can be found, $T_s = 1$, if cannot be found, $T_s = 0$
T_{sd}	If production run dimension(both size and production date) of feed can be found, $T_{sd} = 1$, if cannot be found, $T_{sd} = 0$
CT	Chain traceability (CT=0 or CT=1) If size can be traceable only, CT=0 If both size and production date can be traceable, CT=1
Q	Avg probability that a cage is fed by the size that is contaminated and should be recalled $(0 \leq Q \leq 1)$
P	Avg prob that a cage is fed by the production date and size that is contaminated and should be recalled $(0 \leq P \leq 1)$.
$\Pi^F\ and\ \Pi^M$	The profit of SalmF and FeedM for per cage of fish
C^F, C^M	Recall liability cost of SalmF and FeedM for per cage of fish
Δ^*	An increase in the purchase price of fish feed for each cage by SalmF
ΔI	A direct investment support to FeedM for ID technology from SalmF
ΔF	The increased total benefit of SalmF
ΔM	The increased total cost of FeedM.
ΔS	The increased total benefit of whole supply chain
Parameters	
c_r	Recall cost for a cage of fish

p	SalmF's selling price to Market for one cage of farmed fish
p_M	The SalmF's purchase price for feed of one cage farmed fish
N	The number of cages that the SalmF can harvest after improving the traceability system.
H	Harvesting horizon (month)
$C(ID^F_{Tec})$	Investment cost of SalmF's improvement of ID technology
$C(ID^F_{Gra})$	Investment cost of SalmF's improvement of ID Granularity level
$C(ID^M_{Tec})$	Investment cost of FeedM's improvement of ID coding language
$C(ID^M_{Gra})$	Investment cost of FeedM's improvement of ID Granularity level
Function	
$g(T_d, T_{sd})$	The average recall probability of one cage
$C = f(T_d, T_{sd})$	The average recall cost of a cage considering 1) an H month harvesting horizon where N-6 cages are sent to the market and 6 cages are still in production at the SalmF 2) only one cage of fish is contaminated in the H months horizon.

5.2 Modeling Framework

Currently, the FeedM only needs to record two dimensions about the feed: feed size and production date. As barcode is able to record two dimensions, the FeedM doesn't need to improve from the barcode(internal) to the barcode(GTIN+). If the FeedM and the SalmF want to attain chain traceability, the FeedM must change the barcode's coding language, improving the internal code to GTIN+. The FeedM's current granularity level is sack, which is the finest. There is no reason for the FeedM to change from the finest granularity level to coarser level. Thus, we assume that the granularity level of the FeedM will not change from the sack.

In order to trace harvested fish from a specific cage, the SalmF needs the RFID to record at least three dimensions of the feed: size, production date and cage number. As the barcode can only record two dimensions, lost of recording one dimension cannot be avoided. The SalmF's current granularity level is silo. The SalmF can improve to finer level: from silo to batch or from silo to sack. Compare to the sack level, the batch level is coarser unit. We can package some sacks into one batch. In the sack level, the SalmF can put the RFID on the each sack. In the batch level, SalmF can put the RFID on the each batch.

In our model, there are two main design parameters, ID technology and ID Granularity level. The ID technology choice ID_{Tec} determines the traceability degree $T \in \{ID_{Tec}\}$, which is defined as the probability of retrieving accurate information from the ID technology. Two different leading technologies can be used from the SalmF: Barcode and Radio Frequency Identification (RFID). That is, selectable ID technology for the SalmF is $ID_{Tec}^{F} = \{Barcode, RFID\}$. Two different coding language can be used from the FeedM: Barcode (internal) and Barcode (GTIN+). That is, selectable ID technology for the FeedM is $ID_{Tec}^{M} = \{Barcode = internal\}$ or $\{Barcode = GTIN +\}$. To attain chain traceability with the SalmF, the FeedM must change the barcode's coding language, improving barcode (internal code) to the barcode (GTIN+)

The ID Granularity level choice ID_{Gra} affects amount of information available in terms of product origin and determines the grouping size when recording information about material, components and products. Selectable ID Granularity level choices for the FeedM can be described as $ID_{Gra}^{M} = \{\, Sack\}$ and for the SalmF can be described as $ID_{Gra}^{F} = \{Silo, Batch, Sack\}$. For example, silo-level ID Granularity means all the products in one silo have the same ID code and different silo can be differentiated. ID Granularity level is chosen as a decision variable as Granularity levels will directly affect the amount of recalled products. The less grouping size ID Granularity level one choose the more helpful one to reduce the recalls. For example, if sack-level Granularity of feed is contaminated, it helps to reduce the recalls more than implementing silo-level ID Granularity. Therefore, the traceability degree implementing ID Granularity level is established.

Overall, the design decisions for the FeedM and the SalmF can be described as below.

FeedM: ID technology $ID_{Tec}^{M} = \{Barcode = internal\}$ or $\{Barcode = GTIN +\}$,

ID Granularity level $ID_{Gra}^{M} = \{Sack\}$

SalmF: ID technology $ID_{Tec}^{F} = \{Barcode, RFID\}$, ID Granularity level $ID_{Gra}^{F} = \{Silo, Batch, Sack\}$

As FeedM and SalmF are two individual firms in this supply chain and both of them will priority their own profit, thus, we assume the choice of the two design parameters is independent and the combination of the two design parameters is determined by maximizing the profit of the corresponding party.

If only size dimension of contaminated feed can be found, $T_s = 1$, if cannot be found, $T_s = 0$. If production run (size and production date) dimension of contaminated feed can be found, $T_{sd} = 1$, if cannot be found, $T_{sd} = 0$. CT shows the degree of chain traceability (CT=0, or CT=1). If only size can be traceable, there is no chain traceability in a supply chain (CT=0). If both size and production date can be traceable there exists chain traceability in a supply chain (CT=1).

Table 3 Granularity level and ID technology of SalmF and FeedM

Case	**SalmF**		**FeedM**		$\boldsymbol{T_{sd}, T_s}$	Chain traceability
	Granularity level	ID technology	Granularity level	ID technology		
1	Sack	RFID	Sack	GTIN+	$T_{sd} = 1$ and $T_s = 1$	$CT = 1$
2	Sack	RFID	Sack	Internal code	$T_{sd} = 0$ and $T_s = 1$	$CT = 0$
3	Batch	RFID	Sack	GTIN+	$T_{sd} = 1$ and $T_s = 1$	$CT = 1$
4	Batch	RFID	Sack	Internal code	$T_{sd} = 0$ and $T_s = 1$	$CT = 0$
5	Silo	Barcode	Sack	GTIN+	$T_{sd} = 0$ and $T_s = 0$	$CT = 0$
6	Silo	Barcode	Sack	Internal code	$T_{sd} = 0$ and $T_s = 0$	$CT = 0$

Table 3 describes six possible cases with different the granularity level and ID technology of the SalmF and FeedM. Case 6 represents the current situation of the two firms.

In case 1 and 2, if the SalmF implements RFID with sack-level granularity, each sack of feed has a unique ID code, which can record feed size, production date and cage number. Whether the SalmF can achieve chain traceability with the FeedM depends on which technology (internal code or GTIN+) FeedM will implement. If the FeedM tagged on each sacks with barcode (GTIN+), two dimensions (size and production date) of contaminated feed can be found, $T_s = 1$ and $T_{sd} = 1$. Then, the SalmF can read the necessary information and achieve sufficient chain traceability with the FeedM (Chain traceability, $CT = 1$ in case1). However, if the FeedM uses internal code, which is only readable internally, then it is impossible for the SalmF to read production date. $T_s = 1$ and $T_{sd} = 0$. (Chain traceability, $CT = 0$ in case 2).

In case 3 and 4, if the SalmF implements RFID with Batch–level granularity, each batch will have a unique ID code. Feed sacks with different production date could be packaged into one batch. Whether the SalmF can achieve chain traceability with the FeedM depends on which technology (internal code or GTIN+) FeedM will implement. If the FeedM tagged on each sacks with barcode (GTIN+), two dimensions (size and production date) of contaminated feed can be found, $T_s = 1$ and $T_{sd} = 1$. Then, the SalmF can read the necessary information and achieve sufficient chain traceability with the FeedM (Chain traceability, $CT = 1$ in case 3). However, if the FeedM uses internal code, which is only readable internally, then it is impossible for the SalmF to read production date. $T_s = 1$ and $T_{sd} = 0$. (Chain traceability, $CT = 0$ in case 4).

In case 5 and 6, if SalmF implements barcode with silo-level granularity level, all fish feed with the same size will be filled in the same silo. No matter which ID technology (internal code or GTIN+) the FeedM uses, both size and production date dimension of contaminated feed cannot be found, $T_{sd} = 0$and $T_s = 0$ (Chain traceability, $CT = 0$ in both case 5 and 6). Case 6 is the current situation.

5.3 Contamination probability and Liability cost

Over 31 months period, the SalmF will have 6 cages that are harvested, cage 5 and 6 from the first 10 months, cage 3 and 4 from the second 10 months, and cage 1 and 2 from the third 10 months as shown in Figure 13. Assume that we observe a contaminated fish in one of the cages harvested in the third 10 months period (the fish marked as red in Figure 13) and that only one production run (sacks with similar production date and size) is contaminated. Assume further that cage harvested earlier than the first 10 months period cannot be contaminated based on the contamination source discovered in the third 10 months period, and that we only have on contaminated cage in the whole period.

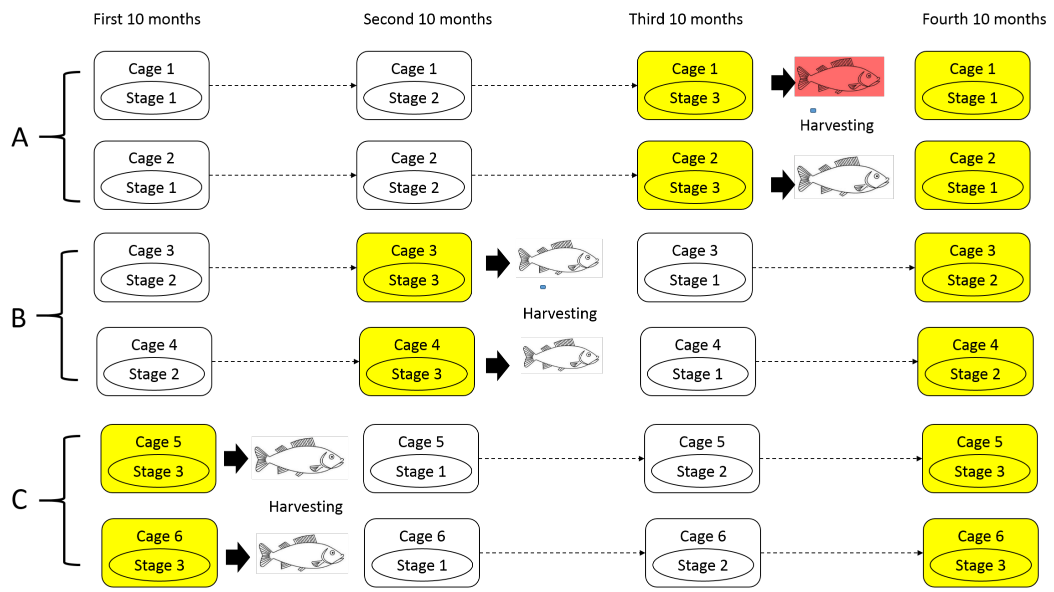

Figure 13 Contaminated fish is detected in the fourth 10 months

Let Q= Avg probability that a cage is fed by the size that is contaminated and should be recalled and P= Avg probability that a cage is fed by the production date and size that is contaminated and should be recalled. We have that $P < Q$, from the calculation and case below. The average probability of Q, given a 31 months horizon, is then calculated based on the probability that each of the twelve cages are fed by the contaminated size, see table 4.

Q= The average probability that a cage is fed by the contaminated size x and should be recalled = $(2 + 2 + 2 + 4)/12$=83.33%

Table 4 Calculation of probability Q

First 10 months		Second 10 months		Third 10 months		Fourth 10 months	
				Cage 1: Market	Probability that Cage 1 is contaminated=1, size x is contaminated	Cage 1: stage 1	Probability that Cage 1 is fed with contaminated size x =1/3
				Cage 2: Market	Probability that Cage 2 is fed with contaminated size =1	Cage 2: stage 1	Probability that Cage 2 is fed with contaminated size x =1/3
		Cage 3: Market	Probability that Cage 3 is fed with contaminated size x =1			Cage 3: stage 2	Probability that Cage 3 is fed with contaminated size x =2/3
		Cage 4 : Market	Probability that Cage 4 is fed with contaminated size x =1			Cage 4: stage 2	Probability that Cage 4 is fed with contaminated size x =2/3
Cage 5: Market	Probability that Cage 5 is fed with contaminated size x =1					Cage 5: Stage 3	Probability that Cage 5 is fed with contaminated size x =1
Cage6 : Market	Probability that Cage 6 is fed with contaminated size x =1					Cage 6: stage 3	Probability that Cage 6 is fed with contaminated size x =1

Contamination Probability	2×1=2		2×1=2		2×1=2		$2\times\frac{1}{3}+2\times\frac{2}{3}+2\times1=4$

Below follow an example on how P can be calculated. Market found that fish from cage 1 is contaminated. Probability of contamination=1 and production run y (production date and size) is contaminated. Assume the probability of another cage that is fed with contaminated production run y $= r_i (0 < r_i < 1), i = 0,1,2$. Assume further, r_i is controlled by time. The closer to the contaminated fish, the bigger the probability that another cage is fed with feed in contaminated production run. We assume the probability that cages harvested earlier than the first ten months period cannot be contaminated, thus r_3=0.

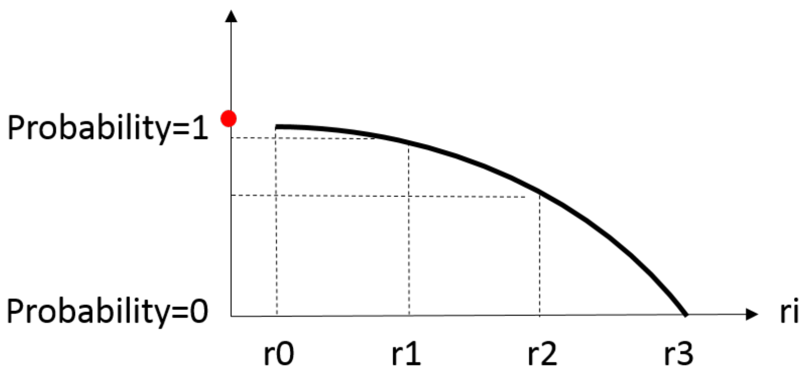

Figure 14 Value of ri, i=0,1,2,3

In stage 1, fish only eat 6mm feed, thus the probability of fed with contaminated production run is $r_1\times\frac{1}{3}$. In stage 2, fish have eaten 6mm and 9mm, thus probability increase to $r_1\times\frac{2}{3}$. Thus, the probabilities in the last column of Table 5 increase from Cage1 to Cage6. See table 5.

Table 5 Calculation of probability P

First 10 months		Second 10 months		Third 10 months		Fourth10 months	
				Cage 1: Market	Probability that Cage 1 is contaminated=1, size x is contaminated	Cage 1: stage 1	Probability that Cage 1 is fed with contaminated production run (production date and size) = $r_1 \times \frac{1}{3}$
				Cage 2: Market	Probability that Cage 2 is fed with contaminated production run (production date and size) = r0	Cage 2: stage 1	Probability that Cage 2 is fed with contaminated production run (production date and size) = $r_1 \times \frac{1}{3}$
		Cage 3: Market	Probability that Cage 3 is fed with contaminated production run (production date and size) = r_1			Cage 3: stage 2	Probability that Cage 3 is fed with contaminated production run (production date and size) = $r_1 \times \frac{2}{3}$
		Cage 4 : Market	Probability that Cage 4 is fed with contaminated production run (production date and size) = r_1			Cage 4: stage 2	Probability that Cage 4 is fed with contaminated production run (production date and size) = $r_1 \times \frac{2}{3}$
Cage 5: Market	Probability that Cage 5 is fed with contamina					Cage 5: Stage 3	Probability that Cage 5 is fed with contamina

	ted production run (production date and size) = r_2						ted production run (production date and size) = r_1
Cage6 : Market	Probability that Cage 6 is fed with contaminated production run (production date and size) = r_2					Cage 6: stage 3	Probability that Cage 6 is fed with contaminated production run (production date and size) = r_1
Probability	$2 \times r_2 = 2r_2$		$2 \times r_1 = 2r_1$		$2 \times r_0 = 2r_0$		$2 \times r_1 \times \frac{1}{3} + 2 \times r_1 \times \frac{2}{3} + 2 \times r_1 = 4r_1$

P = The average probability that a cage is fed by the contaminated production run (size/date) and should be given the 31 months horizon, is then = $(2r_2 + 6r_1 + 2r_0)/12$

In the rest of the text we make the following assumption

a. Q and P are estimated based on a time horizon H in which the Salmon Farmer can send N-6 cages to the market
b. Only cage is contaminated in the given time horizon
c. The recall cost for a cage of fish is equal for all cages regardless of whether the cage is harvested and sold to the market or the cage of fish is still inn production at the Salmon farmer.

There are three cases should addressed when it comes to calculate a probability of total recall on the one cage of fish.

a. If both size and production date dimension of contaminated feed can be found, the cage of fish should be recalled with a probability $T_{sd} * \text{P}$.

b. If size dimension of contaminated feed can be found, while production date dimension of contaminated feed cannot be found, the cage of fish should be recalled with a probability $QT_s * (1 - T_{sd})$

c. If neither size and production date dimension of contaminated feed can be found, the cage of fish should be recalled with a probability $(1 - T_{sd})(1 - T_s)$

Adding up the probabilities of above-mentioned four recall cases leads to the total recall probability for one cage of fish.

$$Recall\ Probability\ (ID_{Tec}^{M}, ID_{Gra}^{M}, ID_{Tec}^{F}, ID_{Gra}^{F}) = g(T_{sd}, T_s) = PT_{sd} + QT_s(1 - T_{sd}) + (1 - T_{sd})(1 - T_s) \quad (2)$$

The average recall probability is decided by the value of T_{sd} and T_s. The average recall cost of a cage considering 1) an H month harvesting horizion where N-6 cages are sent to the market and 6 cages are still in production at the SalmF 2) only one cage of fish is contaminated in the H months horizon $f(T_{sd}, T_s)$ is recall cost c_r multiply by total recall probability $g(T_{sd}, T_s)$. Using an average calculation of the investment cost here is a simplification.

$$C(ID_{Tec}^{M}, ID_{Gra}^{M}, ID_{Tec}^{F}, ID_{Gra}^{F}) = f(T_{sd}, T_s) = c_r * g(T_{sd}, T_s)$$
$$= c_r(PT_{sd} + QT_s(1 - T_{sd}) + (1 - T_{sd})(1 - T_s))$$

<table>
<tr><th rowspan="2">Case</th><th colspan="2">SalmF</th><th colspan="2">FeedM</th><th rowspan="2">$C = f(T_d, T_s)$</th><th></th><th></th><th></th></tr>
<tr><th>Granularity level</th><th>ID technology</th><th>Granularity level</th><th>ID technology</th><th>C^M</th><th>C^F</th><th>CT</th></tr>
<tr><td>1</td><td>Sack</td><td>RFID</td><td>Sack</td><td>GTIN+</td><td>$f(1,1) = c_r P$</td><td>$c_r P$</td><td>0</td><td>$CT = 1$</td></tr>
<tr><td>2</td><td>Sack</td><td>RFID</td><td>Sack</td><td>Internal code</td><td>$f(0,1) = c_r Q$</td><td>0</td><td>c_rQ</td><td>$CT = 0$</td></tr>
<tr><td>3</td><td>Batch</td><td>RFID</td><td>Sack</td><td>GTIN+</td><td>$f(1,1) = c_r P$</td><td>$c_r P$</td><td>0</td><td>$CT = 1$</td></tr>
<tr><td>4</td><td>Batch</td><td>RFID</td><td>Sack</td><td>Internal code</td><td>$f(0,1) = c_r Q$</td><td>0</td><td>c_rQ</td><td>$CT = 0$</td></tr>
<tr><td>5</td><td>Silo</td><td>Barcode</td><td>Sack</td><td>GTIN+</td><td>$f(0,0) = c_r$</td><td>0</td><td>c_r</td><td>$CT = 0$</td></tr>
<tr><td>6</td><td>Silo</td><td>Barcode</td><td>Sack</td><td>Internal code</td><td>$f(0,0) = c_r$</td><td>0</td><td>c_r</td><td>$CT = 0$</td></tr>
</table>

Table 6 Recall cost of the SalmF and the FeedM

Table 6 presents the six different cases to describe 1) the total recall liability cost of one cage 2) recall liability cost of the SalmF and FeedM for per cage of fish, and 3) the presence or absence of the chain traceability between the two parties, according to the combination of three different granularity levels and two different ID technologies. We will explain this in proposition 1 and 2 below.

Proposition1

Proposition 1.0

Improving the traceability degree of the FeedM and the SalmF by implementing an advanced ID technology and a finer granularity level (sack-level or batch-level) can reduces the total liability cost of whole supply chain.

$$c_r P < c_r Q < c_r$$

Proposition 1.1

If SalmF implemented finer granularity level from Silo to Sack with adopting RFID and FeedM implemented ID technology level from Internal code to GTIN+, the total liability cost will be reduced from $c_r$to $c_r P$:

$$C(case\ 1) < C(case\ 6)$$

Proposition 1.2

If the SalmF implemented finer granularity level from Silo to Sack with adopting RFID while the FeedM keeps the internal code as the ID technology, the SalmF cannot read this internal code as well as trace the production date of the feed. The total liability cost in this case will be reduced from c_r to $c_r Q$:

$$C(case\ 2) < C(case\ 6)$$

Proposition 1.3

If the SalmF implemented finer granularity level from Silo to Batch with adopting RFID while the FeedM implemented ID technology level from Internal code to GTIN+ using finest granularity level, the total liability cost will be reduce from c_r to $c_r P$:

$$C(case\ 3) < C(case\ 6)$$

Proposition 1.4

If the SalmF implemented finer granularity level from Silo to Batch with adopting RFID while the FeedM keeps the internal code as the ID technology, the SalmF cannot read this internal code as well as trace the production date of the feed. The total liability cost in this case will be somewhat reduced from c_r to $c_r Q$:

$$C(case\ 4) < C(case\ 6)$$

Proposition 1.5

If the SalmF keeps the granularity level (silo) and ID technology (barcode) while the FeedM implemented ID technology level from Internal code to GTIN+ using finest granularity level, the total liability cost will be the same c_r :

$$C(case\ 5) = C(case\ 6)$$

In overall, we can derive this result.

$$C(case\ 1) = C(case\ 3\ ) < C(case\ 2) < C(case\ 4) < C(case\ 5) = C(case\ 6)$$

The least total recall costs in the supply chain are achieved in case 1 and 3 where the chain traceability between two firms exists (TC=1). This is good news for both the SalmF and the FeedM. The SalmF and FeedM will consider to invest in case 1 or 3. It is important to make the SalmF to decide which case is more beneficial for the SalmF to achieved chain traceability less costly. Let's see the proposition 1.6

Proposition 1.6

An improvement of finest granularity level from batch to Sack will incur extra investment cost for SalmF. Compared selectable options Case 1 to Case 3, there is no reason for the SalmF to adopt the Case 1 than the case 3, because the total liability cost is same in both cases. The SalmF needs to purchase more RFID tag compared to the batch level, because the Sack level needs to tag RFID on each sack of feed.

$$C(case\ 1) = C(case\ 3)$$

From this proposition we can derive that the optimal traceability level for the SalmF is Case 3.

Proposition 2

Now, we need to consider what the FeedM's optimal investment choice is.

$$C^M(case\ 1) = C^M(case\ 3) > C^M(case\ 2) = C^M(case\ 4) = C^M(case\ 5) = C^M(case\ 6) = 0$$

$$C^F(case\ 6) = C^F(case\ 5) > C^F(case\ 4) = C^F(case\ 2) > C^F(case\ 3) = C^F(case\ 1) = 0$$

The above propositions suggest that the traceability degree and precision in the supply chain jointly determine each player's liability and incentive to improve the traceability. If the SalmF invest in an advanced ID technology and in a finer granularity level to improve traceability degree, the probability of discovering to the contaminated feed would be increased. Therefore, the SalmF would bear less liability cost shifting the liability from SalmF to FeedM. The extreme case, SalmF could have no liability costs.

See the following example for a graphically illustration.

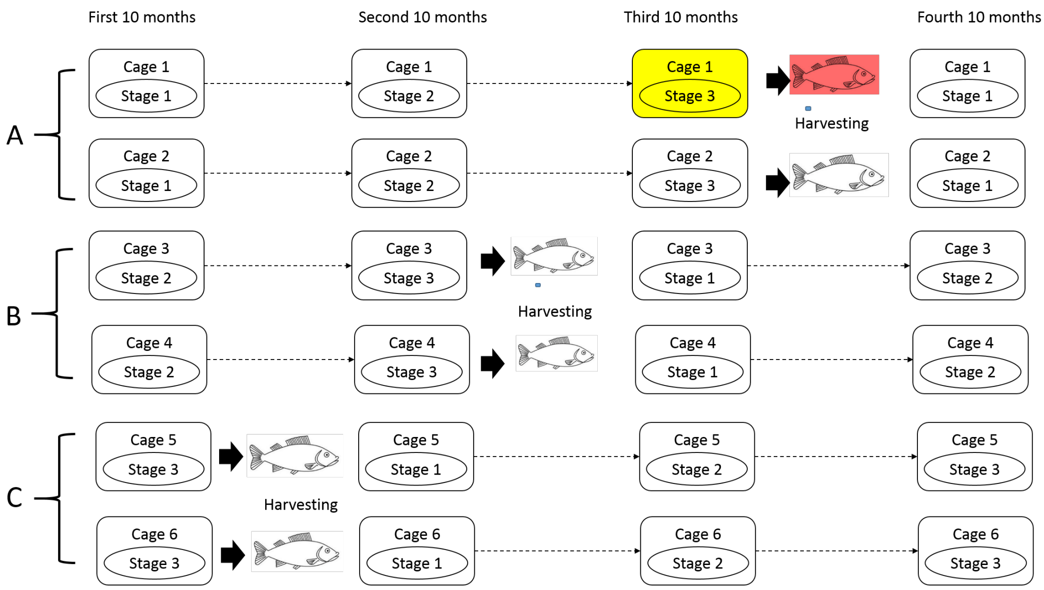

Figure 15 Recall of cage when Tsd=1 and Ts=1

$T_{sd} = 1$ and $T_s = 1$, ensure the SalmF to find both size and production date dimension of contaminated feed. For example, 9mm produced in specific date is contaminated, 9mmPd*, average recall cost of whole supply chain would be $f(T_{sd}, T_s) = f(1,1) = c_r P$. The best case is, if all the cages haven't fed by 9mmPd* except the harvested fish(marked as red) from the cage 1 in third 10 months, then only marked as yellow colored cage in the figure 15 will be recalled.

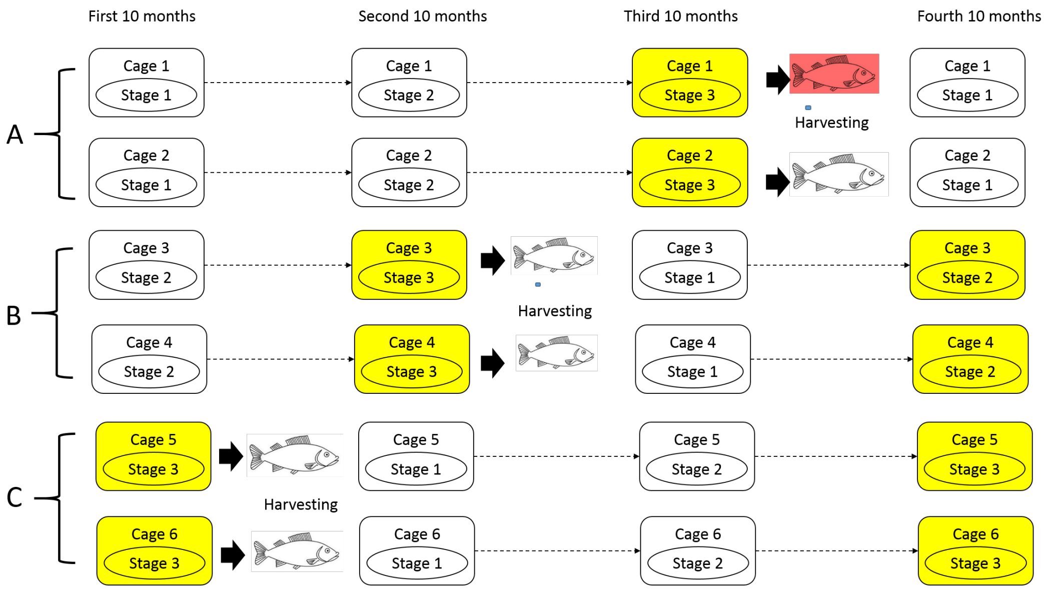

Figure 16 Recall of cage when Tsd=0 and Ts=1

$T_{sd} = 0$ and $T_s = 1$, ensure the SalmF to find only size dimension of contaminated feed. For example, the SalmF can only identify 9mm size feed is contaminated but cannot identify which production date is contaminated. The average recall cost of whole supply chain would be $f(T_{sd}, T_s) = f(0,1) = c_r Q$. The cage that have already fed by 9mm feed must be recalled. 10 cages marked as yellow in fig. 16 need to be recalled.

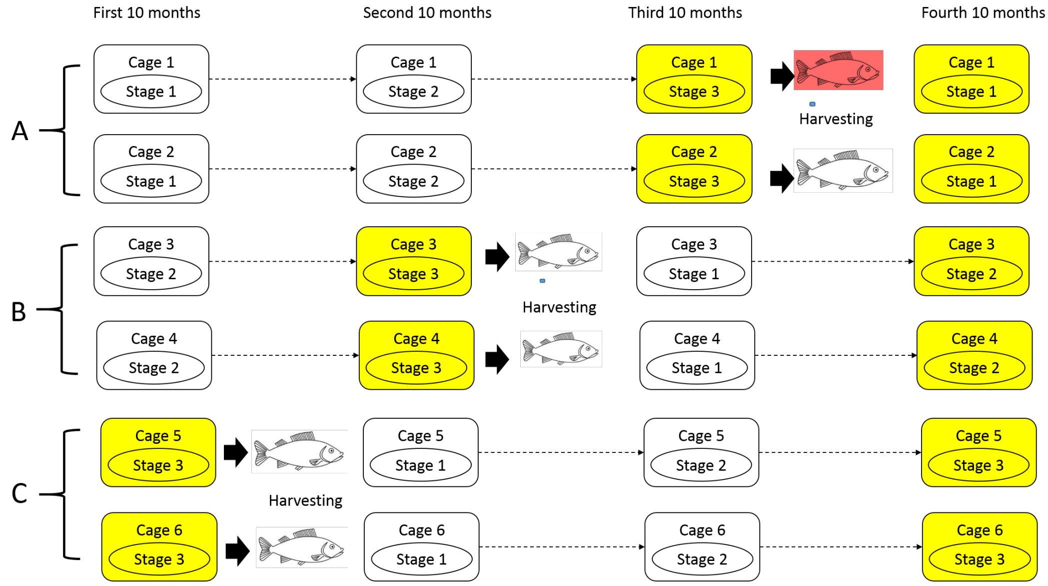

Figure 17 Recall of cage when Tsd=0 and Ts=0

$T_{sd} = 0$ and $T_s = 0$, it suggests that all cages of fish will be recall because cannot trace the feed . The average recall cost per cage $f(T_{sd}, T_s) = f(0,0) = c_r$, 12 cages should be recalled. So excessive recall must happen in this case. This is current situation in our case.

Analysis from proposition 2, we can drive the better chain traceability system leads reduction in total recall liability cost and bring benefits to the society. However, the FeedM is not willing to invest in the case 3 compared to the case 6, since the better traceability system is able to transfer the recall liability cost from the SalmF to the FeedM. If the FeedM decided not to invest in the case 3, the SalmF cannot achieve the chain traceability system. It is impossible RFID to read internal barcode. Therefore, the SalmF must motivate the FeedM to invest in case 3 together to attain chain traceability.

5.4 Interest-sharing mechanism

A rational investment decision of a firm is based on a profit. If the investment decision is not expected to bring enough profit to the firm, the firm is not willing to do so. In our study, we will discuss the trade-off between two options of the SalmF and the FeedM 1) invest in a better chain traceability system or 2) stay with the original poor chain traceability system. The investment decision depends upon the each firm's profit. (4) and (5) describe how to calculate the each firm's profit.

$$\Pi^F = p - p_M - C^F(ID^M_{Tec}, ID^M_{Gra}, ID^F_{Tec}, ID^F_{Gra}) - \frac{C(ID^F_{Tec})}{N} - \frac{C(ID^F_{Gra})}{N} \quad (4)$$

$$\Pi^M = p_M - C^M(ID^M_{Tec}, ID^M_{Gra}, ID^F_{Tec}, ID^F_{Gra}) - \frac{C(ID^M_{Tec})}{N} - \frac{C(ID^M_{Gra})}{N} \quad (5)$$

In (4), p is the selling price for one cage of the farmed fish to the market and p_M is the purchase price for feed for the one cage of the farmed fish. For simplicity we assume that N is the number of cages that the SalmF can harvest after improving the traceability system. Using of the N means that all cages will share the investment cost of improving the traceability system. C^F, C^M are the average recall cost of a cage of SalmF and FeedM considering 1) an H month harvesting horizion where N-6 cages are sent to the market and 6 cages are still in production at the SalmF 2) only one cage of fish is contaminated in the H months horizon.

is the expected liability cost for one cage of the farmed fish in the fish supply chains and it is jointly determined by the choice of ID technology from the FeedM ID^M_{Tec}, the choice of ID Granularity level from the FeedM ID^M_{Gra}, the choice of ID technology from the SalmF ID^F_{Tec} and the choice of ID Granularity level from the SalmF ID^F_{Gra}, as $C(ID^M_{Tec}, ID^M_{Gra}, ID^F_{Tec}, ID^F_{Gra})$. The investments of these are directly associated with ID technology cost C_{tec} and ID Granularity cost C_{gra}.

FeedM's preferable decision is always $ID^M_{Tec} = \{Internal\ code\}, ID^M_{Gra} = \{sack\}$ for the following reasons. If the FeedM choose GTIN+, it incurs more liability cost $C^M(ID^M_{Tec}, ID^M_{Gra}, ID^F_{Tec}, ID^F_{Gra})$ according to Proposition 2. Besides, some investment cost will incur in order to improve ID technology from current internal code to GTIN+. Therefore, according to the profit equation of the FeedM in (5), its preferable design is always internal code and sack, regardless of the design decision of the SalmF. The design decisions of the SalmF and the FeedM are independent, which means that the design decision of the SalmF will not affect the design decision choice of the FeedM. Chain traceability between these two parties cannot be realised when the FeedM wants to stay at the current level of traceability (case6), regardless of the SalmF's choices whether adopts the RFID with finer granularity level or not.

The design decisions of the FeedM in current case 6 were$ID_{Tec}^{M} = \{Internal\ code\}, ID_{Gra}^{M} = \{sack\}$, and the design decisions of the SalmF were $ID_{Tec}^{F} = \{Barcode\}$, $ID_{Gra}^{F} = \{silo\}$. Since the FeedM uses sack-level as ID Granularity level and will not be changed, $C(ID_{Gra}^{M}) = 0$

The incentives for the FeedM to improve traceability system can be explained by two denotations: 1) Δ^* : an increase in the purchase price of fish feed for each cage by the SalmF 2) ΔI : a direct investment support to improve chain traceability by SalmF. $\frac{\Delta I}{N}$ is average investment support for one cage. Δ^* and ΔI can be regarded as a reward for the FeedM to improve the current traceability and can be a compensation for them to invest in GTIN+. The goal of this interest-sharing mechanism is to achieve maximum total profit in the supply chain and this mechanism plays a key role in allocating the total profit in order to make each player to participate.

Under the interest sharing mechanism, we can calculate the profit of the FeedM and the SalmF by formulas (6) and (7).

$$\Pi^F = p - (p_M + \Delta^*) - C^F - \frac{C(ID_{Tec}^{F})}{N} - \frac{C(ID_{Gra}^{F})}{N} - \frac{\Delta I}{N} \quad (6)$$

$$\Pi^M = (p_M + \Delta^*) - C^M - \frac{C(ID_{Tec}^{M})}{N} + \frac{\Delta I}{N} \quad (7)$$

The reasons why the SalmF needs two motivation tools, Δ^* and ΔI, will be explained below. From analysis above shows that if the two players agree to improve traceability system together, the SalmF needs to improve ID technology from the barcode to the RFID and Granularity level from the silo to the batch. The FeedM needs to improve from the barcode (internal code) to the barcode (GTIN+). If the SalmF moved first and invested in the advanced traceability while the FeedM deny to the investment, the SalmF will get a heavy financial loss. First, the total liability will only be reduced to $c_r Q$ instead of $c_r P$. Second, the SalmF cannot identify the source of contamination from the FeedM since the SalmF cannot read the FeedM's internal code. That is, the SalmF still needs to pay for the recall cost alone and cannot transfer liability costs to FeedM. Under this situation, the SalmF is hard to make the decision to move first. At this point, the direct investment ΔI can motivate the FeedM to move first. After the FeedM improve ID technology from the barcode (internal code) to the barcode (GTIN+), Δ^*plays a role in allocating the increased profit within the supply chain.

Table 7 shows cost-benefit interaction between parties after achieved the chain traceability. ΔF stands for the increased total benefit of the SalmF and ΔM stands for the increased total cost of the FeedM. In this case, $\Delta F \geq \Delta M$, which means that after both parties are implementing the better traceability system, some net profit exists in the supply chain. Therefore, this leaves a space to negotiate how to allocate the net profit between the SalmF and the FeedM. This can be shown as

$$c_r - c_r P \geq \frac{C(ID_{Tec}^F)}{N} + \frac{C(ID_{Gra}^F)}{N} + \frac{C(ID_{Tec}^M)}{N} \quad (8)$$

According to formula (8), we believe that improvement of traceability system will bring benefit to whole supply chain. The FeedM and the SalmF's decision depends on ΔF *and* ΔM. The decision of whole supply chain depends on ΔS as shown in table 7.

Table 7 Increase total benefit and cost- cooperation

SalmF	Benefit	c_r
	Cost	$\Delta^* + C(ID_{Tec}^F)/N + C(ID_{Gra}^F)/N + \Delta I/N$
	ΔF	$c_r - \Delta^* - C(ID_{Tec}^F)/N - C(ID_{Gra}^F)/N - \Delta I/N$
FeedM	Benefit	$\Delta^* + \Delta I/N$
	Cost	$c_r P + C(ID_{Tec}^M)/N$
	ΔM	$c_r P + C(ID_{Tec}^M)/N - \Delta^* - \Delta I/N$
Whole supply chain	Benefit	$c_r(1-P)$
	Cost	$C(ID_{Tec}^F)/N + C(ID_{Gra}^F)/N + C(ID_{Tec}^M)/N$
	ΔS	$c_r(1-P) - C(ID_{Tec}^F)/N - C(ID_{Gra}^F)/N - C(ID_{Tec}^M)/N$

Proposition 3

Different parties in a supply chain can have motivation to attain chain traceability if the investment is profitable for the whole supply chain. It is possible that some parties will gain more benefit from the investment and some parties will gain less benefit, even no benefit. As long as the whole supply chain gains benefit than the costs, the different parties should try to cooperate each other to attain the chain traceability by using interest-sharing mechanism to allocate the benefit and the cost in the right ways.

In the case we study shown in table 7, the direct benefit of the whole supply chain is reduced, $c_r(1-P)$. Indirect benefits are the increase purchase price of fish in the market, because implementing the better traceability system brings high brand reputation. The reasons why we call this indirect benefit are 1) we don't know if the customers would like to pay more for the fish that is farmed under the better traceability system 2) the benefit of high reputation is too vague to calculate by function.

The direct costs of the whole supply chain are the investment cost of the better traceability system $C(ID_{Tec}^{F})/N + C(ID_{Gra}^{F})/N + C(ID_{Tec}^{M})/N$, both from the SalmF and the FeedM. If $\Delta S \geq 0$, the whole supply should invest for the better traceability system for sure. If $\Delta S < 0$, it depends on the estimate of increasing of the purchase price of fish in the market and the reputation benefits. As for the FeedM, if $\Delta M > 0$, it means the cost of investing in the better traceability is larger than the benefit. The FeedM will choose to cooperate with the SalmF if, $\Delta M \leq 0$. As for the SalmF, if $\Delta F \geq 0$, the SalmF will take initiative to invest by using interest-sharing mechanism to motivate the FeedM cooperate.

5.5 Solution for the problem

Based on the mathematic models above, we describe solution for the current problems. These solutions focus on how to package fish feed with proper granularity level and how to build chain traceability system between the FeedM and the SalmF. The goal of this solution is to reduce unnecessary recall with minimum costs. Once the ideal chain traceability system set properly, the SalmF can share the liability costs with the FeedM instead of bearing them alone.

FeedM: ID technology $ID_{Tec}^{M} = \{\, GTIN +\}$, ID Granularity level $ID_{Gra}^{M} = \{Sack\}$

SalmF: ID technology $ID_{Tec}^{F} = \{RFID\}$, ID Granularity level $ID_{Gra}^{F} = \{\, Batch\}$

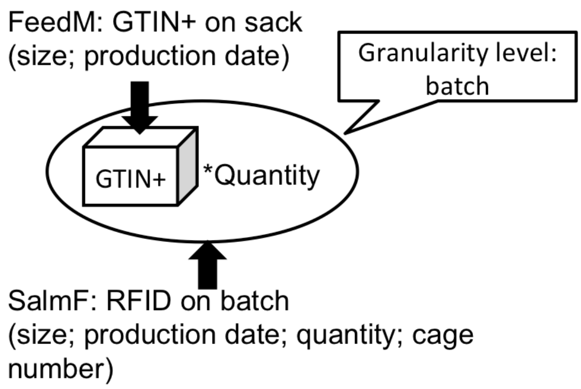

Figure 18 Description of the batch

As shown in Figure 18, the FeedM packages each feed sack into batch and deliver to the SalmF. In one batch, feed may be produced in the same production date or different production date. The FeedM uses the barcode(GTIN+) on each sack to record the feed size and the production date. How many sack of the feed will be packaged into one batch is decided by the SalmF's calculation of how much feed does one cage need during 10 months. The batches also could be smaller than 10 months and a batch can be a smaller set of the SalmF's demand as for example the demand for a month or two months. Each batch is oriented to one cage. The SalmF will put the RFID on each batch to record the feed size, the production date, the quantity of sack in batch and cage number. Also, the SalmF will keep feed sample. Then, the SalmF is able to trace the size and the production date dimensions. The SalmF must test feed sample in order to prove that feed is the reason of recall when the recall incident happened in the market. By this way, the SalmF can ask the FeedM to share the liability cost.

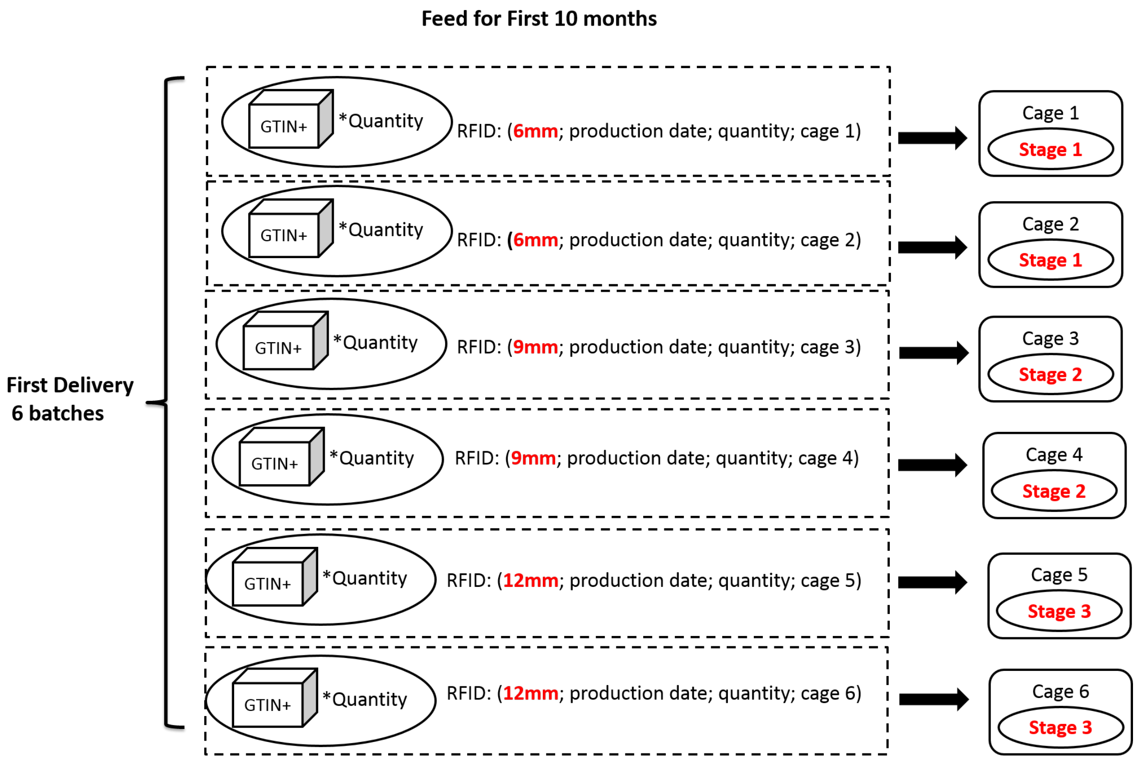

Figure 19 First delivery of six batches from the feed manufacturer to the salmon farmer

Figure 19 shows that six batches are delivered from the FeedM to the SalmF in the first 10 months. Each batch is for feeding fish in the one specific cage. In each batch, the feed can be produced in the different production date. Barcode (GTIN+) on sack can record the production date and the size of the feed.

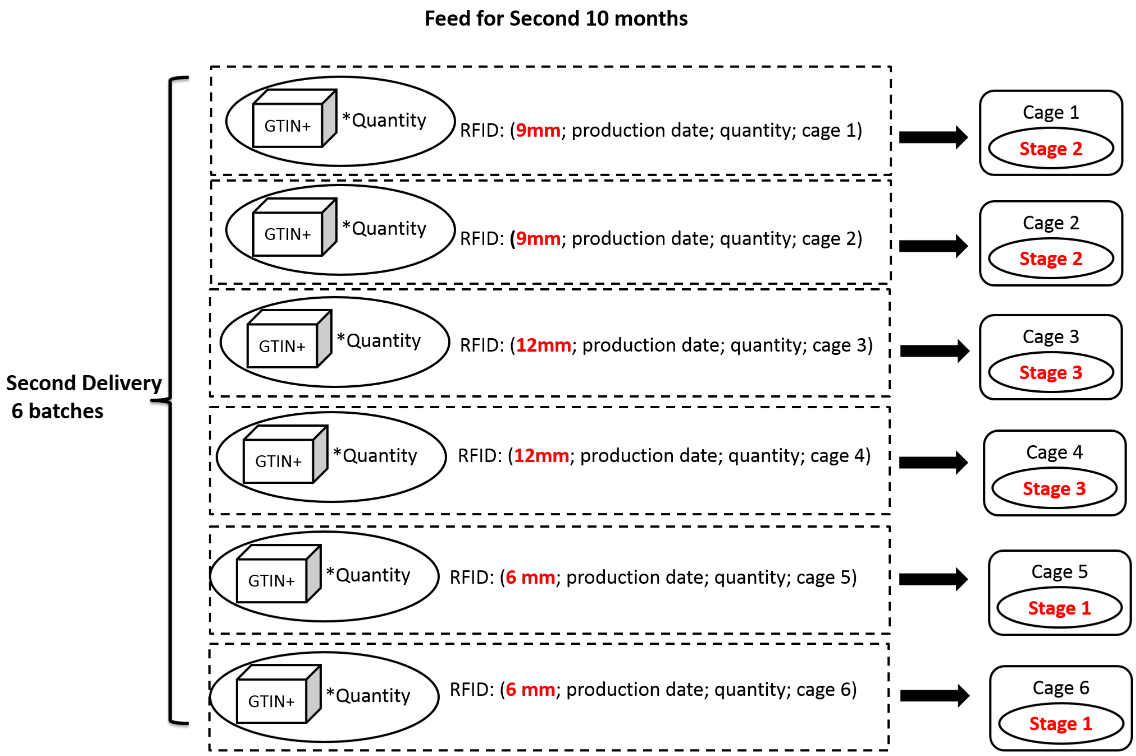

Figure 20 Second delivery of six batches from the feed manufacturer to the salmon farmer

Figure 20 shows that six batches of feed are delivered from the FeedM to the SalmF in the second 10 months. Fish in the cage 1,2,3 and 4 are in the next stage(compared to the Figure 19). The sizes of the feeds for the each cage are changed according to the current stage. Fish in cage 5 and 6 got harvested and were delivered to the market after first 10 months. Then, the SalmF puts new smolts into these empty cages before the second 10 months started. In each batch, feed can be produced in the different date. Quantity depends on SalmF's calculation of how much feed each cage needs.

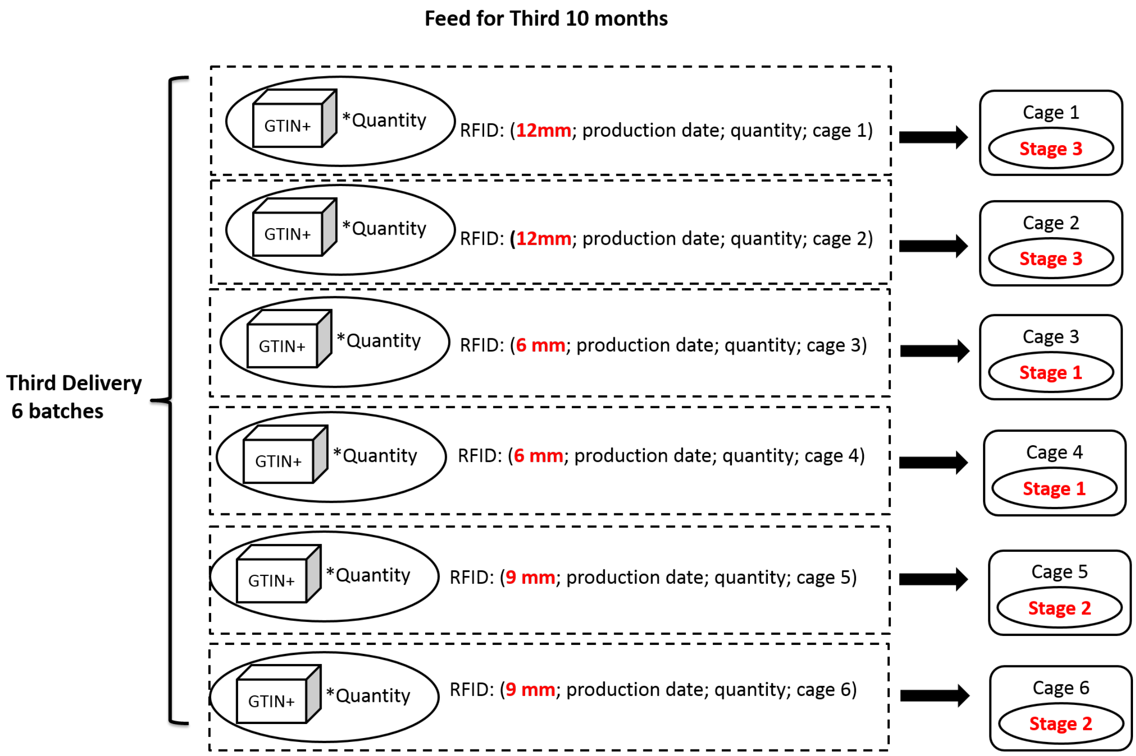

Figure 21 Third delivery of six batches from feed manufacturer to salmon farmer

Figure 21, six batches of feed are delivered from the FeedM to the SalmF in the third 10 months. Compared to the second 10 months period, fish in cage 1,2,5,6 have grown into the stages. The cage 3 and 4 got harvested and then the SalmF puts new smolts into these empty cages before the third 10 months started.

6. Conclusion

Improving traceability at a supply chain level can potentially reduce the liability costs of the whole supply chain. Many previous papers presume that the each party in a supply chain will adopt advanced traceability system voluntarily. However, our analysis shows that it would be difficult for whole supply chain to achieve chain traceability if 1) The each party has their own preferable internal traceability system 2) The costs of implementing the advanced traceability is larger than its benefits 3) Proper incentives is not given for each parity.

In our study, we pay much attention to the cost and benefit analysis first in order to see how different actors in the farmed salmon supply chain perceive the cost and the benefits of implementing the advanced chain traceability system. We derive the fact that traceability's critical importance, from a recall liability costs perspective, decreases as we move from the SalmF to the FeedM in the supply chain. The FeedM prefer cheaper and less precise traceability and shift their liability to the SalmF. However, the total recall liability costs of the whole supply chain perspective are decreasing with the presence of the proper chain traceability between the different parties. To choose what the best for the whole supply chain is more beneficial for both parties. Proper incentives should be given to motive the FeedM to achieve the ideal chain traceability with the SalmF.

There are main findings from this study. Firstly, as for the salmon farmer, investment cost for adopting RFID with a batch-Granularity level is cheaper than adopting RFID with a sack-Granularity level. However, the benefit from selecting one between the two options is the same when the better ID technology, barcode (GTIN+), is applied by the FeedM. Investment in appropriate storage facilities and storage costs also need to be taken into account. Secondly, to reduce unnecessary recall with the minimum costs, the way of packaging fish feed with proper granularity level is important. Thirdly, by using the interest-sharing mechanism, different parties in a supply chain can properly allocate recall liability minimizing the unnecessary recall costs.

Our study has limitations, therefore, future research directions should remain to be investigated. First, in our model, we have only considered a supply chain with one FeedM and one SalmF to make the readers easily can understand the issues discussed in the thesis. If the FeedM has more than one salmon farmer to trade feed, the FeedM's bargaining power will be changed and then it will make different decisions regarding implement of the better traceability system. In our study, we assumed that the ingredient suppliers and the feed manufacturer are one unit, so the feed manufacturer's decisions are only based on the salmon farmer's motivation. However, we can also consider that the liability allocation between the ingredient suppliers and the feed manufacturers will also influence the feed manufacturer's decision. Secondly, we only used inputs presented in the Karlsen's study, so we didn't consider expiry date and delivery costs of feed in our study. In the further study, these two can be considered. Thirdly, we only consider variable P and Q's value and their influence on model in our numerical study. In our model, there are many other variables that could be valued and explained their influence on the model. We have time limitation and use secondary data but this provided limited information and data. Therefore, the next step of the study could be conducting interview and investigation to collect more data.

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