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The fishing industry – toward supply chain modelling



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The fishing industry – toward supply chain modelling

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Abstract

Mathematical models for simulating and optimizing supply chain aspects such as distribution planning and optimal use of raw materials are widely used. However, modelling based on a holistic chain view is less studied, and food-related aspects such as quality and shelf life issues enforce additional requirements onto the chains. In this paper, we consider the supply chain structure of the Danish fishing industry and illustrate the potential of using mathematical models to identify quality and value-adding activities. This is a first step toward innovative supply chain modelling aimed to identify benefits for actors along chains in the fishing industry.

1 Introduction

Food supply chains are complex when compared to more traditional supply chains; the quality is sensitive to handling and storage conditions and the shelf life is limited. These aspects impose additional constraints on handling practices, storage times, delivery efficiency, etc., and call for advanced modelling methods; see e.g. (Lütke Entrup *et al.*, 2005). The reverse bill-of-materials (BOM) is another complication; see (Fullscope, 2007). Traditional products are often assembled from a number of parts that are kept on stock, and the BOM provides the relationship between the parts and the final product. However, for food products a piece of raw material, e.g. a fish or a pig, is often split and used for several products in a disassembly process. Several authors consider food chain aspects such as safety, quality and efficiency; see e.g. (Minegishi and Thiel, 2000; Stringer and Hall, 2006; van der Vorst *et al.*, 2000; van der Vorst *et al.*, 2005).

Supply chain management (SCM) concerns improvement of product flow and reduction of costs in order to providing value-added goods to consumers in optimal ways. This focus on chain improvements has also reached the food industries; see e.g. (Aramyan *et al.*, 2007; Taylor, 2005; van der Vorst and Beulens, 2002). A part of the chain focus in the food industries arises from legal traceability requirements which have mainly been formulated due to food safety, e.g. the outbreak of BSE in the mid 1990ies; see (Anon, 2002a, b). Several authors consider aspects of traceability from practical implementation to assessing its economical value; see e.g. (Jensen *et al.*, 2008; Resende-Filho and Buhr, 2008; Senneset *et al.*, 2007). The chain focus and data sharing aspects of traceability are highly interesting also in an SCM context as traceability may provide access to new data elements that can be exploited in order to improve chain performance.

The fishing industries exhibit particularly challenging supply chains. For instance, fish from marine stocks are caught in the wild whereas most other food products are produced,

grown and manufactured. Fishermen are therefore primarily hunters and not producers. Some fish may be identified individually, e.g. large tunafish, whereas most species must be identified batchwise. This may result in large quality variations within batches, whereas pig and cattle carcasses are easier evaluated individually. Furthermore, the quality variations and uncertainties connected with fish catch often result in complex trading systems such as auction markets in order to balance supply and demand. The contributions of the current paper are twofold. Firstly, to take a first step toward quantitative food supply chain modelling in order to address holistic value-creation, and secondly, to analyze the Danish fishing industry as an example on the fishery specific complications. To the best of our knowledge, this has not previously been done from a research perspective.

2 Supply chain modelling

A supply chain consists of a number of actors who procure raw materials and produce, distribute and sell products to final consumers. Supply chain analysis is concerned with the upstream to downstream flow of raw materials and products, and the reverse flow of orders as illustrated in Figure 1. Additional information may be exploited for SCM and decision support.

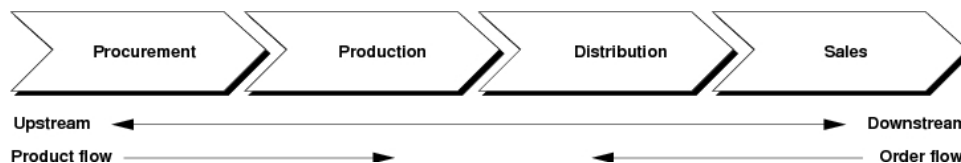


Figure 1. Simple supply chain and indication of upstream/downstream flows.

Supply chain planning is considered at three levels. The *strategic* level is concerned with the design of the supply chain itself, the *tactic* level is concerned with master planning of production intensity, the overall distribution network, etc., and the *operational* level is concerned with weekly or daily planning of activities. In addition, SCM covers aspects such as network organization, collaboration and leadership; see e.g. Stadtler (2005).

Methods for modelling supply chains range from specific operational mathematical models to conceptual models of entire supply chains. Ahumada and Villalobos (2009) give a comprehensive review of models used in the literature regarding the application of planning models in agri-food chains. The models are based on mathematical programming, and are mainly concerned with revenue maximization and cost reduction at either strategic, tactic or operational level. Bjørndal *et al.* (2004) provide a survey of numerous modelling strategies that have been applied within the fishing industries during the last decades. The survey by Bjørndal *et al.* includes references within fields such as biological modelling, economic modelling, mathematical programming, statistical analysis, computer simulations and decision theory. It is also stressed that management practices will become increasingly important and that the ever more complex environment will pose new challenges to the operations research related modelling. Other authors consider simulation approaches; see e.g. Kleijnen, (2005) for a survey, and Ding *et al.*, (2009) for a recent example where simulation is used to estimate the operational performance of solutions suggested by an optimizer. Yet other types of quantitative models include

descriptive statistical models and game theoretic models; see e.g. (Sarmah *et al.*, 2006; Swaminathan, 1998; Yu *et al.*, 2009; Zúñiga-Arias *et al.*, 2009). The more holistic level includes methodologies for value assessment and performance measurement such as value stream analysis (Hines and Rich, 1997), value network analysis (Allee, 2008), and the balanced scorecard (Barber, 2008). Taylor (2005) considers a case from the British pork sector where an analysis team consisting of representatives from three participating companies perform a value chain analysis in order to identify opportunities for improvements along the entire chain from farm to fork. Li *et al.*, (2002) also consider supply chain modelling, but focus on four different levels: scenario model, interdependency model, process model, and information model. These levels illustrate the need for modelling of relevant scenarios in a holistic chain-wide sense, the interdependence between individual organizations and actors in the chain, the co-ordination of individual processes and finally the need for a system capable of efficient information exchange. Information exchange and data models are also studied in papers dealing with traceability; see e.g. (Bechini *et al.*, 2008, Jansen-Vullers *et al.*, 2003).

The current research focuses on quantitative optimization and simulation. The goal is to model aspects of chain coordination and collaboration, as well as alternative use of data in order to quantify synergy effects that one supply chain actor would not be able to achieve alone. A focus on quantitative methods requires operational measures that can be used to evaluate and compare different scenarios, and in turn be used to illustrate benefits for the supply chain actors. Moreover, quantitative methods are important also for decision support.

2.1 An illustrative example

A simple example is given to illustrate the possibilities of quantitative modelling. The example builds on a simple idealization of a supply chain network, and as such it shows the first step toward quantitative supply chain modelling. The model consists of a market step where fresh fish are sorted into quality categories and sold to a number of processors, and it illustrates how decisions taken in one part of the chain influence the profit of the entire chain.

Market step: The fish supplied to the market by the fishermen have a certain distribution of true qualities between 1 and 20 which may represent a Quality Index Measure (QIM). The distribution of qualities is seen in Table 1, and the amounts are given in some arbitrary volume unit. However, the true quality of the raw materials is not directly revealed in the market step. Instead, the raw materials are sorted into a number of sorting categories which can be thought of as E, A and B classifications. The use of sorting categories illustrates how some crucial information, the true qualities, may be hidden for the next actors in the supply chains.

| | | | | | | | | | | |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Quality | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 |
| Amount | 95 | 110 | 100 | 95 | 89 | 83 | 78 | 73 | 66 | 57 |
| Quality | Q11 | Q12 | Q13 | Q14 | Q15 | Q16 | Q17 | Q18 | Q19 | Q20 |
| Amount | 45 | 35 | 25 | 15 | 12 | 10 | 6 | 3 | 2 | 1 |

Table 1. Available fresh fish of different qualities. A total of 1000 volume units are available.

Processors: We consider three processors, who buy raw materials from the market and produce one product each. The processors buy raw materials from one or more of the sorting categories. However, the value of the final products depends on the true quality of the raw materials. All revenues and costs are assumed to be included in the profit of the products, and profit curves for the three products are shown in Figure 2. For instance, it is seen that using one unit of fresh fish of true quality 6 for product two results in a chain profit of 50 monetary units. Finally, we assume that there is a limited demand for the three products such that the maximum demand of product one is 180 units, the maximum demand for product two is 300 units and the maximum demand for product three is 520 units. There is a one-to-one correspondence between fresh fish units and product units such that all 1000 units of fresh fish are used for 1000 product units.

A simple linear programming (LP) model is build to compute which products should be produced from which sorting categories in order to generate the optimal profit. The LP model is outlined in the appendix. Two scenarios are used to illustrate the impact of the sorting categories.

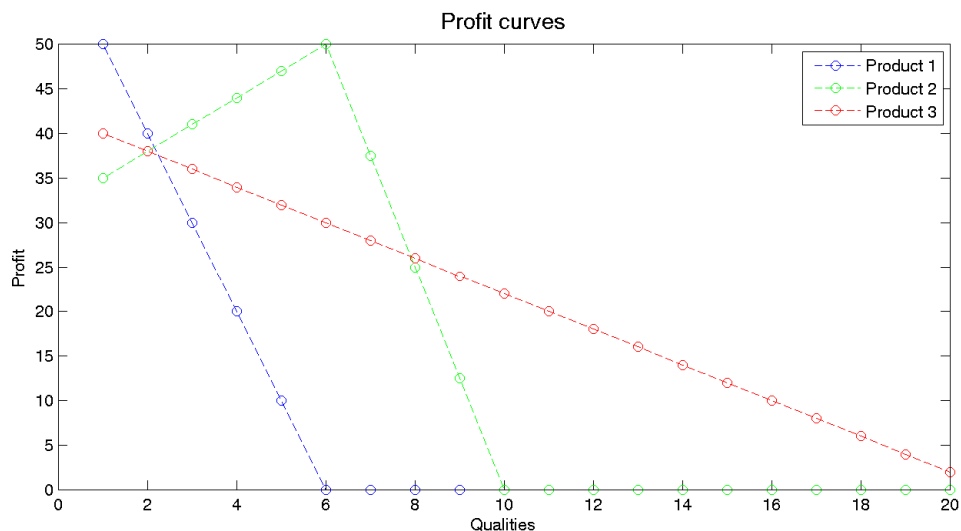


Figure 2. Profit curves for the three considered products.

Scenario 1

Twenty sorting categories are used to reflect the 20 true qualities such that no quality information is hidden. From the profit curves in Figure 2, we see that it is optimal to produce product one from raw materials with true quality 1 and 2, product two from raw materials with true quality 3 to 7, and product three from raw materials with true qualities above 7. However, with the demand restrictions, all 205 units of quality 1 and 2 cannot be used for product one and all raw material of qualities 3 to 7 cannot be used for product two. The LP model is used to compute the optimal use of the raw materials while taking into account the demand restrictions. Specifically, Figure 3 shows this optimal use of the raw materials. For instance, all 95 units of quality 1 and 85 units of quality 2 are used optimally for product one, whereas the remaining 25 units of quality 2 are used for product three. The optimal total profit of the scenario is 34906.50 monetary units.

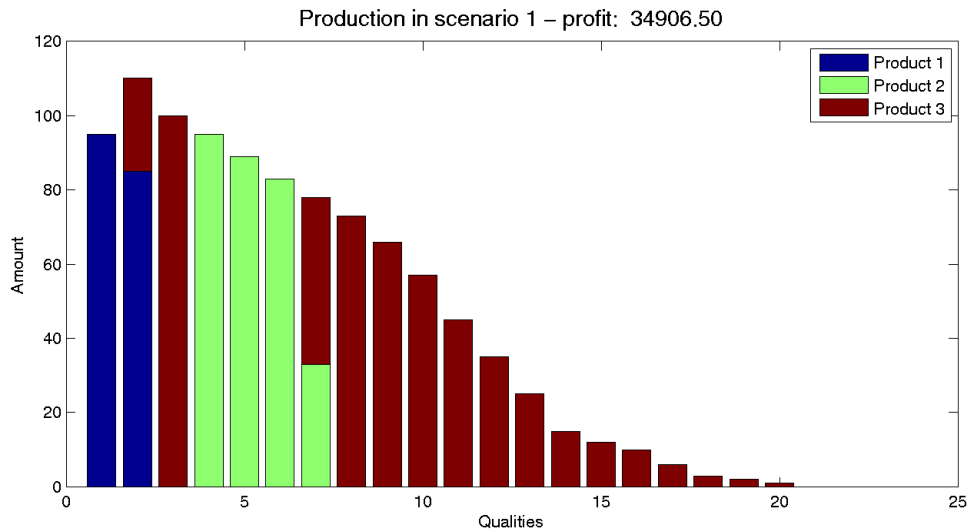


Figure 3. Optimal production of the three products when 20 sorting categories are used.

Scenario 2

The number of sorting categories is reduced to three. A processor buying raw materials from a given sorting category will therefore receive raw materials with all true qualities contained in the sorting category. The sorting categories are defined such that sorting category 1 contains raw materials of quality 1 and 2, sorting category 2 contains raw materials of quality 3 to 7, and sorting category 3 contains the remaining true qualities, i.e. reflecting the theoretical optimal use based on the profit curves. The LP model is again used to compute the optimal use of the raw materials while taking into account the demand restrictions. The solution in Figure 4 shows that product one is produced from raw materials in sorting category one, product two from raw materials in sorting category two, and product three from the remaining raw materials in sorting category one and two, and from additional raw materials from sorting category three. However, the optimal profit amounts to 34051.50 monetary units which is a reduction of approximately 2.4% compared to scenario 1.

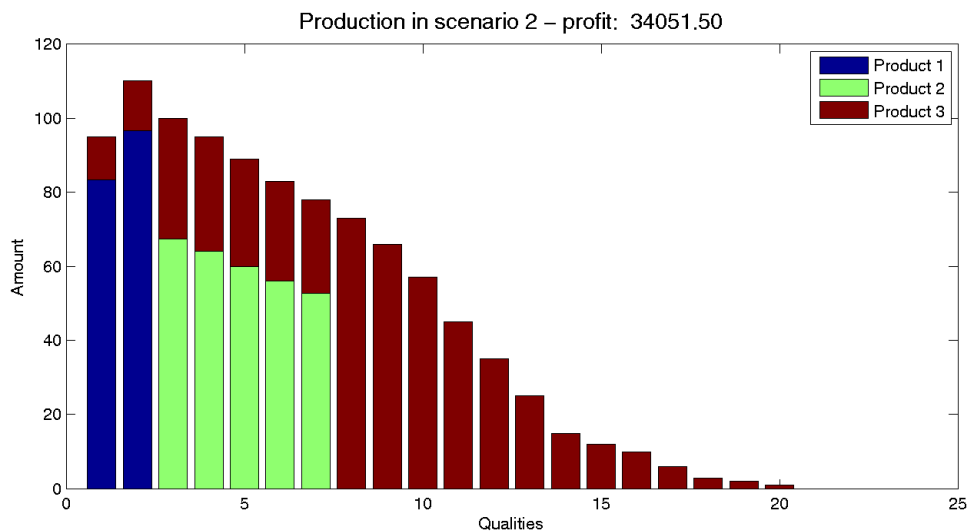


Figure 4. Optimal production of the three products when restricted by three sorting categories.

Example summary

The simple example shows how the sorting performed in the market step has a potential effect on the optimal value creation in the following steps, and therefore on the overall profit generated in the chain. It is emphasized that the same amount of raw materials is used in both scenarios, and that the same amount of each of the three products are produced. The profit loss is caused by non-optimal use of the raw materials. The example also shows how a mathematical model can be used to provide quantitative results indicating the size of the profit loss.

Several complications arise when the models get more advanced and more realistic. For instance, simultaneous decisions on raw material supply and production planning results in complex relationships across the market step. Furthermore, individual behaviour and competition in the chains must also be addressed. The above example is therefore only a first step toward supply chain modelling showing the possible impact of analyzing quantitatively various chain aspects. The following sections provide a deeper insight into the difficulties of the fishing industries through an analysis of the Danish fishing industry.

3 The Danish fishing industry

Denmark is among the major exporters of fish and seafood products worldwide. The fish and seafood are used for a large variety of products ranging from fishmeal for industrial use to fish products for human consumption. The fishing industry is highly diverse; fishermen catch and handle a large number of fish species in the upstream end of the supply chains, and fresh and processed fish products are sold to consumers globally in the downstream end. In-between, a varying number of actors handle, process and distribute fish and fish products.

The main actors in captured fish supply chains as identified in (CWA, 2003) are schematically shown in . However, not all actors appear in every real-world supply chain, and some actors may appear several times in other chains. The analysis of the fishing industry is based on the supply chain in and a number of surveys and reports; see e.g. (Fishery Statistics, 2007; Fødevareøkonomisk Institut, 2009; Madsen 2005), as well as a technical report by Jensen and Clausen, (2007).

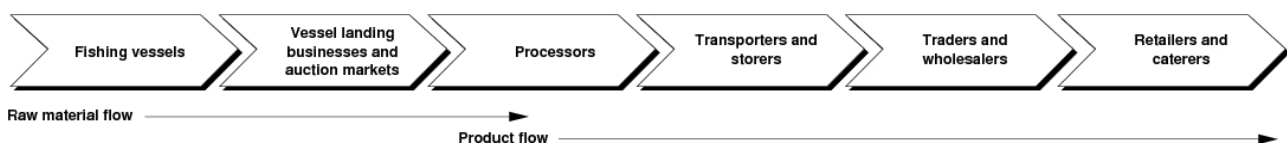


Figure 5. Main actors in the captured fish distribution chain as identified in (CWA, 2003).

3.1 Raw materials and products

The diversity of fish and shellfish species is large in the upstream end of the chains. Focussing on fish, these can be divided into pelagic and demersal species that are generally handled differently due to biological differences. Fish can also be divided into consumer species and industrial species used for human consumption and reduction into fishmeal and fish oil, respectively. However, current initiatives also focus on upgrading of industrial species for human consumption (DFA, 2007). Most food sectors are concerned

only with cultivated, grown or bread raw materials, whereas fish may come from either marine stocks or aquaculture. On a global level the amount of fish from aquaculture is increasing due to stagnating marine stocks and increasing fish and seafood consumption. However, fish from marine stocks still make up the largest part of fresh fish in Denmark.

Intermediate and final products are produced by processors. Some process fresh fish and sell intermediate products, e.g. fish fillets, to further processing in other companies leading to several processing steps. In other cases fresh fish are sold to consumers with a minimum of processing. The final products therefore range from fresh cleaned fish and fillets to processed convenience food. The products may be preserved, frozen or packed as chilled fish. The large variety of raw materials combined with many processing levels results in a huge variety of fish products, and a high complexity of the supply chain network. This diversity of species is different from most other food sectors where fewer categories of raw materials are considered, or where various types of raw materials are more naturally distinguished. Beef, pork and poultry are for instance all part of the meat sector, but are considered as beef, pork and poultry throughout the supply chain from farm to fork. Fish, on the other hand, are often considered as fish and not cod, plaice and herring. This complicates the identification of unique value chains from catch to consumption because substitution between species may occur both at the raw material level and at the final product level. The sustainability issue is also complicated and cover several aspects; for marine stocks an important issue is not to overexploit the stocks, whereas environmental production issues are more important for aquaculture. For similar end products produced from either marine stocks or farmed fish these issues may complicate the consumer's attitudes toward the fish products.

3.2 Firsthand catch and sales

The Danish fishing fleet is heterogeneous, and vessels may be segregated according to size, primary target species, catch gear, etc., and individual vessels often land a variety of species. Biological differences between pelagic and demersal fish mean that vessels are normally specialized in targeting either pelagic or demersal fish. Pelagic fish are caught in great numbers and stored in tanks onboard the vessels whereas demersal fish are often caught by trawl and stored on ice in crates. However, some vessels target both pelagic and demersal fish. Some vessels support seapacking which means that demersal fish can be sorted and graded onboard. Larger factory trawlers may even prepare frozen products ready for sale to retailers. Factory trawlers are not traditionally used in Denmark, but the possibility for a high degree of processing onboard must be kept in mind when considering specific value chains. The main pelagic species are regulated by Individually Transferable Quotas (IOK quotas), and many demersal species are regulated by Vessel Quota Shares (FKA quotas). Both types of quotas can be traded among fishermen. Moreover, fishermen may pool quotas such that they can be shared among several vessels. The number of allowed days at sea for particular vessels is also regulated for some fisheries.

Most demersal fish are landed to be sold through auction markets. The vessels that support seapacking can land fish directly for auctioning, whereas others land to collectors who sort and grade the fish before they are displayed at the auction. This step may indeed result in mixing of landings from several vessels, i.e. affecting the level of traceability. The fish are not traded between fishermen, collectors and auctions, but handled on behalf of the

fishermen who own the fish until they are sold. Collectors and auctions are paid a certain percentage of the obtained sales price. Pelagic fish are not sold through traditional auction markets, but often delivered directly to processors. The pelagic fish may also be landed in a harbour with unloading facilities, and transported to the processing industries by truck. Pelagic fish include industrial fish for reduction into fishmeal and fish oil, e.g. sand eel and sprat, and consumer species such as herring and mackerel. The quality of the fresh fish is used when evaluating and selling the fish, and is crucial for the further processing of both pelagic and demersal fish.

3.3 Processing and handling

The processing industries are segregated according to the raw materials they use and whether the final products are meant for human consumption or not. The Danish fishmeal industry consists of few companies, some of which are co-operatively owned by the fishermen. The production of consumer products can be split between processors dealing with pelagic fish and processors dealing with demersal fish. The pelagic industries are dominated by larger companies, whereas the demersal industries are in general more diverse. A general trend is that only few companies are comparable in size to large companies in other countries such as in Norway, Iceland and Spain (Nielsen, 2005). Demersal fish are often bought on the auction. Representatives from individual companies may buy fish directly from the auctions, but often wholesalers buy up fish on the auctions on behalf of several customers. Many fish processors are specialized and handle only one kind of raw material. The production lines are often highly specialized and optimized, and it is important for the processors to maintain a constant flow of fish. Imported fresh and/or frozen fish are also used in the processing industry, and only around 5% of the fish and seafood products produced in Denmark are sold in Denmark (Madsen, 2005).

Transporters and storers may operate throughout the chain, and handle both fresh and processed fish. Fishing vessels perform both storage and transportation, and subsequent transportation is often carried out by refrigerated trucks. Fresh fish are highly perishable and optimal storage temperatures and correct handling procedures are crucial in order to preserve a high quality and ensure safe products. Moreover, quality and safety problems in one part of the chain will affect also the following actors, and the consumers. Distribution actions such as repacking and redistribution of products may also be performed in order to meet specific customer needs. Distributors may also handle other products than fish and seafood in the later stages of the supply chains.

Retailers and caterers make up the final step in the supply chains; selling products to the consumers. These actors need to fulfil the consumers's demands, but can also perform advertisement and promotion campaigns which affect the demand patterns. Some processing may also be performed at this step, e.g. preparation of meals for the final consumers as well as filleting and production of fish salads.

4 Supply chain structures

A number of characteristics of the fishing industry can be identified from the above survey. Some of these can be used to simplify the view of the supply chain network, whereas others highlight the complexities (indicated below in *italic*):

- Pelagic and demersal fish often belong to different chains from catch to consumption.
- Consumer species and industrial species can in general be considered independently.
- Auction markets are highly used for demersal species, but not for pelagic fish.
- Pelagic industries are in general larger, whereas demersal industries are more diverse.
- *Vessels may target both pelagic and demersal species.*
- *Multi-species fishery means that one vessel may support several value chains.*
- *Value-creation may be obtained by using industrial species for human consumption.*
- *Competition and regulations affect the fish catch.*
- *Raw material and product substitution may occur throughout the chains.*

The fishermen's activities are restricted by quotas and other regulations, and they need to exploit their quotas to optimize profit. Additional catch of a given species may yield additional profit if the quota is not fully exploited. However, it may be difficult to increase the catch; either because it is expensive to do so, or because it is difficult to specifically target one species without violating quotas for other species; see e.g. Kronbak *et al.* (2007) where a model based on multi-species fisheries is used to evaluate the strategic effect of introducing FKA quotas. It is therefore highly important also to consider quality and handling in order to increase the profit. Unpredictable marine stocks and changing weather conditions also affect the catch rates, and deterministic day-to-day planning is difficult. In practice, fishermen have to push as many fish as possible down the supply chain, while maintaining a focus on quality and safety.

Most processing industries are more flexible. They need reliable sourcing, and often rely on raw materials from various sources. In practice this is beneficial because the stochasticity of the fishery is reduced by the multiple sourcing possibilities. Especially the demersal industries can source from various auction markets and import fresh and/or frozen fish in order to maintain a profitable production. It is relevant to study the actual sourcing patterns when focusing on particular value chains. Some industries such as the co-operatively owned fishmeal factories may show tighter bonds to the fishermen. All industries are generally characterized by a market pull, and they need to satisfy the markets in the most cost-efficient way. Moreover, consumers and global retailers get more powerful in their demands for quality and safety. The fishing industry, and the demersal part in particular, is therefore split around the first-hand sales of the fish where the fishermen perform a push of raw materials into the supply chain network, and the processing industries observe a pull from the markets. This results in a decoupling point located around the first-hand sales, and a strong push/pull boundary between the two sides of the sector. This splitting of the sector is also reflected in the governmental bodies controlling quality and safety. Moreover, the original batches of fish as provided by the fishermen may be mixed by collectors before auctioning, and batches may be split among several buyers at the auction; see e.g. (Randrup *et al.*, 2008). It is therefore difficult to identify unique supply chains across the auction markets and this further highlights the splitting of the supply chains. These complexities are illustrated in Figure 6 where the left side shows the fishermen in a complex procurement network, and the right side shows the more supply chain like processing part of the industry. The bottom part of the figure shows that the supply chain

network also includes import and export, as well as the possibility for fishermen to use foreign auction markets.

The distribution and retailing parts of the supply chain network are similar to the distribution and retailing parts of supply chains for other foodstuffs where fresh food aspects such as quality decay and limited shelf life are relevant. In fact, distribution channels are often concerned with several types of food, e.g. a distribution centre that handles both fresh meat and fish products.

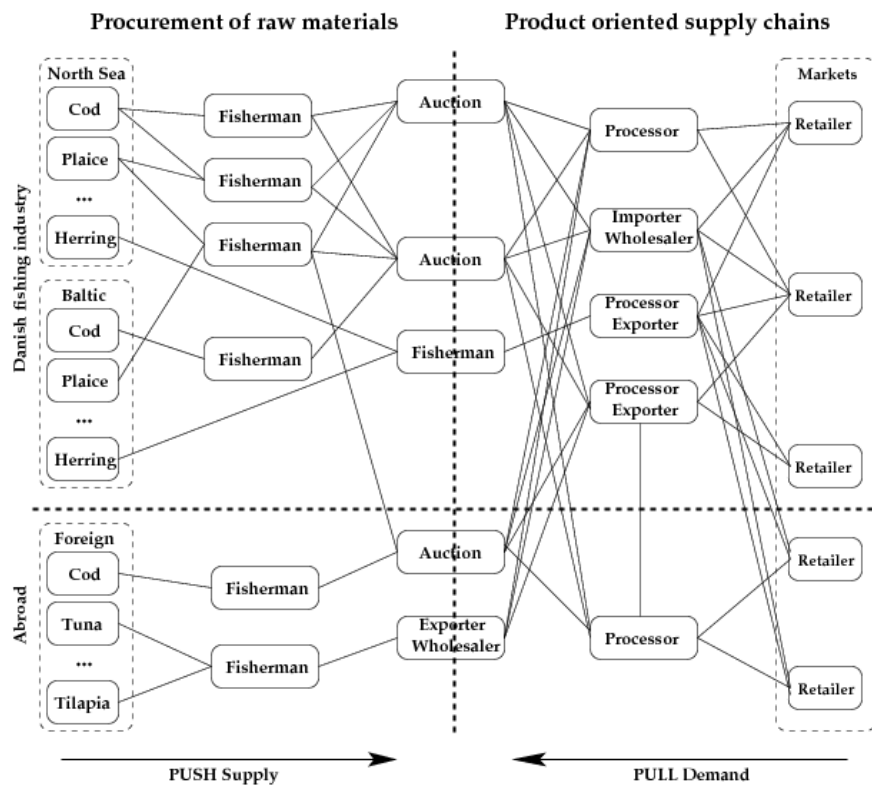


Figure 6. The complex supply network split in procurement and a product oriented supply chain side.

4.1 The future of supply chain modelling

From the pelagic sectors it will be relevant to focus on value chains based on a few large companies and a number of supplying fishermen. The market side of the chains will be determined by the markets of the selected companies. In case of demersal fish, the value chain analyses may also focus on particular processing companies and consider fresh fish as coming from auction markets and import instead of from the fishermen. On the procurement side, the fishing activities may be considered independently using an auction market as the final market for the fresh fish. Modelling and planning of the fishing efforts on the strategic or tactic level may result in improved handling and profit maximization in the first steps of the supply chains; see e.g. (Andersen and Bogetoft, 2007) where gains from quota trade in the Danish fishery are studied. On the “day-to-day” level stochastic parameters limit the possibilities for operational planning. Simulation and advanced forecasting approaches may be used as part of real-time decision support systems. Studying the procurement side and the production side individually follows the intrinsic structure of the supply chain network. However, a holistic perspective includes both the

procurement and the processing part of the industry, and coordination of traceability and use of data between actors, and especially across the auction markets, may indicate new value-adding possibilities. It is therefore interesting in a holistic perspective to investigate the possibilities for constructing models that span across the first-hand sales. Distribution activities and market aspects should also be considered as integrated parts of the chains from catch to consumption.

4.2 Performance measurements and modelling methods

Traditional economic performance measures such as costs and profits are widely used, and indeed profit was also used as the optimization criterion in the example model in Section 2.1. More complicated multi-objective criteria arise if aspects such as quality and consumer satisfaction is to be modelled; see e.g. (Ding, 2009). Quality variations are also found in the simple example by comparing Figure 3 and Figure 4. It is seen that the raw materials used for the three products varies from scenario one to scenario two. For instance, some raw material qualities will never be used for product 3 in scenario one, whereas all raw material qualities are used for product 3 in scenario two. The quality variation may correlate with the consumer's perception of the products, and therefore have an impact on the optimal use of raw materials.

The goal of supply chain modelling is therefore not only to reduce costs, but also to ensure a suitable level of safety and the right quality. Yet other aspects such as flexibility and responsiveness may also result in relevant performance indicators. For instance, a supermarket may occasionally make promotional offers and therefore expect a high degree of volume flexibility from its supplier. Aramyan *et al.*, (2007) consider the evaluation of a conceptual framework for measuring performance in agri-food supply chains using a case study from the tomato industry. The considered framework shows how multiple performance measures from cost and profit, consumer satisfaction and lead times to quality parameters such as appearance and product safety are all important for the performance of the chain. Moreover, specific parameters are often more important to some actors than to others. It is therefore important to identify performance measures that are relevant for the individual actors as well as for the chain.

Planning of supply chains often relies on mathematical programming techniques – as did the simple example in Section 2.1. However, stochastic behaviour, complex chains, continuous quality decay, etc., call for other modelling techniques. The holistic perspective also relates to aspects such as the organization of the supply chains, the collaboration and competition between actors and multiple objectives, all of which complicate the analyses and extend the modelling possibilities. The next steps toward quantitative supply chain modelling will therefore have to include considerations on simulation approaches as well as game theoretic models.

5 Conclusions

A simple mathematical optimization model was used to illustrate the potential for quantitative chain optimization. It was also indicated that several optimization criteria based on as well cost and profit as quality and safety influence the supply chain performance when considered in a holistic fashion. Moreover, the Danish fishing industry

was analyzed in order to identify some of the issues that complicate the supply chain networks when fish and fish products are concerned.

In practice, quantitative results such as the computed profit loss of 2.4% from scenario one to scenario two in the example in Section 2.1 are easy to communicate and understand. Therefore, suitable quantitative models are useful for communicating the effect of changing the structure of supply chains and/or the flow of raw materials and products. It is also concluded that a holistic perspective is important because decisions taken in different parts of the chain have a joint impact on the chain performance.

The complex structure of the fishing industry leads to complex supply chain networks. This in turn complicates the models that are needed to analyze the supply chains. Future modelling of more advanced and realistic supply chain aspects therefore needs to consider several modelling techniques in order to obtain quantitative results in a holistic setting. Analyses of such results are expected to be useful when addressing chain performance and collaboration between supply chain actors. Moreover, quantitative results are useful when communicating the impact of the models to the supply chain actors. Quantitative results are therefore expected to be eye-openers in connection with proposed changes and lead to a common ground for improving value creation in future supply chains.

Appendix

The simple linear programming (LP) model used for the example in Section 2.1 is outlined below. The model is implemented in GAMS and solved by CPLEX on a SUN Solaris system. The sets, parameters and decision variables of the model are defined as:

Sets:

| Name | Description | Values |
|------|--------------------|---|
| p | Products | 1, 2, 3 |
| q | Qualities | 1, 2, ..., 20 |
| c | Sorting categories | 1, 2, ..., 20 or 1, 2, 3 (scenario 1 and 2, respectively) |

Parameters:

| Name | Description |
|------------------|---|
| $PROFIT_{q,p}$ | Profit when producing one unit of p from one raw material unit of quality q . |
| $RAWDIST_q$ | Units of raw materials of quality q . |
| $DEMAND_p$ | Maximum demand for product p . |
| $CATEGORY_{q,c}$ | Binary parameter: 1 if raw material of quality q belongs to category c , 0 otherwise. |

Decision variables:

| Name | Description |
|------------|---|
| $u_{q,p}$ | Amount of raw materials of quality q used for product p . |
| $uc_{c,p}$ | Fraction of category c used for product p . |

The model is constructed to maximize the profit and the objective function is:

$$\max \sum_{q,p} PROFIT_{q,p} u_{q,p}$$

The model is constrained by the following equalities and inequalities:

- (1) $\sum_p uc_{c,p} \leq 1$
- (2) $u_{q,p} = RAWDIST_q \sum_c CATEGORY_{q,c} uc_{c,p}, \forall q, c$
- (3) $\sum_q u_{q,p} \leq DEMAND_p, \forall p$
- (4) $u_{q,p} \geq 0, \forall q, p$
- (5) $uc_{c,p} \geq 0, \forall c, p$

The constraints are: (1) not more than the available raw materials in each sorting category is used, (2) $u_{q,p}$ is equal to the amount of raw materials of quality q used for product p , and (3) the maximum demand is not exceeded. Constraints (4) and (5) enforce non-negative usage.

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Mathematical models for simulating and optimizing supply chain aspects such as distribution planning and optimal use of raw materials are widely used. However, modelling based on a holistic chain view is less studied, and food-related aspects such as quality and shelf life issues enforce additional requirements onto the chains. In this paper, we consider the supply chain structure of the Danish fishing industry and illustrate the potential of using mathematical models to identify quality and value-adding activities. This is a first step toward innovative supply chain modelling aimed to identify benefits for actors along chains in the fishing industry.

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