



Compilation and Economic Analysis of the Process of Fresh Fish from Catch to Retailer

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Compilation and Economic Analysis of the Process of Fresh Fish from Catch to Retailer

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30 ECTS thesis submitted in partial fulfillment of a
Magister Scientiarum degree in Industrial Engineering

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Abstract

The main objective of this thesis is to investigate whether the value of raw material in export of fresh whitefish can be increased by choosing more economic and/or value adding methods in different links of the chain *from catch to retailer*. The role of economical analysis is discussed, and ways to evaluate shortest path and minimum cost throughout the process parallel of maintaining or increasing the quality of the product. Results from experiments in this field are analysed and put in context with other parts of the process. Different cooling, processing and transportation methods are evaluated and disadvantages and advantages are discussed.

Results show that appropriate cooling on board and in processing and temperature control during transportation is very important in the process. Economical analysis showed that investing in liquid cooling machine on board and liquid cooling machine (LC) and contact blast and cooling (CBC) machine in processing are profitable alternatives. The use of LC and CBC together has showed in experiments that it brings the product up to 5 days in additional shelf-life which allows exporters to reconsider their transportation mode. In packaging, EPS packaging is especially recommended due to its insulations characteristic when there is risk of temperature abuse. Result regarding transportation methods show that shipping is recommended to protect the quality of the product. Shipping has also the advantage of being about four times less expensive than flight. Regarding environmental factors shipping should be the optimal transportation method.

Key words: Economical feasibility, cash flow analysis, shelf-life, fish fillets, cooling techniques, packaging, transportation, network flow.

Útdráttur

Meginmarkmið ritgerðarinnar er að kanna hvort virði fersk fisks í útflutningi megi auka með því að velja hagkvæmari og/eða virðisaukandi aðferðir í mismunandi hlekkjum keðjunnar *frá veiðum til neytanda*. Hlutverk arðsemisgreiningar er rætt og leiðir til að meta stystu leið og lægsta kostnað í gegnum ferlið samhliða því að viðhalda eða auka gæði viðkomandi vöru. Niðurstöður frá tilraunum á þessu fræðasviði eru greindar og skoðaðar í heildarsamhengi. Mismunandi kæli-, framleiðslu- og flutningsaðferðir eru skoðaðar og kostir og gallar ræddir.

Niðurstöður sýna að viðeigandi kæling um borð, kæling í vinnslu og eftirlit með hitastigi í flutningi eru mikilvægir þættir í ferlinu. Arðsemisgreining sýnir að fjárfesting í kælibúnaði um borð og í vinnslu s.s. vökvakælingu og roðkælibúnaði eru arðbærir valkostir. Notkun á vökvakælingu og roðkælibúnaði í vinnslu getur fært vöru allt að 5 daga í auknu geymsluþoli sem gefur útflutningsaðilum færi á að endurskoða flutningsaðferðir sínar. EPS pakkningar reynast bestí kostur vegna góðs einangrunargildis ef hætta er á hitasveiflum í flutningi. Í flutningi hefur skipaflutningur yfirburði hvað varðar stöðuleika á hitastigi og viðhald á gæðum vörunnar. Skipaflutningur er einnig u.þ.b. fjórum sinnum ódýrari en flugfrakt. Hvað varðar umhverfissjónarmið er skipaflutningur ávallt bestí kostur.

Lykilorð: Arðsemisgreining, sjóðstreymi, geymsluþol, fiskflök, kælitækni, pökkun, flutningsaðferðir, netflæði.

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Abbreviations

AE	Annual equivalent worth
CBC	Combined blast and contact
CP	Corrugated plastic
CPI	Crushed plate ice
EPS	Expanded polystyrene
EUR	Euro
IRR	Internal rate of return
ISK	Icelandic Krona
LI	Liquid ice
LQ	Liquid cooling
MAP	Modified atmosphere packaging
MARR	Minimum attractive rate of return
NC	No cooling
NPV	Net present value
RSL	Remaining shelf-life

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1 Introduction

Virtually all businesses at some time face investment decisions of some magnitude. Investment in equipment is usually based on one of five engineering economic decisions: (1) equipment and process selection, (2) equipment replacement, (3) new product or product expansion, (4) cost reduction and (5) service or quality improvement. Management will have to address key questions such as if the firm has knowledge and skill to undertake the new investment, does the investment really increase quality, does the new equipment require more or less personnel and even more questions. The factors of time and uncertainty are defining aspects of every investment project. Carrying out a feasibility or economic analysis is therefore one of the most critical steps in the decision-making process.

An economic or feasibility analysis is an effective analytical tool that can be used to evaluate investments from various perspectives, e.g. technical, legal, financial, market and organisational. It is a systematic approach to determine the optimum use of resources and often involving two or more alternatives in achieving a specific objective under the given assumptions and constraints. Result of the analysis is normally a predominant factor since most investments are not realised if they do not generate profit for the project owners. In this thesis both economic influence as well as other beneficial factors will be analysed, especially factors that influence the quality of the product. Precision and reliability of economic analysis relies on the accuracy of the information used in the analysis.

The main objective of this thesis is to investigate whether the value of raw material in export of fresh whitefish can be increased by choosing more economic and/or value adding processing and transportation methods in different processes *from catch to retailer*. To be more specific the main objective is further detailed in the following research questions:

1. Which procedures in the process *from catch to retailer* (for fresh whitefish fillets) bring the product the best quality and longest shelf-life?
2. Is the use of special cooling equipment economic (such as cooling equipment on board or in processing)?
3. Are there some parts of the whole process *from catch to retailer* that fit better with one than another (e.g. fits specific cooling technique better with one transportation method than other)?
4. Which transportation method is most economic when impact on shelf-life is considered?
5. Has location of processor great impact on shelf-life?

The research questions will be answered in this thesis. Published reports and results from experiments are fundamental resources. Many of the resources are published by Matís ohf. Matís is a research and development company which has the goal of increasing the value of food processing and production as well as ensuring the safety and quality of food products. Information is also provided from seafood companies (processors and exporters) to enrich the outcome of the project.

In this thesis processing methods, transportation methods and equipment in processing will be economically analysed. Factors influencing quality and therefore shelf-life of the

product are also considered. Specific compositions and chilling protocols for each link in the fresh fish supply chain will be recommended based on theory and experiments as well as other discussion related to the topic of this thesis.

The thesis is structured in the following way: Chapter 1 is the introduction and in chapter 2 the market situation of Icelandic exporters is reviewed. Chapter 0 is an overview of the theory of economic feasibility and related aspects, such as project financing and modelling of economic feasibility.

The process from catch to retailer is broken up into four parts and each chapter is dedicated to one part at a time. Chapters 4 – 7 are in the same order as links in the fresh fish fillets supply chain appear. Chapter 4 is dedicated to *catching*, chapter 5 to *processing*, chapter 6 to *packaging* and chapter 7 is to *transportation*. In chapter 4 different procedures in cooling after catch are discussed and results from experiments presented. In chapter 5 new cooling technique in processing and results from shelf life experiments are discussed. In chapter 6 different packaging options are presented and results from experiments discussed. In chapter 7 different transportation options are presented and compared. In chapter 0 investments in both the catching and processing parts are analysed. In chapter 9 results and discussion are illustrated and in chapter 10 the conclusion of the thesis is listed.

2 Market situation

A few nations in the world are as dependent on fisheries as Iceland considering the population size. Although Iceland is among the smallest nations of the world, with a population of slightly more than 300 thousand people, it is nevertheless among the world's largest fishing nations (Icelandic Fisheries, 2010).

The total number of persons involved/employees in the fishing (and the fish industry) is very low, or only about 4,000 (9,000) for the past few years. The productivity of the Icelandic fishing fleet is therefore among the highest in the world. Few other countries catch as much fish with so few fishermen and vessels (Icelandic Fisheries, 2010).

In 2005, Iceland caught 1.67 million tons, ranking 14th on a global scale. This is around average for Iceland, as it has been ranking from the 10th to the 21st high place since 1950 (Icelandic Fisheries, 2010).

Productivity in both fishing and fish processing has thus constantly increased through innovation in equipment design and product development.

In recent years, fisheries companies have actively been aiming for enhanced efficiency and benefit from economies of scale through mergers and acquisitions. Consequently, the largest companies have expanded, and the concentration of quota holdings has risen. The 10 and 15 largest fisheries companies in terms of quota holdings owned 51 % and 66 % of the total respectively in June 2008 (Icelandic Fisheries, 2010).

The fluctuations of the Icelandic currency (ISK) explain some of the variation in profitability. When the index is high, the ISK is weak and when it is low, the ISK is strong. The ISK was lowest in 2001 which was the best year ever for the Icelandic fishing industry. On the other hand, 2005, when the ISK was strongest, was the second worst year for the industry since 2001.

Since October 2008, Iceland has experienced economic difficulties following the start of the global financial crisis. It is now heading towards gradual recovery, with multilateral assistance from the IMF and partner states playing a key role. Many industries in Iceland have problems due to this situation, although industries primarily based on export, such as the fishing industry, are benefiting from more favourable exchange rates (Icelandic Fisheries, 2010).

The modern Icelandic seafood industry exported products for about 209 billion Icelandic Kronas (ISK), roughly equal to 1.3 billion Euros in 2009. The majority was exported to Europe. The United Kingdom, France, Germany, Norway (mainly fish meal) and Spain are the largest consumers of Icelandic seafood products. A considerable share is also exported to other European countries, America, Asia and Africa. Icelandic products are known for their high quality and have a strong tradition on these markets.

The annual export of fresh fish products (fillets and loins) from Iceland was about 15 to 23 thousand tons from 2004 to 2009 (Statistics Iceland, 2010). The development in export of fresh fillets has been changing in the last two years. Quantity has decreased while value has increased as can be seen in Figure 1. In Iceland cod has always been the most important fish species, accounting for more than half of the total demersal catch until the early 1980s.

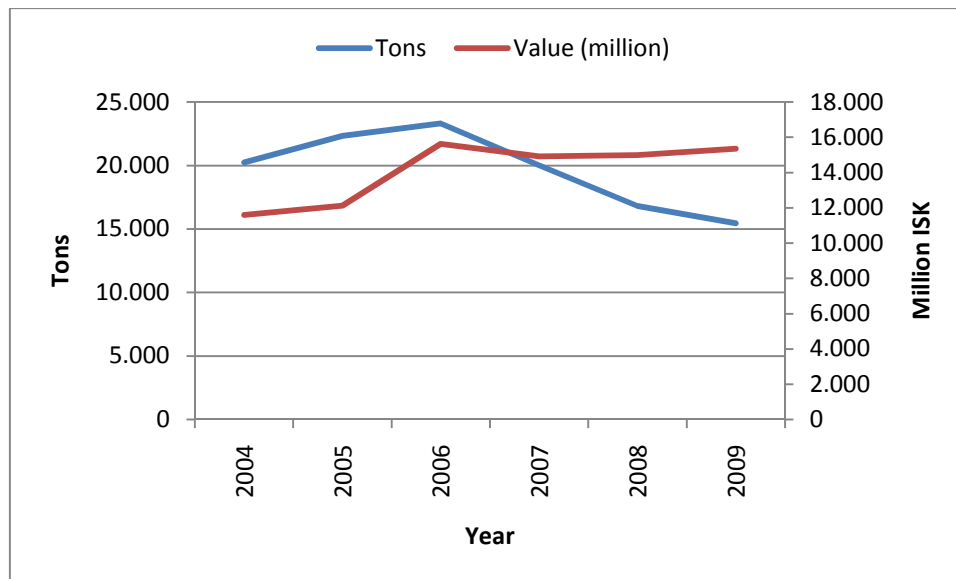


Figure 1. Changes in quantity and value in export of fresh fillets over time 2004 - 2009.

Britain, Belgium and USA are the three biggest purchasers of Icelandic fresh fish products. Britain has about 40 % share while Belgium and USA have about 20 % share each country. Icelandic processors must strive to preserve their products as well as possible and keep them competitive on market throughout sometimes inadequately temperature controlled transportation phase.

2.1 Profit

Investing in new equipment or implementing new methods in catching, cooling and packaging or in other parts of the process is not primarily for profiting (even though investing is usually not realised unless it is profitable). According to interviews with two of the largest exporters in Iceland (with accumulated 15 % market share), they do not recognise the use of improving equipment or methods as a check to a direct profit. It is rather seen as a confirmation that the buyers/customers can trust that the product is high class product and the buyer can trust that the product has freshness for certain time. Buyers pay more for product that has history of uniform and reliable quality and the exporter has to work hard to sustain the same quality standard all the time.

2.1.1 Sales price

According to exporters, it is quite hard or not possible at all to obtain information about development of sales prices throughout lifetime of the product based on methods used in the processing. Prices are controlled by supply and demand of the concerned product at the time and the reputation of the exporter/seller is also important. Seller with highly respected reputations is more likely to be chosen than less respected seller.

Sales managers or sales persons follow the market and agree or negotiate on offers made by buyers. Sales price for fresh fish loins can vary from €7.5 up to €12 per kg. Loins are an important and leading product in fresh cod export. Prices for fillets are a bit lower or €6 to €9 per kg. Prices are very unstable and can go up or down within the same week. The price

difference between a few days can even vary up to 50 – 70 % on the same product, all controlled by market forces. When the product has obvious defects the prices are lower and can vary from €4 to €8 per kg, depending on the market and offers from buyers. These numbers are used in this report in calculation to evaluate how much various techniques or methods bring the product in EUR based on improvement in shelf life.

As expected, sales price is an important factor for exporters and processors financial success.

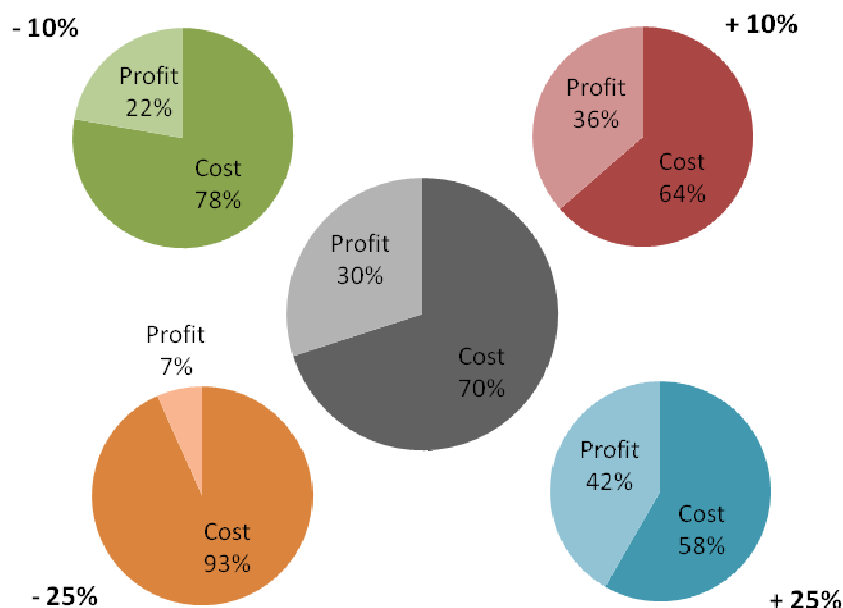


Figure 2. Change in profit as sales price changes.

Figure 2 shows how profit changes when sales price changes. For simplification it is assumed that cost is 70 % of sales price (total cost, including both operational and administrative cost). The figure shows what happens if sales price goes up or down by 10 – 25 %.

2.1.2 Cost

Every step in the chain from *catch* to *retailer* costs and can be divided into e.g. administrative cost, operational cost or other cost. In this report, only cost that can be labelled directly to the product such as new technology, transportation, packaging and a few other things are analysed. Salary, housing and other operational or administrative costs are not included.

2.2 Flow

When processing fresh products it should be a priority issue to get to the market as soon as possible. The objective of many real-world network models is to ship goods from one set of locations to another set of locations at minimum cost, subject to various constraints. In fresh fish processing and other chains minimum cost is not always the only goal; time is also a great success factor.

There are a few variations of models to optimise the best way through networks. The simplest models include a single product that must be shipped via one mode of transportation in a particular period of time. More complex models – and much larger ones – can include multiple products, multiple modes of transportation, and/or multiple time periods. This general class of problems is referred to as a minimum cost network flow problem. Minimum cost is a large parameter but as well is time. The shortest path between two points in a network is then an effective way to use. The typical shortest path problem is a special case of the minimum cost network flow problem. Special algorithms can solve these more general models very quickly (Albright and Winston, 2009).

Various ways are possible through the processing and the transportation process for fresh fish. Figure 3 shows the network flow of the whole process and different paths through the chain from catch to retailer. A different cost estimate is behind each node in the network and each node also has a different impact on the quality of the product, including shelf-life.

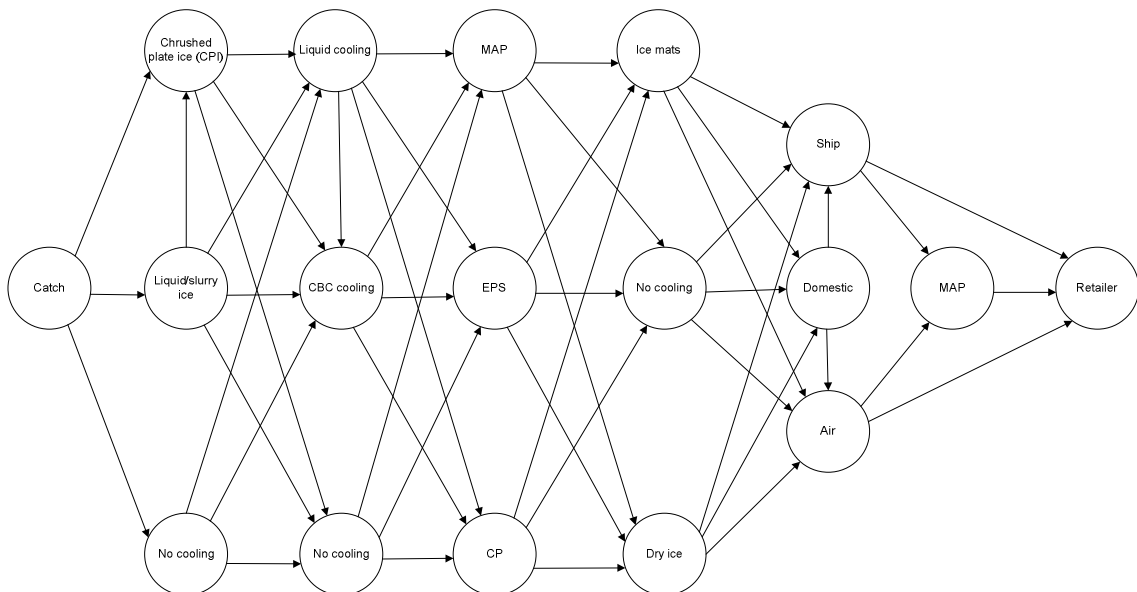


Figure 3. Network flow of the process from catch to retailer.

2.3 Shelf-life

In the recent years, techniques have been developed to protect products in the food industry against temperature abuse or other environmental factors and some of the new techniques even increase the shelf-life. Shelf-life is defined as the period during which the product maintains its microbiological safety and sensory qualities at a specific storage temperature. It is based on identified hazards for the product, heat or other preservation treatments, packaging method and other hurdles or inhibiting factors that may be used.

For sensory evaluation Torry scale is often used (Shewan, Macintosh, Tucher and Ehrenberg, 1953) both in industry and in research. When Torry scale is used the product is graded from 10 (most fresh) down to 3 (spoiled). The storage life of fish has been defined as coming to an end when an average sensory score of cooked fish samples has reached 5.5 on the Torry scheme (Martinsdóttir and others, 2001) Factors that influence the time it takes for product to reach grade 5.5 or lower are for example biological conditions of the fish, handling of the raw material after catch, cooling in all steps of the process, temperature in storage rooms and hygienic aspects that could increase/decrease the risk of microbial growth.

In this report shelf-life refers to the total life time of the product, or from catch until the product has been rated 5.5 or lower according to the Torry scheme.

3 Engineering economic decisions

In engineering economic analysis approximately ten principles apply for nearly all project investment analysis (Wiley, 2010; Park, 2002). The first principle is the time value of money, that is: the economic value of a sum depends on when it is received. Because money has both earning as well as purchasing power over time, a euro received today has a greater value than a euro received at some future time. Other principles are to make investments that are economically justified, choose the mutually exclusive investment alternative that maximises economic worth, marginal revenues must exceed marginal cost, compare investment alternatives over a common period of time and a few others.

3.1 Rate of return

Rate of return is determined by how the investment is financed. Rate of return used in this project is 11 %. Rate of return in Figure 4 is calculated as a ratio between catch limits and sales price of percentage of catch in cod. Real interests are evaluates as weighted average real interests of lending institutions.

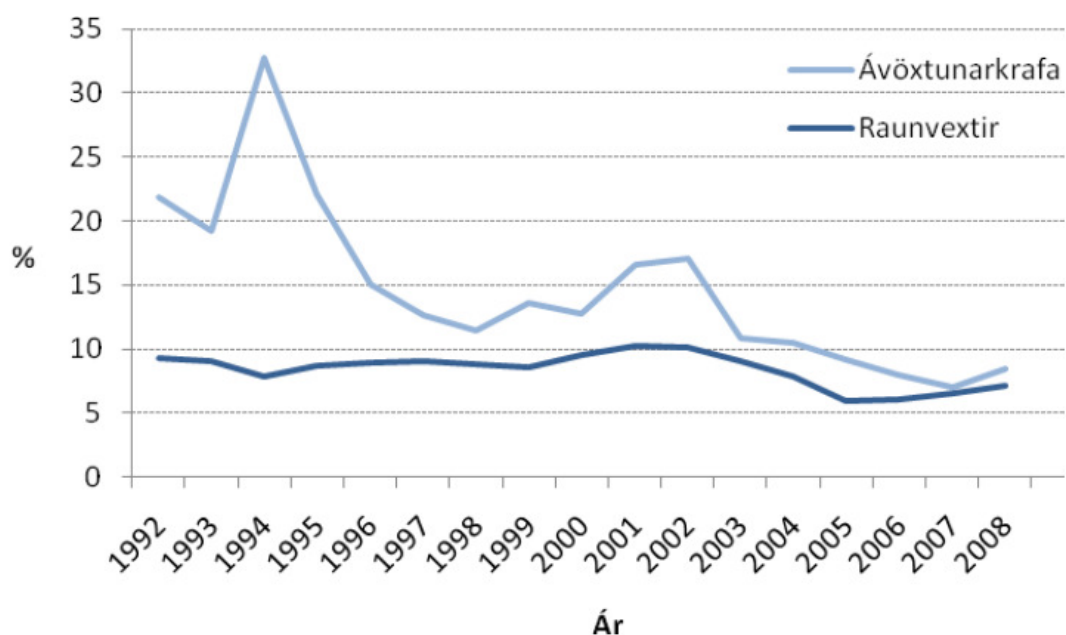


Figure 4. Rate of return (light blue) and real interest (dark blue) in the Icelandic fish industry (Kristófersson et al., 2010).

Figure 4 shows calculations of ratio between catch limits and sales price of percentage of catch in cod in the Icelandic quota system 1992 – 2009. The similarity in rate of return and real interests in recent years is explained by less uncertainty about future development of the cod stock and profit of manufacturers and exporters in the fish industry.

3.2 Interests

Figure 5 shows how non-indexed interests have been decreasing in the last 15 months and lowest interest rate on loan is under 10 % in 2010 compared to over 20 % fall 2008, shortly after the collapse of the Icelandic banks.

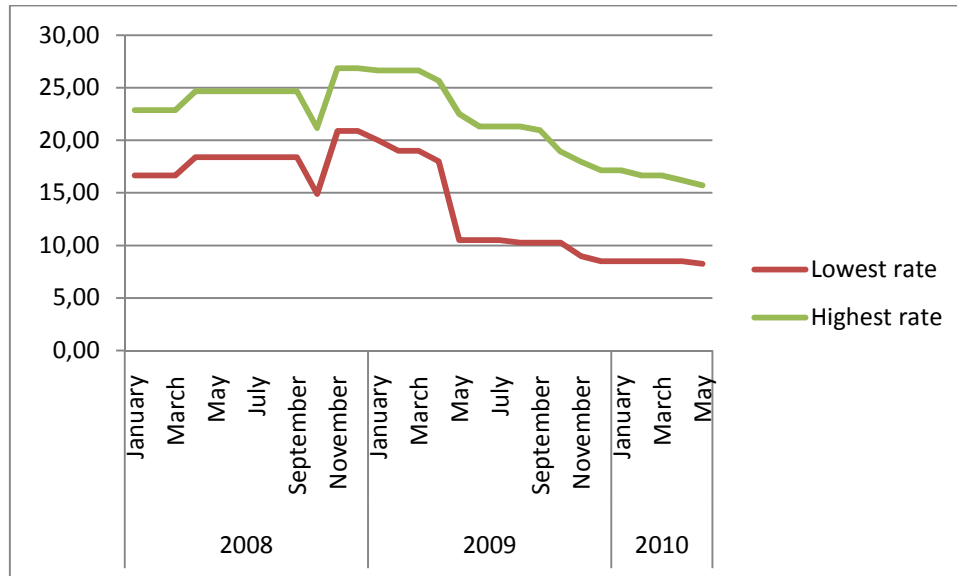


Figure 5. Changes in interest rates (%) in Iceland for non – indexed bank loans over time 2008-2010 .

Based on average interest rate offered by banks for financing capital equipment it is assumed that the interest rate in this report is 10.10 % (June 2010).

3.3 Net present value

Problems involving the time value of money can be conveniently represented graphically as a cash flow diagram or present the cash flow in table form. When cash flow is obvious it is easy to determine the net present value to find the real return of the investment. It is a standard method for using the time value of money to appraise long-term projects. Important parameters are the interests, investment cost, revenues and costs.

In order to calculate the net present value (NPV), the interest rate used for discounting the cash flows needs to be determined. The interest rate is often referred to as Minimum Attractive Rate of Return (MARR) and it represents the rate at which the investor can alternatively invest his money, i.e. the return of the most preferable alternative investment. The planning horizon of the project also needs to be determined, and the cash flows for each period of the planning horizon projected (Park, 2002).

The net present value, PW, of the project can be calculated with the following equation:

$$PW(i) = \frac{A_0}{(1+i)^0} + \frac{A_1}{(1+i)^1} + \dots + \frac{A_n}{(1+i)^n}$$
$$PW(i) = \sum_{n=0}^N \frac{A_n}{(1+i)^n}$$

where

PW(i) = NPW calculated at i,

A_n = Net cash flow at the end of period n,

i = MARR (or cost of capital),

n = Service life of the project.

(Park, 2002; 289)

If the $PW(i)$ is positive for a single project, the project should be accepted, since a positive NPV means that the project has greater equivalent value of inflows than outflows and therefore makes a profit (Park, 2002).

According to Park (2002) the decision rule for NPV is:

If $PW(i) > 0$, accept the investment.

If $PW(i) = 0$, remain indifferent to the investment.

If $PW(i) < 0$, reject the investment.

For every investment in this project n, lifetime of the investment, is 10 years and annual cash flow, A_n , is constant throughout the lifetime. P is investment cost and return rate, i, is 11 %.

3.3.1 Break-even point analysis

When using break-even point analysis it can be estimated how long it will take for the investment until it is profitable or at what time-point the cash flow reaches zero (since the investment is negative cash flow).

3.3.2 Annual equivalent worth

The annual equivalent worth (AE) criterion provides a basis for measuring investment worth by determining equal payments on an annual basis. Knowing that lump-sum cash amount can be converted into a series of equal annual payments, we may first find the net present worth (NPW) of the original series and then multiply this amount by the capital recovery factor:

$$AE(i) = PW(i) \left(\frac{i(1+i)^0}{(1+i)^0 - 1} + \frac{i(1+i)^1}{(1+i)^1 - 1} + \dots + \frac{i(1+i)^n}{(1+i)^n - 1} \right)$$

$$AE(i) = PW(i) \sum_{n=0}^N \frac{i(1+i)^n}{(1+i)^n - 1}$$

where

$PW(i)$ = NPW calculated at i ,

i = MARR (or cost of capital),

n = Service life of the project.

(Park, 2002; 346)

According to Park (2002) the decision rule for AE is:

If $AE(i) > 0$, accept the investment.

If $AE(i) = 0$, remain indifferent to the investment.

If $AE(i) < 0$, reject the investment.

For every investment in this project n , lifetime of the investment, is 10 years and return rate, i , is 11 %.

3.4 Cost of capital

3.4.1 Internal rate of return (IRR)

Internal rate of return (IRR) is a capital budgeting metric that indicates the quality of the investment. The internal rate of return is the value of interests or discount rate that makes the net present value (NPV) of the investment's cash flow equal to zero. If the IRR value is greater than the rate of return that could be earned by investment of equal risk (e.g. a bank account, bonds or machine) then the investment will add value for the company.

According to Park (2002; 410) the value of IRR is found by solving for i from the following equation:

$$PW(i) = \sum_{n=0}^N \frac{A_n}{(1+i)^n} = 0$$

If $IRR > MARR$, accept the investment.

If $IRR = MARR$, remain indifferent.

If $IRR < MARR$, reject the investment.

3.5 Sensitivity analysis

Sensitivity analysis can give decision makers an insight into project risk associated with changes in input parameters since changes of input parameters effect the net present value (NPV) of the project. Sensitivity analysis highlights which parameters should be defined as key parameters in the project. Key parameters are the ones that influence the results the most. Sensitivity analysis is conducted by determining how much output values change relative to a given change in input parameters. First a base case is defined from the most-likely value for each variable. These are the same values as used in the economical analysis described above. For simplification it is assumed that every variable is independent, that is only one variable at a time is changed by a specified percentage and other variables are held constant at the base case value. Next step is to calculate a new net present value (NPV). This is done for all variables of interest and for the percentage change in variable that is assumed possible (Park, 2002).

A convenient and an effective way to present the results of sensitivity analysis are plotting sensitivity graphs. The slopes of the lines show how sensitive the output to changes in input variables. The steeper the slope is the more sensitive the outcome is to a change in a particular variable (Park, 2002).

3.6 Depreciation

Fixed assets such as equipment are economic resources that are acquired to provide future cash flows. Generally, depreciation can be defined as the gradual decrease in utility of fixed assets with use and time. Depreciation usually has two sides, economic depreciation and accounting depreciation. Economic depreciation is the purchase price minus market value. Accounting depreciation provides the organisation information to assess its financial position. In calculations in this report accounting depreciation is used. Accounting depreciation is a fraction of the cost of the investment that is chargeable as an expense in each of the accounting periods in which the investment provides service to the firm, and each charge is meant to be a percentage of the whole cost which matches the percentage of the value utilised in the given period. It depends on the type of the investment how high the percent is in each accounting period. For investments like real estate the percentage is much lower than for process equipment where it is expected it has predetermined lifetime.

4 Catch

Once the catch is received it is very important to minimize the holding time and once the fish has been allowed to bleed in running seawater/water it should be pre-cooled further down to a temperature as close to the intended storage temperature as possible. Cooling shortly after catch is one of the most important factors in quality of the raw material in latter steps in the process from catch until the product is sold in retail store/supermarket.

The term cooling refers to the process of extracting heat from the raw material without freezing it.

Cooling can be broken up into two steps:

1. Cooling from initial temperature of the raw material down to its optimal storage temperature.
2. To maintain the optimised temperature during storage time.

According to Gunnarsson (2001), cooling right after catching has impact on the product lifetime. The benefits gained by cooling right after catching are the following:

- Slows down the growth of microbes and extends therefore the total shelf-life of the product.
- Extends the time of rigor mortis and minimises gaping in the flesh of the raw material.
- Increases blood flow, which leads to whiter flesh.
- Minimises weight decrease of the product. The higher the temperature of the flesh, the more weight loss of the product is expected.

Cooling after catch can be performed in several ways, such as cooling with crushed plate ice, liquid or slurry ice cooling. Often these methods are used together as a combination.

4.1 Results from experiments

Figure 6 shows how temperature was maintained in the raw material for different ice types in a study conducted by Matís in October 2008. Two different types of liquid ice (denoted as LIA and LIB) and crushed plate ice (FI+FI, where +FI denotes top icing with crushed plate ice) were used for chilling 100 kg of whole, gutted cod.

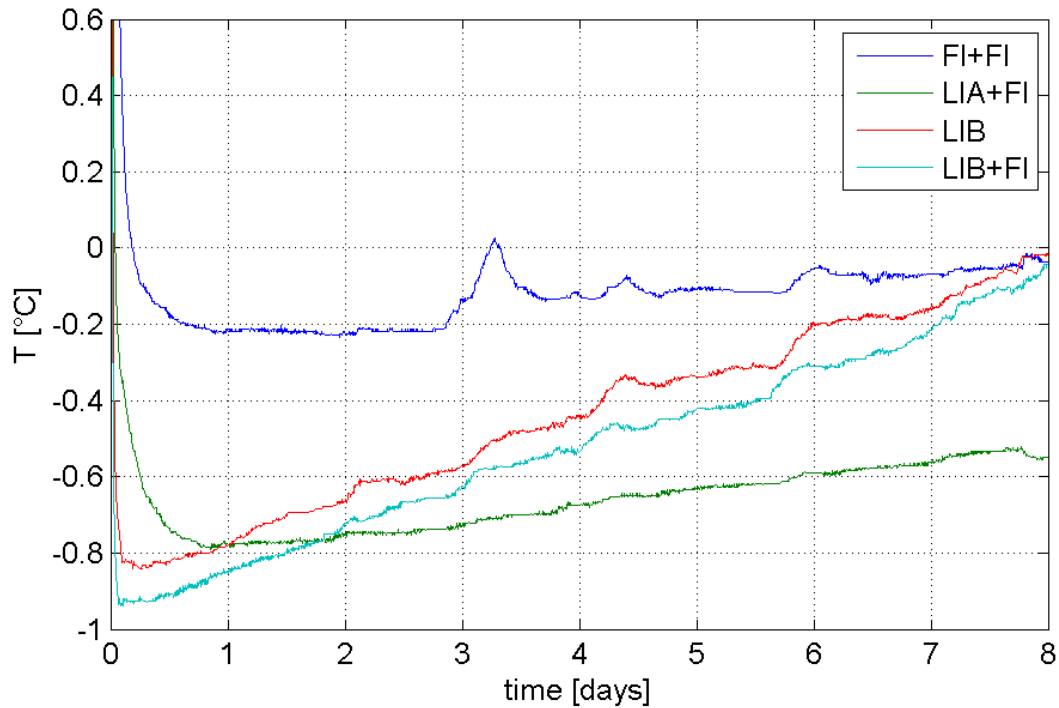


Figure 6. Maintenance of temperature as a function of time for different ice types (Thorvaldsson, Lauzon and Margeirsson, 2008)

It can be seen that even though the temperature of the crushed plate ice is slightly higher than the temperature of the liquid ice, it is better maintained throughout the storage period. The reason for this is probably a larger area of contact for the liquid ice both with the walls of the tub and the fish.

This result implies that the best solution is to initially cool the raw material with liquid ice, re-ice with crushed plate ice after 24 hours, and then maintain the temperature after that with crushed plate ice as needed.

No marked difference was seen in microbial and chemical measurements whether plate ice or liquid ice was used prior to filleting but according to sensory analysis, the experimental group where liquid ice was used had one day extension in freshness and shelf-life compared to the group with plate ice. Temperature was usually slightly higher in the plate ice group than the liquid ice group during storage (Magnússon et al., 2009).

5 Processing

The processing is different between manufacturers and products. For fresh cod fillets or loins the process is, however, quite similar between different processors. Equipment or techniques might be different but the goal is in general the same: to deliver fully processed product that has been appropriately chilled and handled, is labelled by good quality and is easy to sell. Figure 7 shows different implementation of the processing process from catch until the processed product is packed.

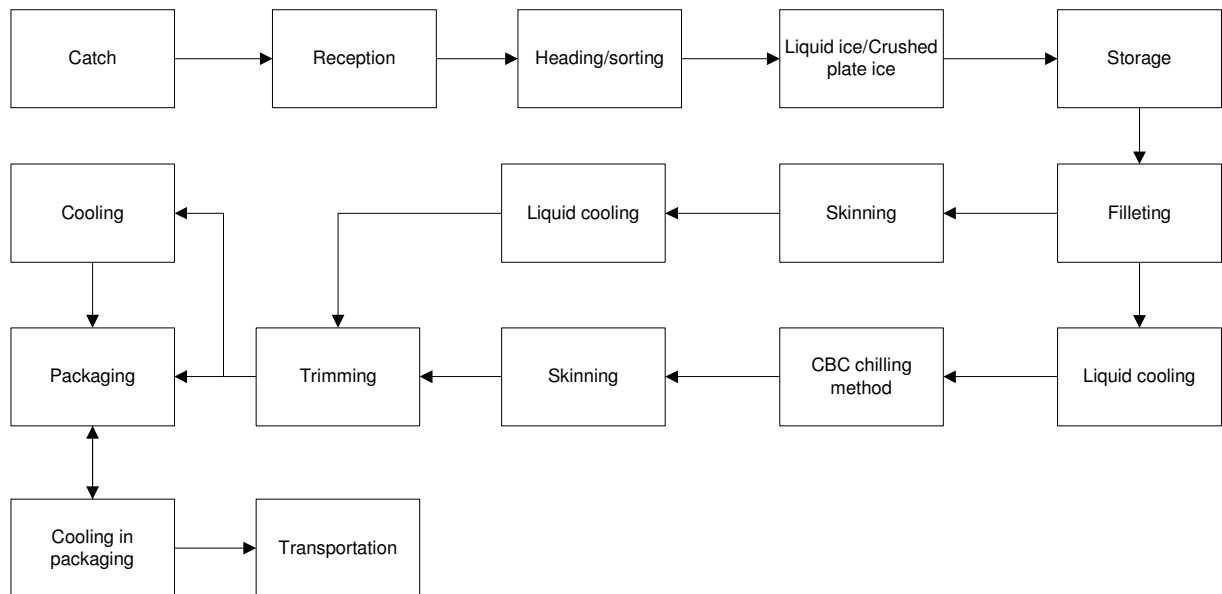


Figure 7. Common implementations of the processing process.

5.1 Chilled room before processing

The raw material is stored in a chilled storage room until processing. During storage the temperature of the chilled room should be held close to 0 °C, and time minimized in pre-processing (e.g. gutting, beheading) since there is always a risk of temperature abuse. After pre-processing, the raw material should be chilled as soon as possible. The raw material should preferably not exceed 0 °C when it enters filleting. When planning processing of raw fish it is important to choose carefully which processing methods suit each product. Important factors are for example how well the product maintains desirable temperature and if the method has impact on length of shelf-life.

5.2 Holding time and air temperature in processing room

Even though best possible chilling technique is used during processing, the temperature in the processing and storage room is very important and time during processing should be minimized. Research conducted by Matís has shown that the temperature of fillets can increase by 3 – 4 °C for every half an hour they are left without cooling in a processing room at 14 °C (Valtýsdóttir, Margeirsson and Arason, 2009).

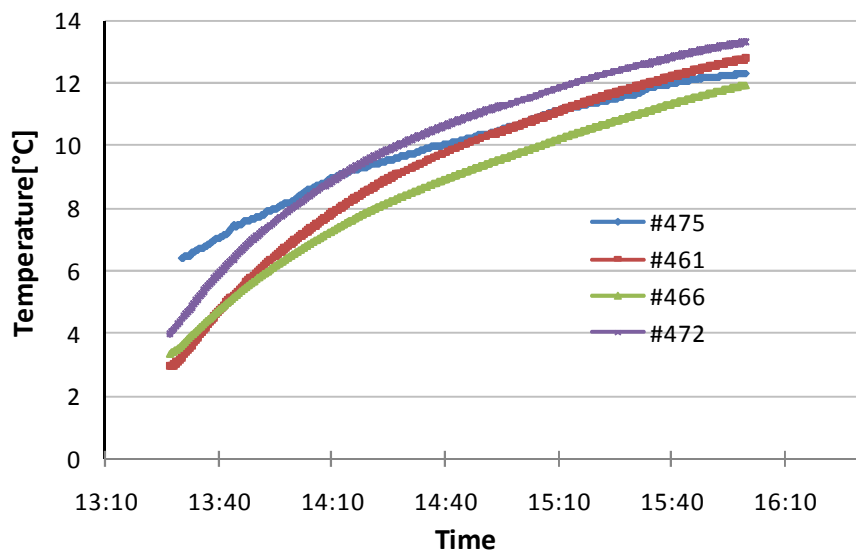


Figure 8. Temperature increase in fillets in a 18 °C hot processing room (Valtýsdóttir et. al., 2009).

Figure 8 shows the temperature increase in four fillets which were left without cooling in an 18 °C warm processing room having initially been cooled in a liquid cooler. The temperature increases by approximately 6 – 7 °C for every hour they are left without cooling. Such a scenario is very likely for example if the fillets are left without cooling during a lunch break or if the trimming is a bottleneck in the processing line, but trimming itself should not take more time than 2 – 4 minutes. For better protection against temperature abuse all water used in the processing should not exceed 2 °C if possible.

As Figure 8 shows, when processed product is left in room temperature for shorter or longer time it has great impact on the product. Unwariness for the temperature can therefore possibly reduce the positive effect of new technology, shorten shelf-life or in worst cases the product has to be sold as a second class product.

5.3 Liquid cooling / slurry ice cooling

Liquid or slurry ice cooling is the process of putting fillets in a liquid cooling medium with a preferable temperature of $-1.5\text{ }^{\circ}\text{C}$ to $-0.5\text{ }^{\circ}\text{C}$. The purpose is to pre-cool the product in processing prior to packaging.

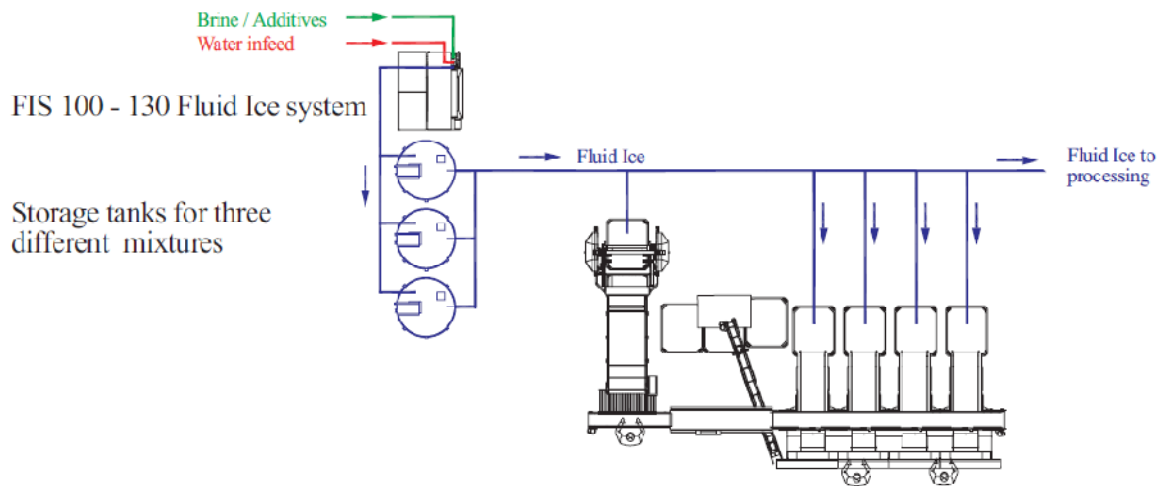


Figure 9. Typical application for fluid ice system (Skaginn, 2009).

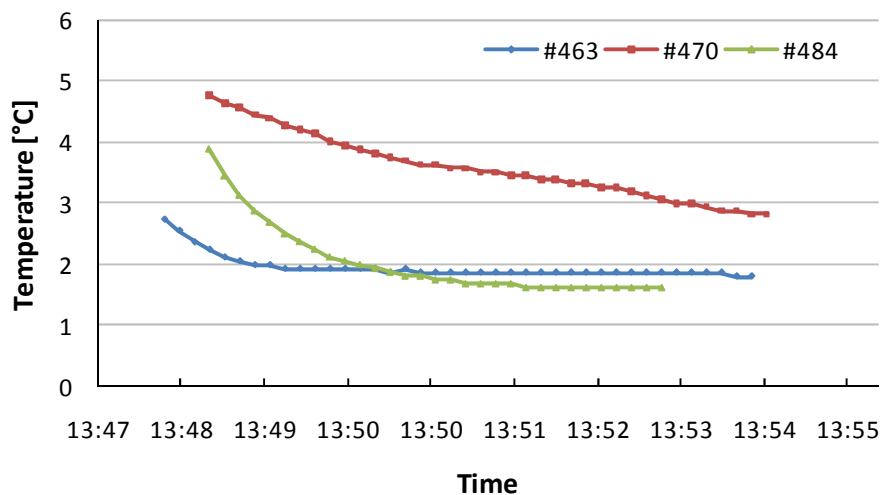


Figure 10. Temperature in three fillets as a function of time in liquid cooler (Valtýsdóttir et al., 2009).

Figure 10 shows graphically what is happening to the product during the liquid cooling process. Results are based on experiment done in July 2009 and show the temperature profiles of three fillets running through a 3 m long liquid cooler in approximately 6 minutes. During that period the temperature of the fillets decreases by 1 – 2 $^{\circ}\text{C}$, which is dependent on the initial temperature and size of the fillets, the temperature and flow of the cooling medium and the time which the fillets spend in the liquid cooling.

The ice and salt concentration in a slurry ice cooler should be 10 % and 1 - 2 % or more, which should result in the desired cooling medium temperature of -1 °C (Valtýsdóttir, Margeirsson and Arason, 2010).

Despite its advantages, the risk of cross contamination is considerable in liquid cooling. In order to minimize the risk the fillets should be kept in the liquid for a limited amount of time and the cooling medium should be renewed frequently. When the product is kept in same liquid cooling media for long time, growth of microbes can lead to decrease in shelf-life.

5.4 CBC cooling or similar techniques

Combined blast and contact (CBC) cooling is a new cooling technique developed by Skaginn hf. where heat is extracted from fillets both by conduction through a teflon coated aluminium conveyor belt and by convection, where cold air is simultaneously blasted over the fillets (Skaginn hf., 2003). According to studies (Magnússon et al., 2009; Olafsdóttir, Lauzon, Martinsdóttir and Kristbergsson, 2006; Arnþórsdóttir, Arason and Margeirsson, 2008) the most preferable method in processing before packaging regarding extended shelf-life of the product is to combine in processing both liquid cooling (LC) and CBC cooling system or similar technique. When liquid cooling is used together with a CBC chilling system it both serves the purpose of cooling the raw material and to increase its salt content slightly in order to lower its freezing temperature in the CBC chilling machine. Liquid cooling is placed right before the product enters the CBC chilling machine.

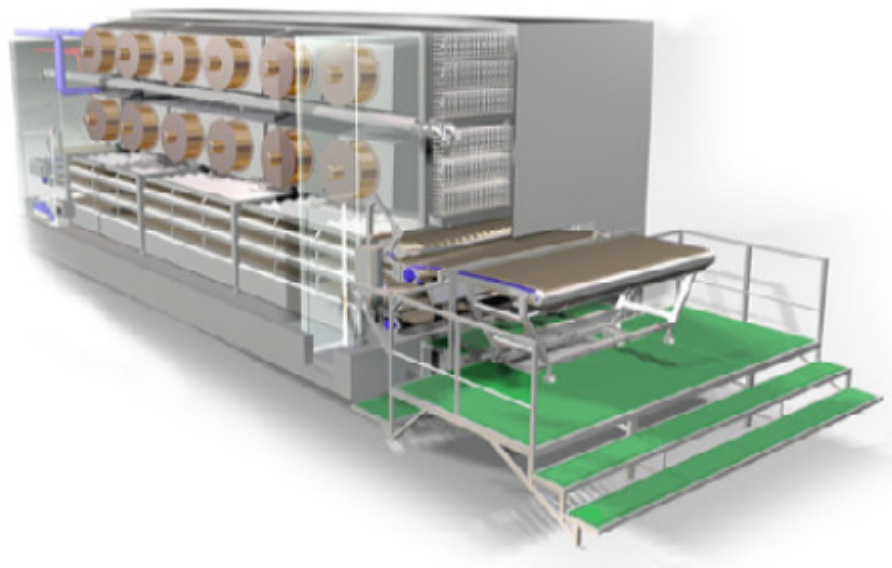


Figure 11. CBC super chiller from Skaginn.

The impact of CBC cooling on the temperature maintenance of abused fillets has been found to be considerable when compared to liquid cooling (LC) in process or untreated fillets. Magnússon et al. (2009) revealed that abused CBC and LC fillets were found to have 100% extended shelf-life, respectively, compared to similarly abused control fillets with a shelf-life of 6 days from processing. It is therefore an advantageous method to process fillets to be shipped as fresh products since it will help in maintaining freshness and shelf-life despite breakage in the cold chain. Furthermore, a bacterial growth-retarding effect of CBC processing on SSO has been observed.

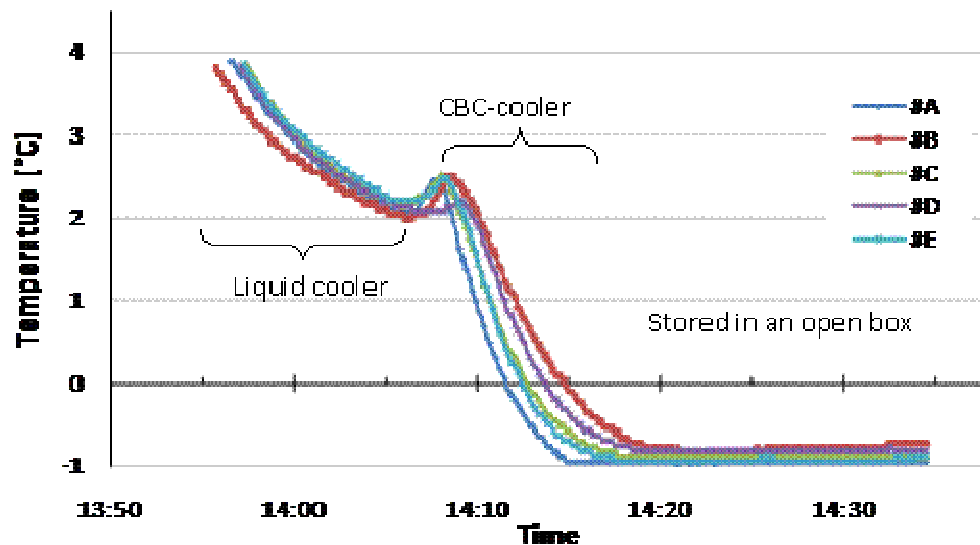


Figure 12. The temperature of five different fillets as a function of time (Valtýsdóttir et al., 2009).

Figure 12 shows the temperature development of 5 different fillets going through a CBC cooling process. The temperature of the fillets can be seen to decrease by 2 °C in 10 minutes in the liquid cooling. The rapid cooling of the fillets in the CBC chilling machine can then be observed where the temperature decreases by approximately 3.5 °C in about 7 minutes, down to a temperature where the phase change begins. The chilling is therefore both of greater magnitude and happens faster than in liquid cooling.

Another interesting feature on Figure 12 is that once the fillets have gone through the CBC cooler and are stored in an open box at 14 °C for 10 minutes their temperature remains stable (some measures show up to 40 minutes, but 10 minutes was the most common result in this experiment). The reason for this is that a large part of the cooling energy added to the fillets in the CBC cooler is in the form of phase change as cooling capacity, so that the temperature remains stable until most of the ice has melted.

Matís's experiments on the impact on shelf-life all include the using of CBC chilling machine from Skaginn ehf. Therefore it gives more exact results using the same equipment in economical analysis in the current report.

5.5 Results from experiments

A few experiments have been conducted in comparing different cooling techniques like liquid ice and crushed plate ice before processing and liquid cooling and CBC cooling method in processing. The biggest published experiments (Martinsdóttir et al., 2004; Magnússon et al., 2009) were made in the fall 2003 and in October 2008.

Experiments done in October - December 2003 (Martinsdóttir et al., 2004) show that temperature and treatment of the fish in the beginning has significant impact on shelf-life and results of sensory evaluation, chemical, microbial analysis and electronic nose measurements confirm these speculations. Low temperature during the process is a fundamental issue for lengthening shelf-life of fresh fish and by using CBC cooling method the temperature of the product remains below 0 °C during the rest of the processing time. When fillets are chilled with CBC chilling machine the damage process slows significantly down compared to traditional processing methods.

Table 1. Main results from experiments on shelf-life done in October 2003.

Group	On-board	Processing	Shelf-life
1	CPI	Trad. (Baader)	12 days
2	CPI	Trad. (Baader)	12 days *
3	CPI	LC – CBC	13 days
4	CPI	Trad. (Baader)	8 days **

* Group 2 was moved on the third day to a room with temperature 16 °C over night.

** Group 4 suffered from temperature abuse, before processing the raw material was stored non-chilled for 8 hours (but still in chilled room) and then moved to a room with temperature 16 °C over night.

Experiments from 2008 (Magnússon, et al., 2009) show that using liquid cooling in processing can extend the shelf-life by up to 25 %.

The best result is yielded when liquid cooling and CBC chilling method are used together. Even though groups 1 and 2 have the same result, measures showed that the spoilage process was faster in group 2, where the product suffered from temperature abuse. In the experiments mentioned above the raw material was stored unprocessed for up to three days before processing. Total shelf-life with traditional processing method was 12 days but with CBC chilling method 13 days. Compared to another group which suffered from great temperature abuse the total shelf-life was only 8 days (Martinsdóttir et al., 2004:42). Results from group 4 illustrate how important it is to protect the product from temperature abuse, especially if the product suffers from temperature abuse before processing, it can cut shelf-life down for up to 5 days. Five days is for example the whole time it takes to ship the product or almost one work week in sale by retailer.

Table 2. Main results from experiments on shelf-life done in November 2003.

Group	On-board	Processing	Shelf-life
1	LI	LC – Trad. (Baader)	14 days
2	LI	LC – Trad. (Baader)	11 days *

* Group 2 was moved on third day in a room with 18 – 20 °C for 16 hours.

In the experiment in November 2003 (Martinsdóttir et al., 2004) the raw material was processed only one day after catching. For wild fish intended to be sold as fresh fish it is though usually recommended that the fish is not processed until after rigor mortis which can take 24 – 48 hours. In October and December (see Table 3 and Table 4) the raw material was processed 2.5 – 3 days after catching. The fluctuation in temperature on day 3 decreased the shelf-life for three days.

Table 3. Main results from experiments on shelf-life done in December 2003.

Group	On-board	Processing	Shelf-life
1	LI	LC – CBC	14 days *
2	LI	LC – CBC	15+ days **
3	LI	LC – CBC	15 days ***

* Group 1 was stored in 0.5 °C the whole time.

** Group 2 was stored in -1.5 °C the whole time.

*** Group 3 was stored in -1.5 °C for the first 7 days and then moved to 0.5 °C the rest of the time.

Temperature of the storage room is also important since experiments showed that raw material stored and processed in temperature around -1.5 °C had longer shelf life than when the temperature was 0.5 °C (Martinsdóttir et al., 2004:50).

In experiment from October 2008 (Magnússon et al., 2009) different cooling techniques were compared to each other considering freshness in days and shelf-life of the product. The purpose of that experiment was to examine two different cooling methods on-board, to apply different cooling techniques during processing at fish plant including the CBC (combined blast and contact) cooling and to compare storage of packed cod fillets kept either at steady temperature (-1 °C) or under temperature fluctuations.

The material was divided into four groups and different cooling methods were used both on-board and in processing. Experimental groups and main results can be seen in Table 4.

Table 4. Main results from experiments on shelf-life done in October 2008.

Group	On-board	Processing	Shelf-life
1	CPI	LC – CBC	14 – 15 days
2	CPI	LC	9 – 12 days
3	CPI	NC	8 – 11 days
4	LI	LC – CBC	15 – 16 days

No marked difference was seen in microbial and chemical measurements whether crushed plate ice or liquid ice was used on-board prior to processing but according to sensory analysis, the experimental group where liquid ice was used had one day extension in freshness and shelf-life compared to the group only chilled crushed plate ice and no extra chilling in the processing (Magnússon et al., 2009:20).

No marked difference was seen in microbial counts between groups that were stored at a constant temperature around -1 °C compared to groups where temperature fluctuations were used during early phases of storage (Magnússon et al., 2009:30).

According to sensory, microbiological and chemical analysis, the combined blast and contact (CBC) cooling clearly resulted in longer freshness period and shelf-life extension in comparison with the two groups where this technique was not applied. Temperature was lower in the groups where CBC cooling was applied in processing during the storage period (Magnússon et al., 2009:30).

Table 1 to Table 4 support that when groups suffer from temperature abuse the shelf-life is 1 – 4 days less than when steady temperature is maintained. As the experiments from November 2003 present that longer shelf-life is gained when the raw material is processed as soon after catch as possible. The longest shelf-life is obtained when using liquid ice or crushed plate ice on board and liquid cooling and CBC chilling method in processing, or up to 14 – 16 days. That gives manufacturers an opportunity to reconsider their packaging option, transportation option, brings them stronger position in markets and should result in higher sales price.

In addition to the benefits of using CBC chilling machine in the processing mentioned above, experiments show that processing yield of the product increases by up to 3 % when CBC chilling method is used compared to traditional method (Martinsdóttir et al., 2004:12).

Figure 13 shows graphical comparison between different solutions (based on above mentioned experiments) in cooling technique mentioned above both during cooling and storage on board and in processing.

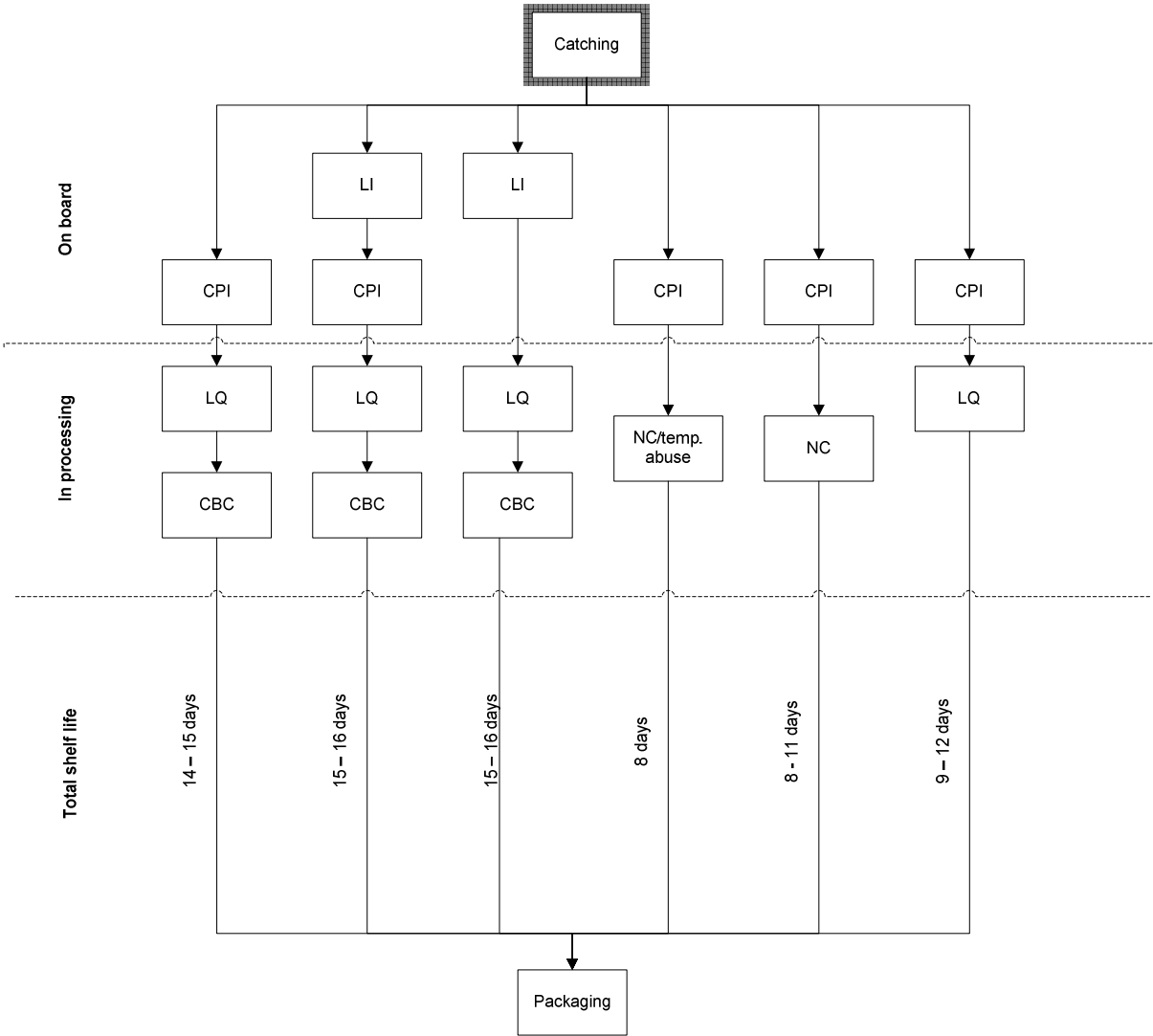


Figure 13. Flow chart of shelf-life which compares different ways in cooling.

5.5.1 Added-value

Based on information on sales price and shelf-life experiments described in chapter 5.5 it is easier to estimate how much in Euros each day additional shelf-life brings to the product. As mentioned in chapter 2.1.1 sales price is controlled by supply and demand but uniform quality and good reputation of the seller are also important. Reports were not available about development of the sales price throughout lifetime of the product.

As experiments regarding length of shelf-life presented above, additional cooling in processing such as liquid cooling and CBC chilling method used together can bring fresh fish product up to 5 days in extra shelf-life and gives an extra protection for temperature abuse after processing. Given that sales price on fresh fish loins varies from €7.5 up to €12 per kg and with that knowledge it is known that when fresh fish loins or fillets are damaged or not longer sold as high class product the price can be around €4 to €8 per kg. Therefore it should not be an overestimate to say that these extra days obtained by the before mentioned technologies in chilling in processing bring to the product at least €1 worth per kg or €0.20 per each additional day in shelf-life. It is more likely that this number can be even higher but it is more reasonable to start with a lower number than higher. Sensitivity analysis will be conducted later in this report and that should give information on what happens in economical context if the added-value is higher than estimated.

6 Packaging

The aim of this chapter is to compare results between the use of different packaging, shelf-life increase and/or decrease of the use of specific packaging and to analyse cost difference between packaging.

The fundamental role of most packaging is to store and protect the raw material from external factors such as the heat, oxygen, moist, light, animals, bacteria, chemicals and other. The packaging has also role in marketing success. The negative impact of unsatisfactory ambient temperature fluctuations during distribution of perishable products can still be dampened by thermal insulation of the packaging.

Choosing the right packaging can be influenced by factors like:

- How well the packaging handles temperature abuse
- Cost
- Space required for storage
- Weight
- Environmental issues, such as disposal and recycling
- Strength

Some studies (Mai, Margeirsson, Bogason, Sigurgísladóttir and Arason, 2010; Martinsdóttir et al., 2010; Margeirsson et al., 2008) have revealed that temperature control in real fish cold chains is quite often far from what is described in the ATP (1970) (fish temperature should be as close to 0 °C as possible without freezing the products), thereby decreasing product quality, shortening shelf-life and decreasing product value. In large parts of fresh fish distribution chains, the inside boxes of whole pallets are protected against thermal load from the ambient air by the neighbouring boxes. This is, however, not always the case because frequently, pallets are broken up before being loaded in order to maximize volume exploitation of the cargo hold. That applies especially when air transportation is used.

Mostly two types of packaging have been used in experiments conducted by Matís, Reykjavík: boxes made of expanded polystyrene (EPS) and corrugated plastic (CP). EPS is commonly used for transporting of fresh fish from Iceland to UK, but CP has been getting more attention recently. To maintain the temperature of the product during transportation both ice packs and dry ice have been used.

Modified atmosphere packaging (MAP) has been used in the Icelandic meat industry but not yet for export in the Icelandic fish industry. In this chapter advantages and disadvantages of using MAP in international transport are discussed and what effect it has on shelf-life.

6.1 Pre-cooling before packaging

Pre-cooling before packaging is very important. One of the purposes of packaging is to protect the product from temperature abuse and also if the product has not reached optimal temperature (-2° C to 0 °C). The product is more insusceptible for cooling down after it has been packed. Experiments and calculations were conducted by Matís and showed that fish pre-cooled down to -1 °C before packaging into a single 5 kg EPS box was around 9.8 hours to reach mean product temperature of 0 °C when stored at 15 °C for 10 hours. With similar calculations it has been shown that fish originally at 1 °C reaches up to 6.6 °C mean product temperature in 9.8 hours. That means that by pre-cooling fresh white fish fillets down to -1 °C before packaging in EPS boxes the fresh fish product earns an extra 10 hours in protection against temperature abuse of 15 °C (Margeirsson, Þorvaldsson, Arason, Lauzon and Martinsdóttir, 2009b). It should be noted that this applies to a single free standing 5 kg EPS box in still weather not taking direct sunlight into account.

6.2 Expanded polystyrene (EPS)

Expanded polystyrene boxes (EPS) have been utilised for export of fresh fish from Iceland for many years. EPS boxes are often white, manufactured from moulded polystyrene beads and up to 98 % of the boxes consist of air pores. The air decreases the density and increases the insulation performance but decreases strength and increases required storage volume for the boxes (Margeirsson, Arason and Pálsson, 2009a).

The most common sizes of EPS boxes used for fresh fish fillets are 3 kg, 5 kg and 7 kg.

Table 5. Common types of EPS boxes

Type of box	Price*
3 kg	€0.77
5 kg	€0.78
7 kg	€0.83

*Based on exchange rate 9. June 2010.



Figure 14. Fresh fish fillets packed in new type of EPS box.



Figure 15. EPS packaging ready for transport. Outside of boxes are temperature loggers used in experiments.

6.3 Corrugated plastic (CP)

Another type of commonly used fresh fish packaging is made of corrugated plastic (CP). These boxes are produced from extruded corrugated plastic (polypropylene) sheets which are 2 – 3.5 mm in thickness. The CP boxes can be flat packaged, which can save valuable storage space.



Figure 16. Fresh fish fillets packed in CP.

Most common size of CP boxes used for fresh fish fillets are 3 kg, 6 kg and 7 – 10 kg. But according to sales person of CP packaging each box can be packed with more value than in sales description. For example a 3 kg packaging can take up to 4.5 kg of fresh fillets.

Table 6. Common types of CP boxes.

Type of box	Price (€)*
3 kg	€1.07
6 kg	€1.45
7 – 10 kg	€1.99

*Based on exchange rate 9. June 2010.

6.4 Ice packs

Ice packs contain frozen water and are put on top of the fillets before closing the packaging, such as EPS or CP. The weight of ice packs usually varies from 125 g and up to 250 g for 3 – 7 kg of fresh fish fillets.



Figure 17. Ice pack from Promens Tempra put on top of fresh fillets inside EPS packaging before transportation.

Table 7. Common types of ice packs

Type of ice pack	Price (EUR)*
150 g (gel pack)	€0.13
250 g	€0.16

*Based on exchange rate 9. June 2010.

6.5 Dry ice

Dry ice is frozen carbon dioxide a normal part of our earth's atmosphere. Dry ice is particularly useful for freezing, and keeping things frozen because of its very low temperature: -78.5°C . Dry ice is widely used because it is simple to freeze and easy to handle using insulated gloves. Dry ice changes directly from a solid to a gas -sublimation- in normal atmospheric conditions without going through a wet liquid stage. Therefore it gets the name "dry ice". As a general rule, dry ice will sublimate at a rate of five to ten pounds every 24 hours in a typical ice chest. Dry ice sublimates faster than regular ice melts but will extend the life of regular ice. Commercial shippers of perishable food often use dry ice even for non frozen goods. Dry ice gives more than twice the cooling energy per pound of weight and three times the cooling energy per volume than regular water ice (H_2O). It is often mixed with regular ice to save shipping weight and extend the cooling energy of water ice. The resulting dry ice snow is packed in the top of a shipping container offering extended cooling without electrical refrigeration equipment and connections (Dry ice, 2010).

Dry ice is used for cooling in packaging in flight. For 3 or 5 kg packaging around 200 g of dry ice is put in each box.

Dry ice does not require extra place in the packaging so quantity in the box is the same as it is without dry ice. And as mentioned above the dry ice melts and vanishes so the airlines do not charge extra for the weight of the dry ice.

6.6 Modified atmosphere packaging (MAP)

Modified atmosphere packaging (MAP) techniques are now used on a wide range of fresh or chilled foods, including raw and cooked meats as poultry, fish, fresh pasta, fruit and vegetables, and more recently coffee, tea and bakery products. In this preservation technique the air surrounding the food in the package is changed to another composition of the air inside the box. The mixture of gases in the package depends on the type of product, packaging materials and storage temperature. The safety and stability of foods depends on the microorganisms initially present being unable to overcome various adverse factors, both extrinsic and intrinsic to the food, and multiply. Modification of the atmosphere surrounding the food may provide one condition or 'hurdle' that helps restrict the growth of microorganisms. Another 'hurdle' can be provided by storage at low temperatures (4 °C). The combination of chill temperatures and MAP generally results in a more effective and safer storage regime and longer shelf-life (Phillips, 1996).

Use of MAP does not eliminate the necessity for proper, safe manufacturing procedures nor the need for careful handling at all stages from factory to table (Phillips, 1996).

According to food guidance in the United Kingdom (Food Standard Agency, 2010), products stored at 3 – 8 °C (such as fresh fish fillets) can be registered with up to 10 days shelf-life when packed for the first time in modified atmosphere packaging. That means even though the fish has reached near end of originally defined shelf-life just by packing into MAP brings the product extra 10 days in sale. If repacked again in MAP shelf-life should not restart counting.

When MAP is used the product is packed after transportation, usually in the destination country. A few disadvantages are if packed before transportation since the product may not be repacked for longer shelf-life and the transportation time is than part of the extra 10 days provided by MAP. The second one is that MAP takes a lot more space since a large part is air. When packed in CP or EPS boxes the product's bulk density is about 500 kg/m³, but when MA-packed it can be assumed that this number goes down to 200 kg/m³.

When fresh fish product is MA-packed it is very important that the temperature does not exceed 2 °C since when the temperature gets too high, the gas can dissolve and possibly encourage specific microbes to grow (Ólafsson, 1999).



Figure 18. Fresh fillets ready for MA packaging.



Figure 19. One type of MA packaging ready for consumer.

When package has a large size to weight ratio, the package's dimensional weight (bulk density) has to be considered since if the product goes under 200 kg/m^3 airlines charge according to dimensional weight. Since MAP does usually not reach the limit of 200 kg/m^3 it is charged according to true weight of the freight.

6.7 Experimental results

6.7.1 EPS vs. CP

Thermal performance of both EPS and CP wholesale fresh fish boxes has been investigated and compared by Margeirsson et al. (2009a). Packaging contained fresh white fish fillets and challenged by ambient temperature conditions in both real situations and experiments where temperature was simulated to different temperature abuse. Results from temperature mapping of real cold chains were taken into consideration when designing the dynamic temperature conditions in the experiments.

The two different wholesale box types are shown in Figure 15 and Figure 16. The most common sizes are 3 and 5 kg in EPS and 3 or 6 kg in CP. But the boxes are also available in other sizes. The thermal properties of the boxes are presented in Table 8.

Table 8. Thermal properties of wholesale fish boxes (Margeirsson et al., 2009a).

Type	ρ (kg/m ³)	c_p (kJ/kg/K)	k (W/m/K)
EPS	22	1.28 ± 0.05	0.031-0.036
CP	150-270	1.90	0.038-0.045

In the aforementioned study it was shown that expanded polystyrene (EPS) wholesale boxes are more thermally protective, provide better protection against temperature abuse and maintain temperature of the product better than corrugated plastic (CP) wholesale boxes (Margeirsson, Gospavic, Pálsson, Arason and Popov, 2010a; Anyadiiegwu and Archer, 2002; Margeirsson et al, 2010b). The difference in insulation performance of the two packaging types is not as obvious for multiple packages loaded on pallets as for single packages.

When CBC chilling method is not used prior to packaging, ice packs (or other form of additional cooling inside packaging) should be put in the boxes. The worst combination of packaging turned out to be CP boxes without any ice packs. EPS boxes without ice packs showed a little bit better results than CP boxes with ice packs (Margeirsson et al., 2009a).

Figure 20 shows how temperature inside boxes increases more when no ice packs were used inside packaging.

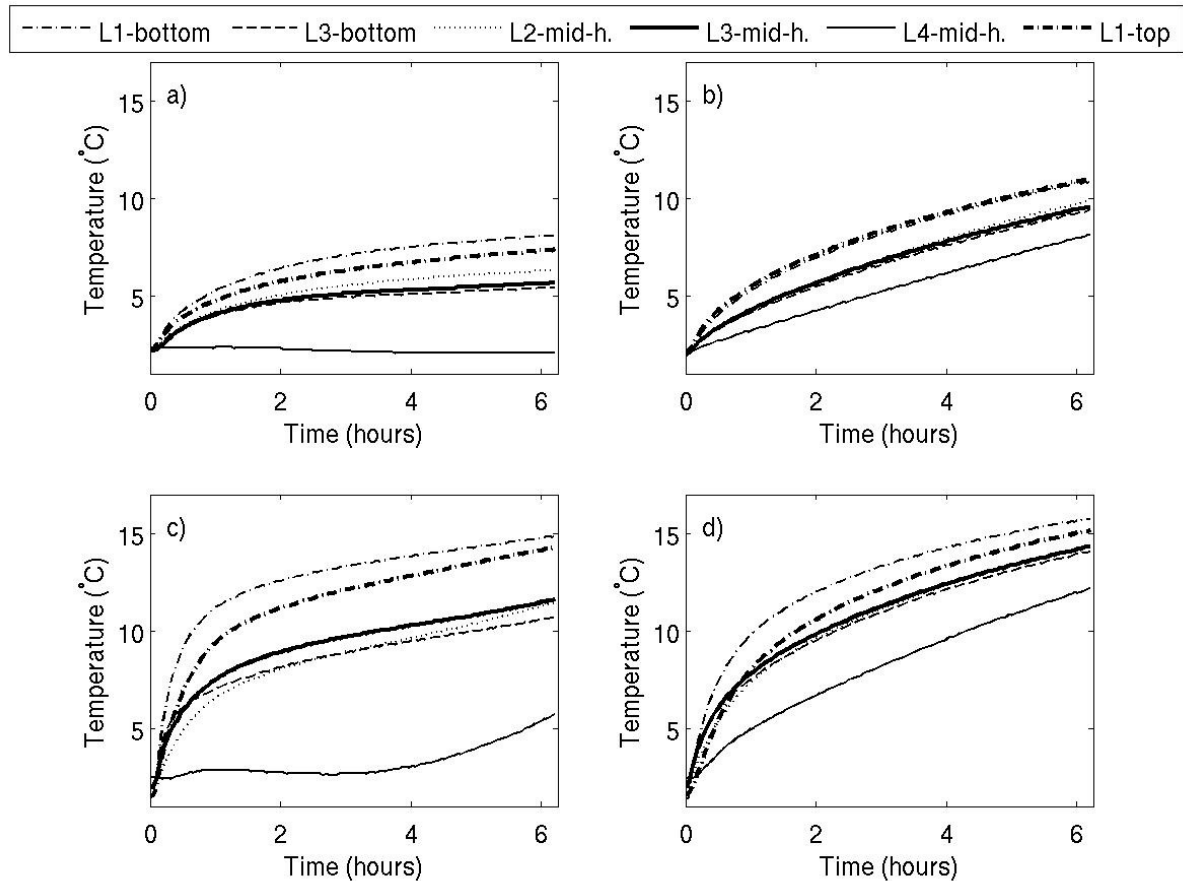


Figure 20. Temperature evolution at different positions inside wholesale boxes containing haddock fillets during 6.20 hours temperature abuse with mean ambient temperature 19.4 °C: a) EPS with ice pack, b) EPS without ice pack, c) CP with ice pack and d) CP without ice pack (Margeirsson et al., 2010a). L1: corner, L2: short side, L3: long side, L4: middle.

Since the CP boxes are less insulating and less protected against temperature abuse, they might suit better for example when the product is in need to be cooled down after packaging and it is ensured that sufficiently low temperature is maintained throughout both storage and transportation.

Experiments (Martinsdóttir et al., 2010; Mai et al., 2010) have shown that temperature is very stable inside ship containers. The critical time in ship transport is the time after packing and until the product is put in the ship and then after the ship arrives. But since the temperature in many chill chains can be quite unreliable, effective pre-cooling before packaging is important. A suitable combination is well pre-cooled product in thermally

insulated EPS box or comparable packaging, especially in air freight chains. In containerized sea borne chill chains the insulation requirements on the packaging are much less and thus more possibilities to use less insulated packaging materials.

In the United Kingdom, usage of EPS and CP boxes as wholesale fresh fish boxes has been estimated at 14 and 0.6 million boxes, respectively (Seafish Industry Authority, 2009) but the ratio between these two box types may change in the future with the environmental and economic reasons in mind. Since the CP packaging is relatively new, more emphasis has been put on investigating thermal insulation of EPS.

When environmental matters such as disposal and recycling are considered the CP boxes are more conveniently designed. They can be flat packaged, which can save valuable storage space and makes recycling or disposal much easier.

Figure 21 and Figure 22 show packaging ready for disposal or recycling. Both pictures are taken from CP box dealer and comparison is therefore not perfectly realistic. However, by comparing the two figures it is obvious that EPS packaging needs more space than CP packaging.



Figure 21. EPS boxes ready for disposal or recycling (Samhentir – kassagerðin ehf, 2010)



Figure 22. CP boxes ready for disposal or recycling (Samhentir – kassagerðin ehf, 2010).

Calculations have also been done on whether size of packaging has effect on how well the product can deal with temperature abuse. The estimated warm up of fresh white fish fillets in a single 3 kg EPS box and a single 5 kg EPS box, respectively is shown in Figure 23.

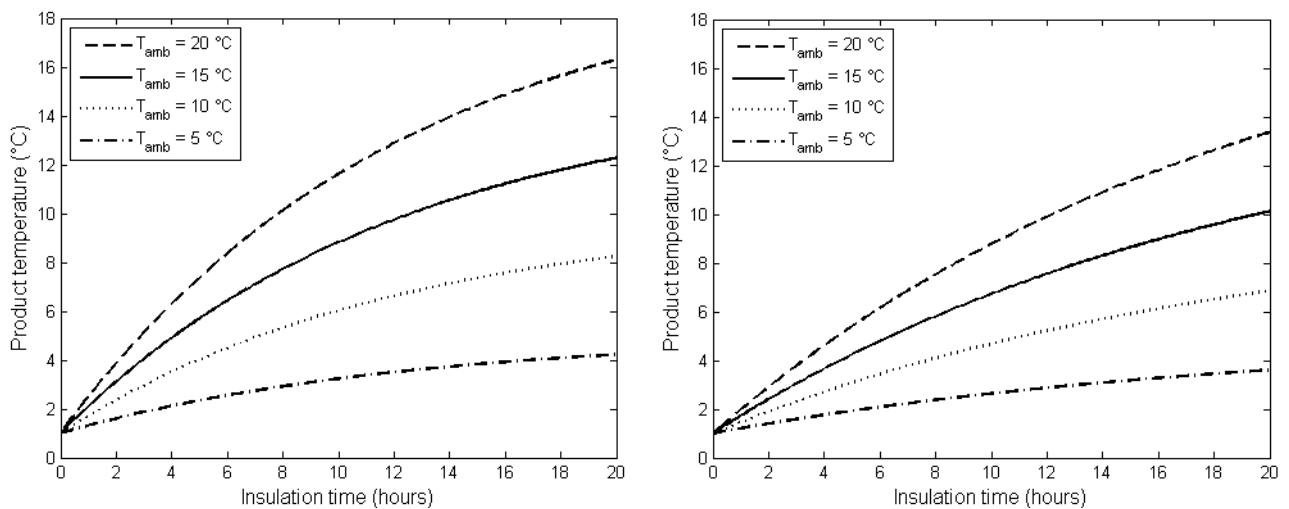


Figure 23. Warm up of 3 kg (left) and 5 kg (right) of fresh white fish fillets in a single 3 and 5 kg EPS boxes. The

initial fillet temperature is assumed to be 1 °C (Margeirsson et al., 2009a).

These figures reveal the importance of minimizing the time that the packaged fish fillets are stored in single packages at as low temperature as 10 °C even though they are packed in well insulated EPS boxes. They also show that fillets in 3 kg EPS boxes are more negatively affected by thermal loads than fillets in 5 kg EPS boxes. If there is risk of

temperature fluctuation for short or long time it is recommended that larger packaging units are used instead of smaller ones.



Figure 24. Comparison of space needed for different packaging. On the left are CP boxes and the right EPS boxes (Eggertsson, 2004).

Figure 24 shows how much more space EPS boxes need than CP boxes. Around 460 kg are packaged in the CP boxes and around 440 kg in the EPS boxes in the figure above.

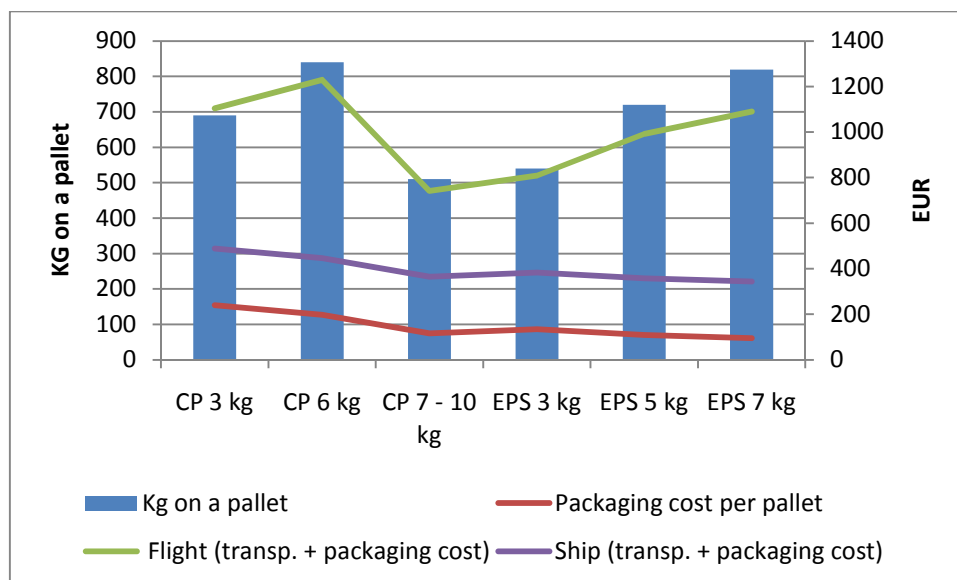


Figure 25. Comparison of amount and price per pallet of different types of packaging.

As Figure 25 shows the cost in transportation with flight is in harmony with quantity since you pay by weight when using flight transport. When shipping by sea you pay for the whole container and one container can take limited number of pallets. If amount of

transported product does not fill a whole container it is possible to pay only for the space used. The most economic packaging choice is 7 kg EPS packaging. Surprisingly, according to information from a few dealers with EPS and CP boxes, it is cheaper to use EPS packaging than CP.

6.7.2 Ice packs

According to Margeirsson et al. (2009a: 17) and Margeirsson et al. (2010a) applying frozen ice packs into wholesale fish boxes made of e.g. CP and EPS is an effective way to protect fresh fish fillets against temperature abuse.

When using specific chilling techniques such as CBC chilling machine it has been shown (Martinsdóttir et al., 2010) that ice packs do not add extra protection against temperature abuse since the product temperature is brought down to -1.0 to -0.5 °C in the CBC cooling process and the ambient temperature normally is very close to the product temperature. This situation only applies in well controlled ship freight.

However, ice packs have been represented as protection against temperature abuse and as mentioned experiments have shown it can help to maintain the product temperature. Therefore buyers often insist that ice packs are used, even though it does not provide any extra protection to the product.

6.7.3 MAP

Fresh fish exported from Iceland is most of the time packaged in EPS or CP boxes. MA packaging is usually done after transportation and as mentioned in chapter 6.6 the shelf-life of the product earns up to extra 10 days just by changing packaging.

In experiment from 2007 (Guðjónsdóttir et al., 2008) conducted by Matís results showed that combined effect of MAP and superchilling of cod loins packed 7 days post catch led to remaining shelf-life (RSL) after packaging of 4 – 8 days. If the product was packed as soon as two days after catch, the sensory analysis showed shelf-life 19 days or up to 21 day after catch. If the product was kept at ambient temperature of -2.0 ± 0.4 °C the product reached maximum shelf-life. These results therefore demonstrate that delaying processing of raw material is undesirable if it is intended to be MA packed and sold as more valuable products.

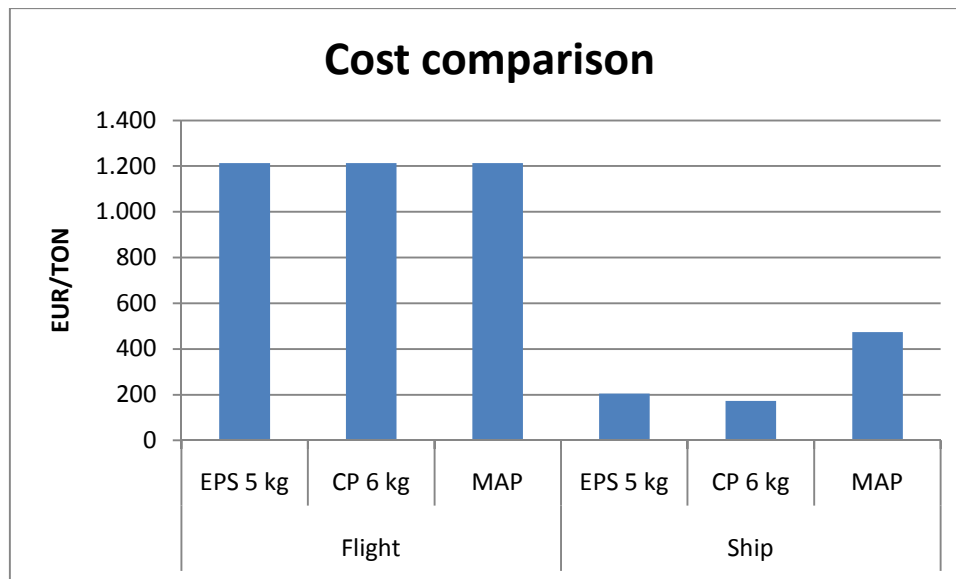


Figure 26. Cost comparison of MAP, EPS and CP boxes in transport.

As mentioned in chapter 6.6 the weight and cubic measure of the MA packaging falls within limits so in air freight, only actual weight of the product should be charged like for EPS and CP boxes. The EPS and CP boxes are also of similar weight so the charge for each kg in air transport is the same for all three types of packaging as Figure 26 shows.

Shipping MA-packed fish is more expensive. In shipping the container can only take limited number of pallets and on one pallet you can stack less amount of product since the packaging takes its space as mentioned in chapter 6.6. If the fish is MA packed, you can stack about 200 kg/m³ but around 500 kg/m³ when packed in EPS or CP.

6.8 Disposal and recycling

6.8.1 ESB directive

The European Commission has issued a directive to amend Directive (94/62/EC) on packaging and packaging waste. The directive aims at preventing or minimising the impact of packaging and packaging waste. Given the differences in costs and benefits for recycling different materials, the directive also contains specific targets for plastics, metals, paper/board and glass. The specific targets will improve the overall level of environmental protection in the EU. The directive was issued in 1994 and no later than 5 years, member states in the European Union should implement it in national law. In article 6 it is stated that between 50 – 65 % of weight of packaging should be recovered. In the same article it is stated that 25 – 45 % of the weight of packaging should be recycled with a minimum of 15 % by weight for each packaging material. This directive applies to UK companies or groups that have total annual turnover of more than £2 million and handle over than 50 tons of packaging per year. Both disposal and recycling is not obligation of the exporter. Retailers take care of recycling and pay the pertaining cost.

6.8.2 Recycling EPS

There are two main options for recycling EPS waste; incineration - yielding energy-recovery, and recycling into other forms such as garden furniture and building insulation. Both require the EPS to be compacted first. For a company with around 25 tons of EPS per year, the payback period for a compacting machine costing around £20,000 can be as short as two years. If the compacted EPS is sold to a recycling company for about £50 per tonne and the costs of disposal to landfill are saved. The price recyclers will pay ranges from around £50 to £80 per tonne (The BPF expanded polystyrene group, 2010).

According to BPF EPS Group website (2010) 8 of 22 recyclers of EPS boxes agree to recycle or recover uncompacted boxes. Usually the recyclers insist that the boxes are clean. That means in almost all cases retailers are demanded to at least clean the boxes and preferably compact them.

6.8.3 Recycling CP

The easiest plastics to recycle are those which, like polypropylene, are from the polyolefin family. The material is simply granulated and reprocessed. There is a ready market for the recycled material. The re-processed granules can be re-extruded into fluted polypropylene, but as this cannot be of white colour it has numerous other applications in construction and horticulture for example (Tri Pack, 2010).

6.8.4 Disposal of raw material

A lot of food ends up as waste. Food waste can have a dramatically varied impact, depending on the amount produced and how it is dealt with; in some countries the amount of food waste is negligible and has little impact. In countries such as the US and the UK however, the social, economic and environmental impact of food wastage is enormous. In UK alone, 6.7 million tons per year of wasted food (purchased and edible food which is discarded) amounts to a cost of £10.2 billion each year (Wikipedia, 2010a). According to WRAP (Waste & Resources Action Programme) (2007), one third of all the food people buy ends up as waste.

The food industry produces large amounts of food waste, with retailers alone generating 1.600.000 tons of food waste per year. Supermarkets particularly have been criticised for wasting items which are damaged or unsold, but that often remain edible. However exact statistics for the amount of food wasted by supermarkets is mostly unavailable.

In 2007 the UK government started the campaign “War on waste”, a programme aimed at reducing Britain’s food waste. In June 2009 it was announced that the project had already showed some success and had prevented 137.000 tons of waste that made savings of £300 million (Wikipedia, 2010b).

Exporters do not carry cost of waste of their product except when the product does not fulfil pre-labelled freshness time. But by using new techniques in processing, packaging that protect from temperature abuse and transportation with sufficient temperature control it increases freshness time of the product which should lead to less waste, both in supermarkets and by the consumer. These factors mentioned also encourage the price to remain high and the product is labelled as first class product.

7 Transportation

Transportation is a large part of the product life cycle when exporting fresh products from Iceland. Three methods are mainly used. That is by air freight, by sea freight and by road freight. Experiments (Mai et al., 2010; Martinsdóttir et al., 2010) have been done by Matís for road, air and sea transportation. When exporting from Iceland road transportation is used to get to the airport or harbour and when the factory is far away from the international departure facility.

Based on information from Statistics Iceland (2010), about 40 % of exported fresh fish goes to Britain. Most of exported fresh fish goes to EES countries or up to 80 % of total value.

7.1 Transport post processing

When transportation method is chosen both cost and time are big factors influencing the selection. With better technology to increase shelf-life and new results from experiments it gives more diverseness when choosing the most suitable transportation method.

A few years back air freight became much more popular than before and exporters used air freight instead of shipping freight. Air freight has the advantage over shipping that it takes less time and the product is soon on the market.

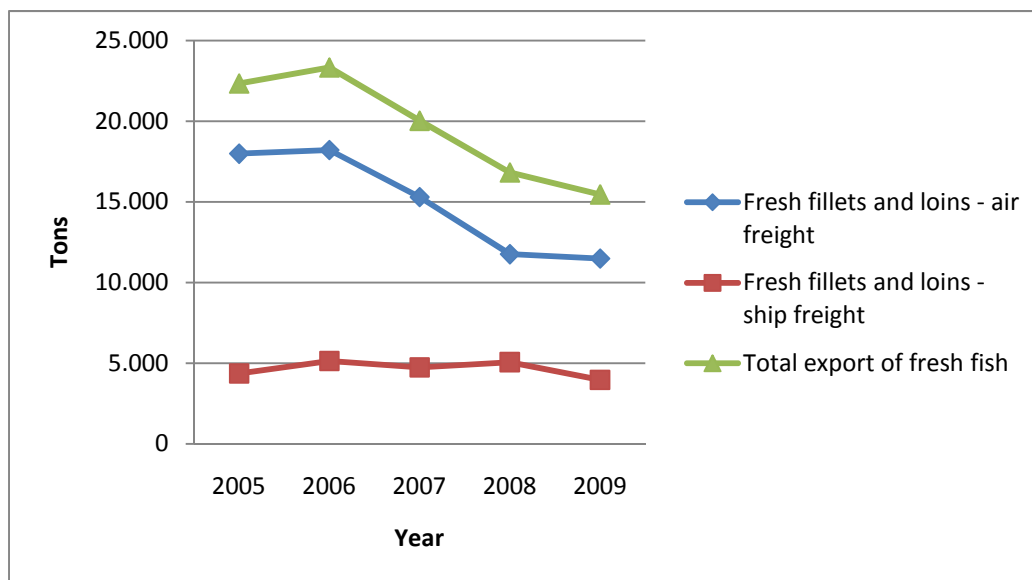


Figure 27. Quantity of export of fresh fish in 2005 – 2009 (Statistics Iceland, 2010).

As Figure 27 shows total quantity of exported fresh fish products has been decreasing the last 4 years. The figure shows obviously how the reduction in quantity is all on cost of air freight while ship freight is almost constant.

It is recommended that the temperature of the product should always be checked before transportation. Both the manufacturer and the transportation company should place emphasis on keeping the air temperature between -2 °C and 4 °C during the transportation process when the distance and/or time is short. When travelling long distance or long time it is recommended to keep the temperature between -2 °C and 0 °C. Those temperature intervals are considered optimal for superchilled fresh fish products.

When container is used for transportation the air temperature in the container should be monitored. The most sensitive location for the product is usually in the back of the container close to the roof since the cooling unit is usually located in the front of the container. The storage room (container, storage, freight etc.) should also not be overloaded.

If the product is supposed to be transported in a container for short distance and the environmental conditions are stable and ambient temperature close to 0 °C it is an option to consider the use of insulated container (without cooling unit). That could for example be the case when domestic transportation is needed during the winter.

7.1.1 Temperature loggers

Temperature both inside and outside of packages has been explored. At least eight loggings have been done to monitor temperature abuse during transportation, both by air and by sea. The purpose of those experiments was to monitor the temperature throughout the transportation phase and to explore temperature abuse during transportation.

Figure 28 shows pictures of the data loggers used in Matís's trials, e.g. in Martinsdottir et al. (2010).



Figure 28. DS1922L temperature data logger on the left and UTBI-001 temperature data logger on the right.

7.2 Experiments

As mentioned above experiments for both air and sea transportation have been done by Mátis. The loggers in Figure 28 are usually put inside and/or outside the packaging before sea or air transportation. In these experiments the methods are different, part of the product transported multimodal. In the experiments processing methods are different and packaging and cooling in packaging also. Storage time in each experiment differs and the transportation time is not always the same.

The purpose of these experiments was to explore temperature abuse during the whole transportation process and see if the temperature was fluctuating and if so, how great the fluctuations were. The aim of the experiments was also to find out if the product was in potential risk of damage during the transportation process.

However, there is still only one scientific publication (Mai et al., 2010) on the temperature mapping and comparison for a real supply chain of fresh cod loins or haddock fillets from processing to market by air and sea transportation and gives opportunity for more studies to confirm Mai's results.

7.3 Domestic transport

Road transport is the most common transfer method for domestic transportation. Since the amount is usually in tons it is both more convenient and less expensive to load a container or truck for transport. When the product is put into a container it requires not so much handling of the product and the product that goes further with ship can stay in the same container until destination.

7.4 Sea transport

The experiments (Mai et al., 2010; Martinsdóttir et al., 2010) cited to in this chapter contain data from trials executed in September and October 2008 and February 2009, in total four experiments. In all experiments product was transported by truck to harbour, then with ship to harbour in England or Central Europe and then again with truck to destination.

Usually the product is packed into wholesale fish boxes, made of e.g. EPS or CP, then on a palette and finally palettes are put into a container.

Three types of containers are available, normal containers, insulated containers and temperature controlled containers. In temperature controlled containers the working temperature ranges from -30 °C to +25 °C [reefer containers]. Usually whole container is used for exporting fresh fish. If the amount does not fill container it is an option to buy a part of container for transport.

In the experiments mentioned above temperature controlled containers were used in all cases.

The regular process after packaging when transported with ship is usually the following:

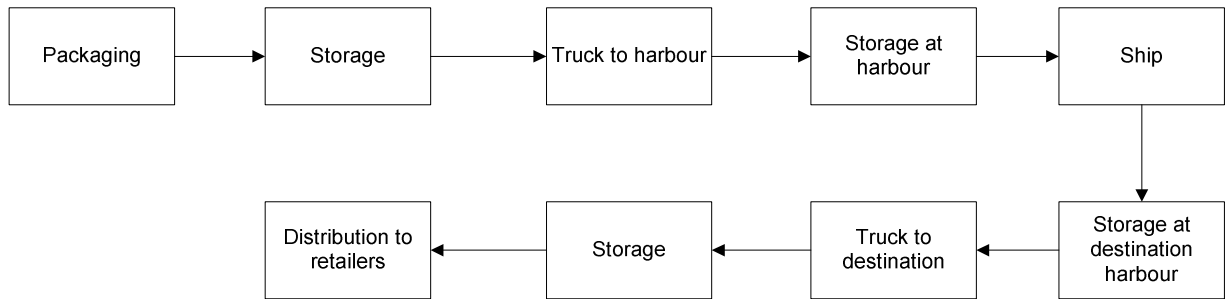


Figure 29. Common implementation of the process when ship is used for transportation.

Between steps are loading and unloading of trucks and ship. There can also be extra or less of storages during the process. The product is stored in the container during travelling.

Air temperature should be kept between -2°C and 0°C for optimal storage of superchilled fish products. The superchilled storage conditions during sea transport are in general more important than during road transport since, normally, sea transport lasts longer (Mai et al., 2010).

The big advantage that sea freight has compared to air freight is continuity in the transport, i.e. the chain has few and relatively secure handover points regarding temperature control. Containers (refrigerated and non-refrigerated) are multimodal equipment, which generally allow goods to be switched between land and sea transport without the need of breaking up the cargo.

7.5 Air transport

As mentioned in chapter 7.1 there are times in the recent years where use of airplanes for fresh fish transport has been the most common transportation method. Flight is much faster freight than by ship and the product is sooner on the market.

The regular process when air transport is used is normally the following:

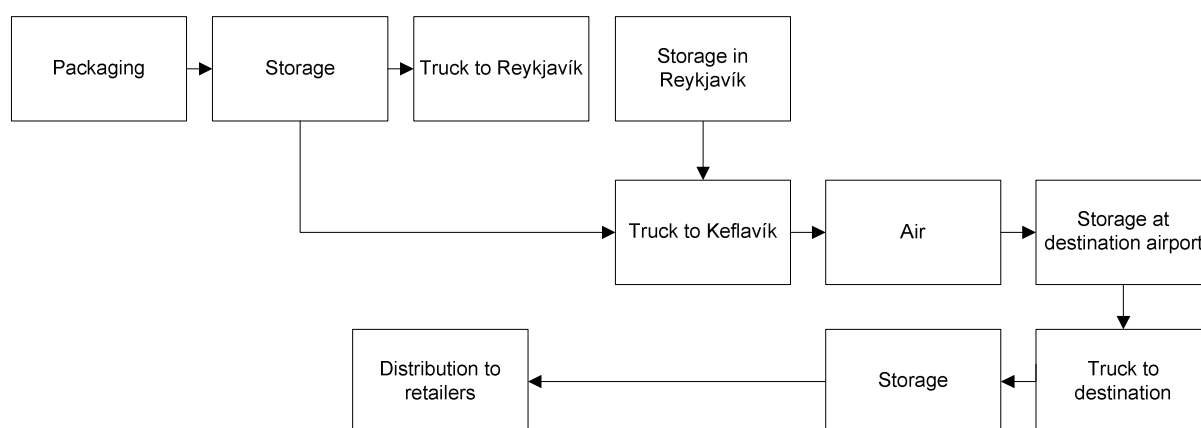


Figure 30. Common implementation of the process when air freight is used for transportation.

Between the above mentioned steps are both loading and unloading of trucks and airplanes. There can also be extra or less of storages during the process. The product is not as isolated as in container, there is more direct handling, usually more storages and the product is stored on palettes which are free standing (not in a container). And in passenger planes the palettes are often broken up (Margeirsson et al., 2010).

As mentioned in chapter 0 it is recommended to apply pre-cooling before packaging as one step of the processing. Fish products packaged at -0.5°C simply can take more temperature abuse than products at 4°C when packaged. Packages should also be well insulated and packed densely.

7.6 Results from experiments

7.6.1 Ship freight

Experiments have shown that temperature is very stable inside refrigerated containers. The critical time when shipping product is until the product is put in the ship and then after the ship arrives in destination harbour, where the product usually travels by truck to final destination.

It experiments in September 2008 (Mai et al., 2010) and experiment from February 2009 (Martinsdóttir et al., 2010) results showed that the temperature of the product inside the boxes were very stable compared to air transportation. Large reason for that is because in

the sea freight chain the boxes are kept in a refrigerated container for the whole trip from processor to the final destination. Therefore travelling time should not lead to additional decrease in shelf-life since the risk of temperature abuse is quite low.

In the experiments ice was put in on top of some of the fillets when packed into the EPS boxes to compare whether ice packs were really needed.

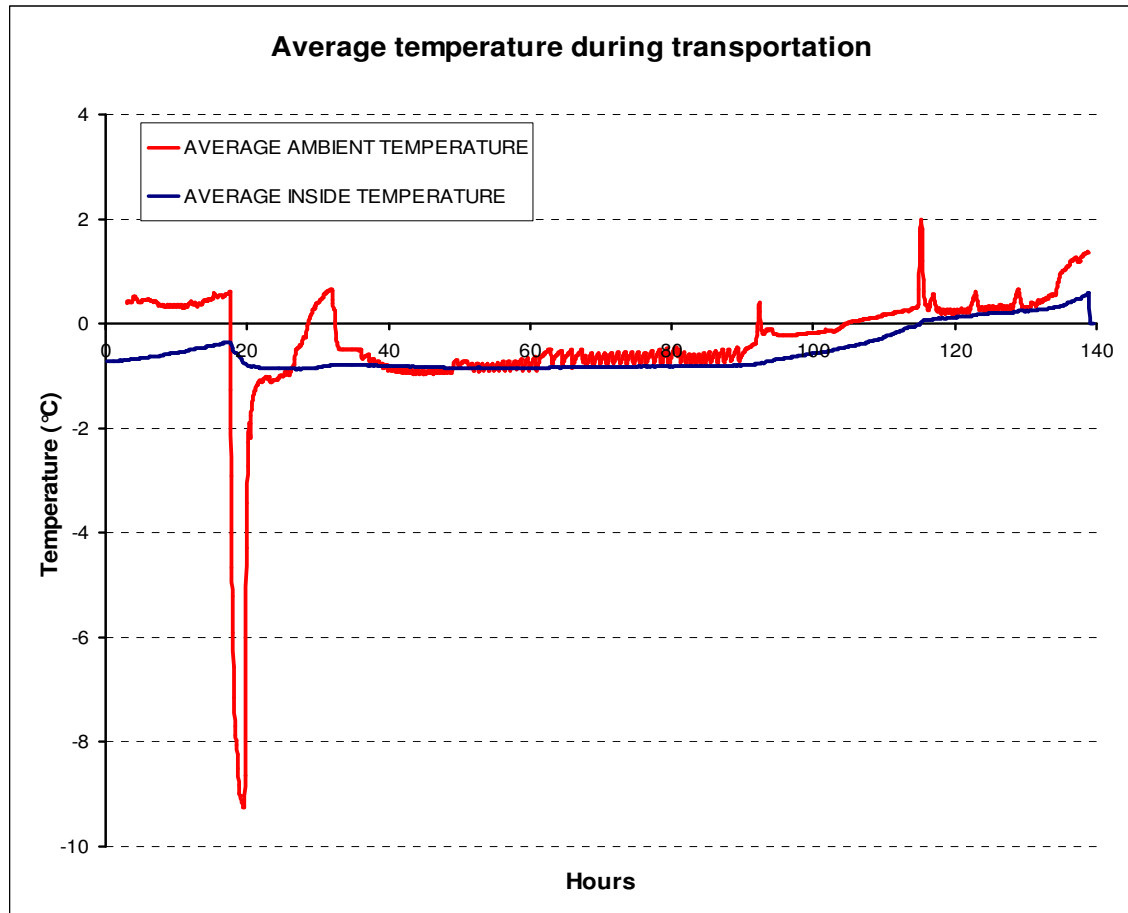


Figure 31. Average ambient and inside temperature during transportation in ship (Martinsdóttir et al., 2010).

Figure 31 shows how steady temperature is during ship transportation. Ambient temperature is optimal most part of the transportation time and has therefore a very small negative influence on the temperature of the product. In the end, the travel from destination harbour to final destination, both ambient and inside temperature increase about one to two degrees. The temperature is though within optimal temperature limits (-2 °C to 0 °C) very large part of the transporting time. Mai et al. (2010) showed the same results in their experiments for ship transportation.

Based on this figure and other results it can be concluded that shipment does not affect or damage benefits (e.g. longer shelf-life) earned by cooling right after catch, using CBC chilling machine in processing or the use of properly chilled storage.

7.6.2 Air freight

The transportation of perishable products such as fresh fish is common by air as it is very fast. However, during loading, unloading, truck and air transportation, storage and holding the product is normally subject to temperature abuse, which means that considerable part of its journey is un-protected.

Experiments have shown that the product is at some risk of temperature abuse during the transportation process. The reason is lot of handling with the product and more steps during travelling. Storages are sometimes non-chilled and when product is stored for long time in non-chilled storage it can affect the product greatly by increasing temperature in the product itself (Martinsdóttir et al., 2010; Magnússon et al., 2009).

Recent experiments (Mai et al., 2010; Martinsdóttir et al., 2010) confirm that there are certain critical points which can be improved regarding the temperature control in the supply chain from Iceland to the UK and central Europe. Cooling the product below 0 °C without freezing is important to ensure the highest quality of the fresh product and to make the product less sensitive to temperature fluctuations during transportation and storage.

In contrast, high fluctuation of ambient temperature causes a very large variability of inside temperature, especially for boxes with many free sides such as bottom and top corner boxes (Mai et al., 2010; Martinsdóttir et al., 2010).

Due to the insulation of the packages and surrounding boxes, it is very difficult to cool down the product after packaging. A good solution would be to use some superchilling technique, for example a CBC cooling system or slurry ice, to chill the product before packing. In the experiments in July 2008 (passenger flight) and September 2008 (sea freight), product was pre-chilled by CBC chilling machine. Therefore its initial temperature (-0.6 to 0.6 °C) was much lower than in the other two air freights where the initial temperature was as high as 5.5 °C (Mai et al., 2010).

However, long shipment time causes a relatively short remaining shelf-life of product in sea freight. This indicates that the trade off between transportation modes would need to be based on several aspects such as quality and safety, available time to reach market, as well as differential costing of transport (air versus ship), and the resulting environmental impact for the different options (Mai et al., 2010).

Figure 32 shows remaining of shelf-life (RSL) after transportation. Length of total shelf-life is based on processing method used and handling and storing of the product during catching, processing and packaging.

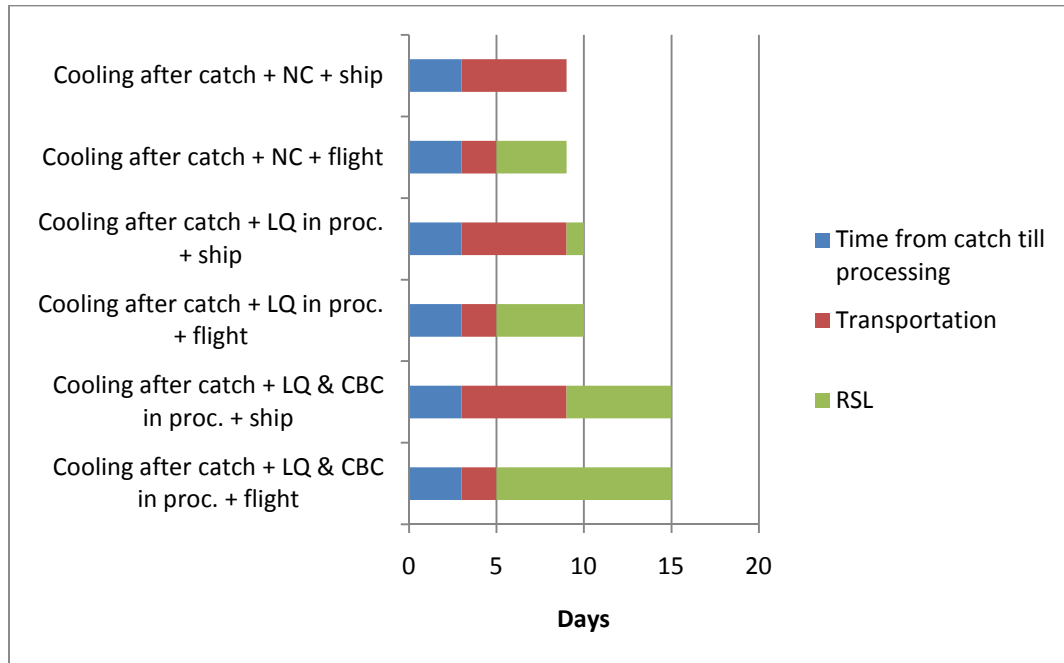


Figure 32. Comparison of remaining shelf-life (RSL) after transportation.

Sea transport takes about 5 days whereas flight transport often takes only about 2 days. Therefore transportation is a large part of the shelf-life when the product is shipped. And as can be seen on the above figure there is no time left if the product is not properly chilled in processing. It depends on buyers whether they accept the product as high class product, with such a few days left in shelf-life. As mentioned before, when CBC chilling method is used shelf-life increases for a few days, even up to 10 days are left after transportation if the product is transported by airplane. When the product reaches destination it takes often up to two days until the product has landed in retail stores or supermarkets.

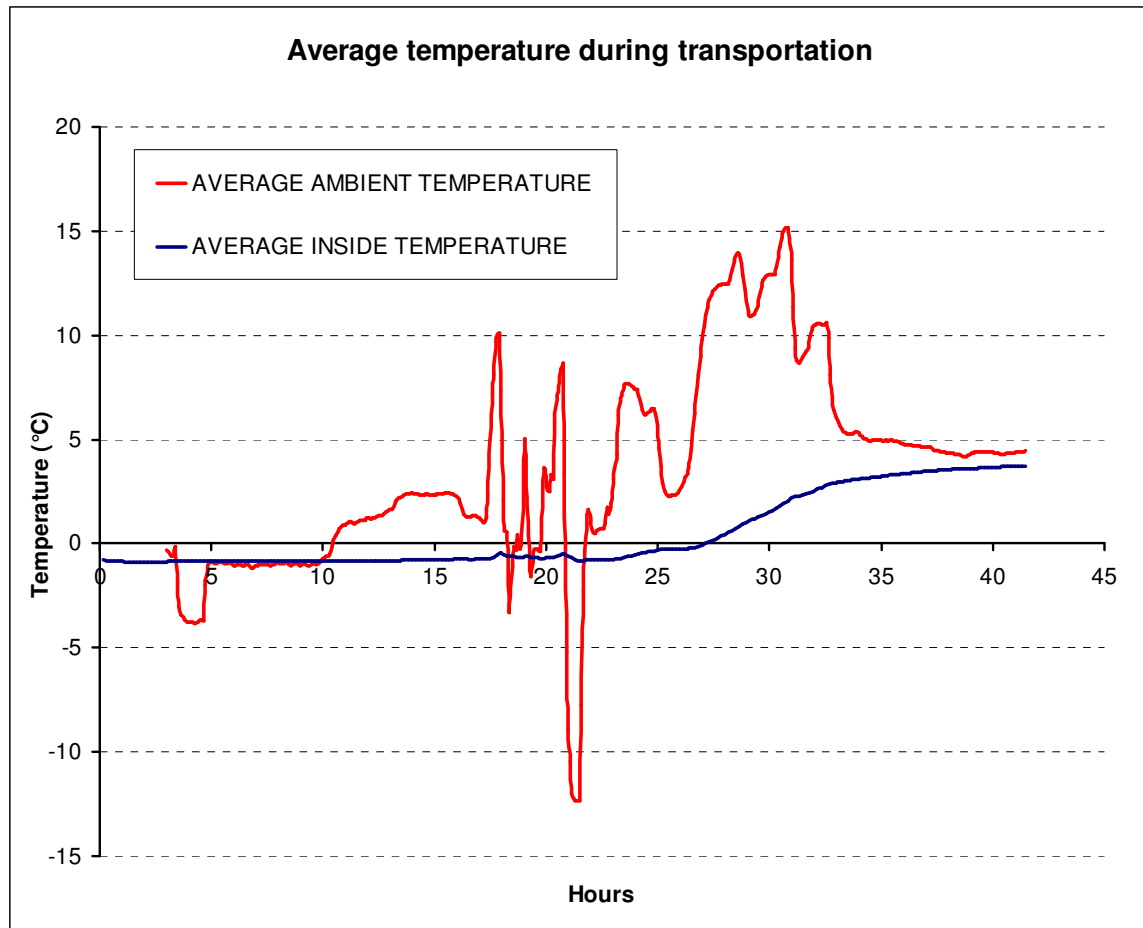


Figure 33. Ambient temperature in air freight (Martinsdóttir et al., 2010).

The packaging and travelling process took about 44 hours in the experiment done in February 2009. Figure 33 shows ambient air temperature fluctuating as inside temperature increases constantly. Changes in ambient air temperature for short time period does not appear to affect the product temperature dramatically but as ambient air temperature remains high for longer time, the product temperature increases more noticeably. When ambient air temperature drops again (after approx. 33 hours), the product temperature does not decrease since the ambient air temperature is still higher than the temperature inside the packaging.

As Figure 33 shows the time interval between hours 27 and 31 the average ambient temperature is above 10 °C. During that same time interval, average inside temperature rises by about 2.3 °C. In experiment from November 2003 group 2 suffered from temperature abuse on third day after processing and was kept in room with temperature of 16 °C for 16 hours. That caused three days in shelf-life decrease. Even though situations on Figure 33 do not present such dramatic temperature abuse it is likely that those four hours can have critical consequences on the length of shelf-life.

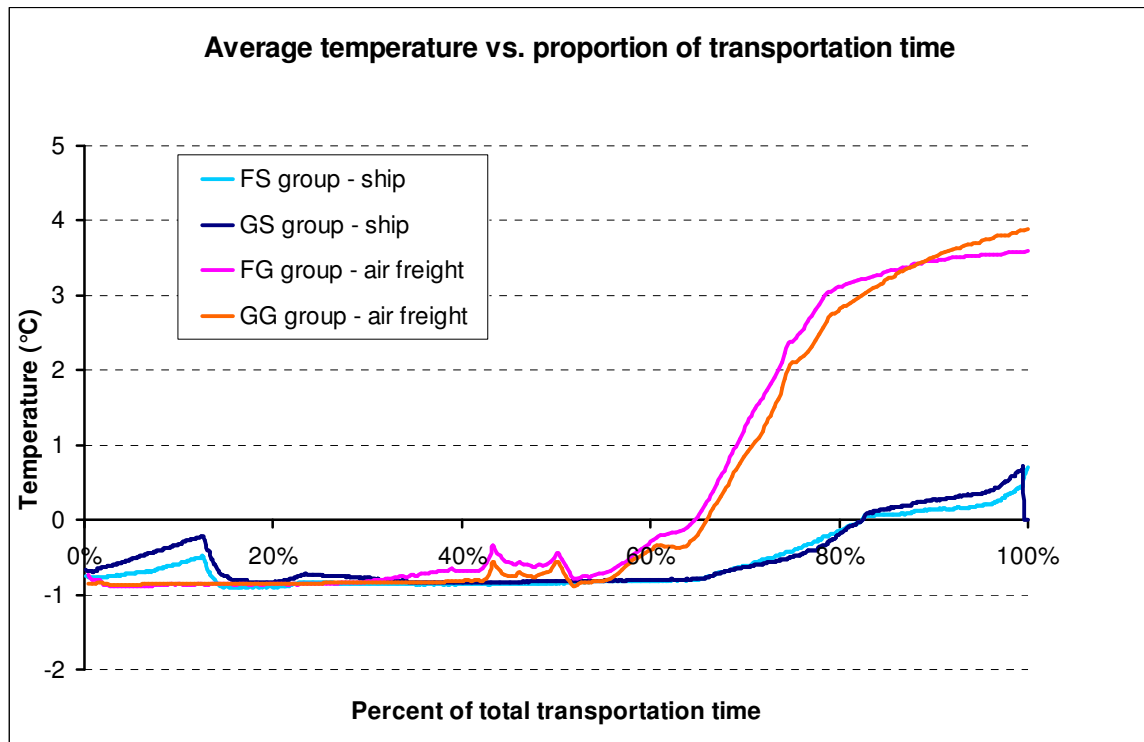


Figure 34. Comparison of average inside temperature in flight and shipping (Martinsdóttir et al., 2010.)

The groups named FS and FG contained icepacks as extra chilling inside the box. Groups GS and GG did not contain icepacks. As mentioned in chapter 6.7.2 and is obvious in this figure is that there is hardly any difference between product with ice packs or without when packed in EPS boxes.

Figure 34 also shows how temperature develops throughout the transportation process. As can be seen temperature rises earlier in the air freight process and the temperature of the product starts fluctuating after about 42 % of total transportation time and has reaches above zero degrees after about 64 % of the time. By ship, temperature of the product starts rising after about 66 % of total transportation time and reaches zero after 81 % of the time. At the end of the process, average temperature inside boxes is 3 degrees lower when transferred by ship than by air freight.

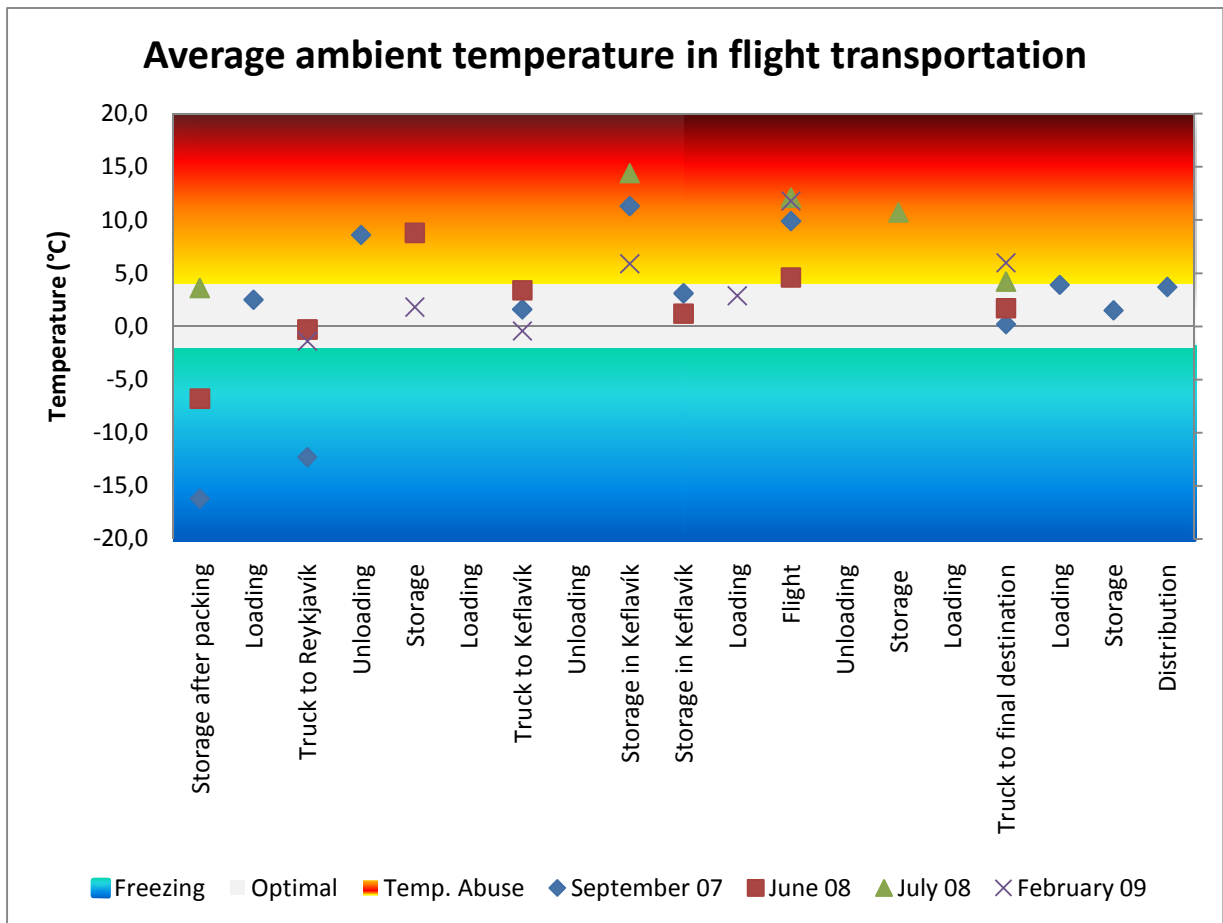


Figure 35. Average ambient temperature in flight transportation..

Figure 35 shows results from total of four experiments in flight. Every dot on the graph shows average ambient temperature in specific place or process. The grey area stands for optimal temperature interval during flight or -2 to 4 °C. Blue means that the product is at risk of freezing and the yellow and red area shows where the product suffers from temperature abuse because of high ambient temperature. According to Figure 35, the most risk is when loading and unloading, during flight and when product is kept in storage. The average temperature reaches up to 15 °C. As stated in Table 2 in chapter 5.5, a product that was moved to room temperature (18 – 20 °C) for 16 hours decreased its shelf-life for 3 days. When product suffers from temperature abuse over and over before it reaches supermarket or consumer it can be assumed that the product loses even more of its original defined shelf-life. That can have great impact both on sales price and goodwill in business. As mentioned in chapter 2.1.1, loss of revenues of dropping down to second class product can vary from €1 to €4 per kg.

Figure 36 shows temperature intervals during transportation. All measures are done by loggers placed outside the boxes and measure the ambient temperature.

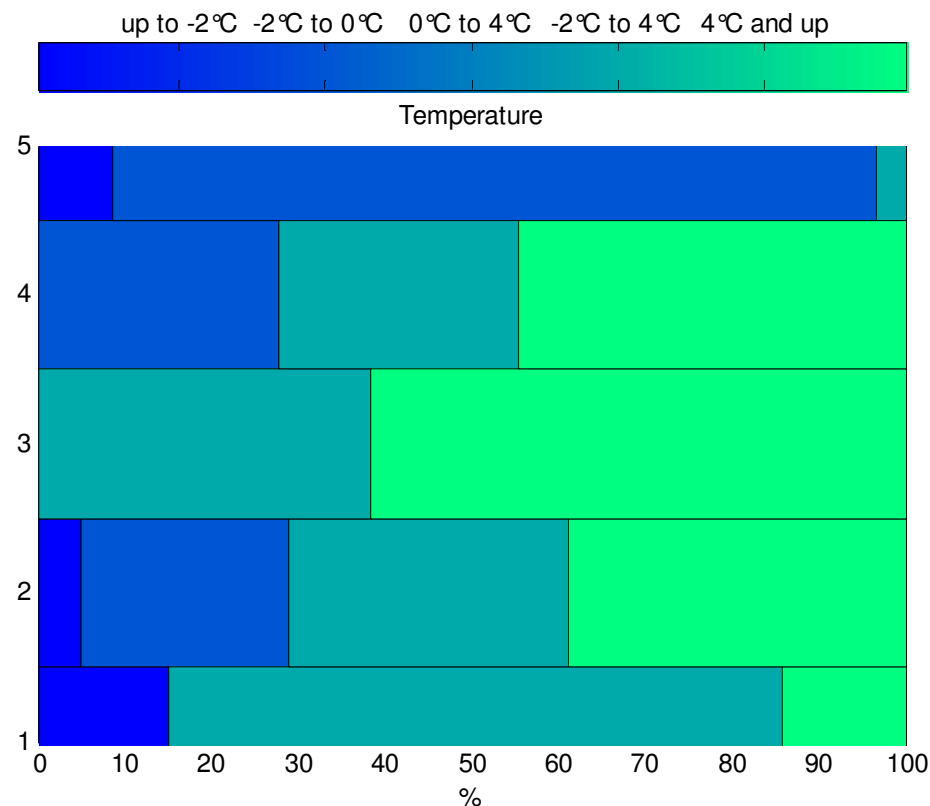


Figure 36. Temperature intervals during transportation.

During flight and short distances it is recommended that temperature should be no lower than -2°C and no higher than 4°C . During ship transportation the temperature should be held between -2°C and 0°C since the travelling time is very long and both stable and low temperature are very important for the quality of the product. In Figure 36 trials 1 to 4 show results from measurements in air transportation. Trial 5 is from sea transport in February 2009. The flight experiments were done in September 2007, June and July 2008 and February 2009. Results show that the temperature during flight outside recommended temperature limits (-2°C and 4°C) is up to 70 % of the total time. And the temperature is up to 61 % of the time over 4°C . Results from the sea experiment show that the temperature is within limits (-2°C to 0°C) in 88 % of the time.

Mai et al. (2010) refer to resources where total abusing time during flight transportation was 14.5 hours (ambient temperature $> 5^{\circ}\text{C}$), which was 36.1 % of the total logistics time from producer to final destination. Results from experiments therefore confirm over and over that perishable food faces un-refrigerated temperature for large part of its voyage.

A few tips to minimize this temperature abuse is to ship the products as late as possible to the airport, protect the product from both sun and rain and try to select direct flight as that cuts down number of stops or storage time.

7.7 Cost

When the advantages and disadvantages of effect on the product when different transportation methods are chosen and cost considered, ship transportation can be considered as low-cost method while air transportation is much more expensive.

Based on cost information from logistic companies both in the sea and air transport industry, the following figure shows difference in cost per ton transported with each method.

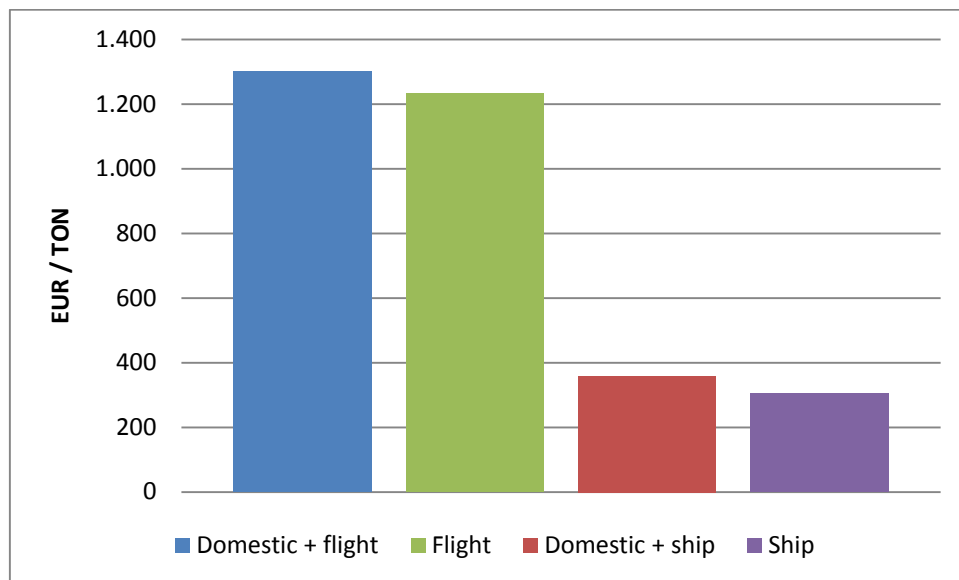


Figure 37. Cost difference in different transportation methods.

Figure 37 shows about four times cost difference between air and ship (assumed 40 feet container is used and around 12 – 14 tons are transported in freight). Domestic in this case means that the processing and packing was done outside the capital Reykjavík. Truck from Reykjavík to airport at Keflavík is included, and also a local truck trip is included when exporter is located in the capital area. Exact results show that when the manufacturer is outside Reykjavík and decides to use flight the cost is around €1,300 per ton. When the product is transferred from the capital area to the airport in Keflavík the cost is a little bit lower or around €1,200 per ton. When ship transport is chosen the cost is around €360 per ton with domestic transport and around €300 per ton with local transport (short distance).

Figure 38 shows accumulated cost difference for 10 years if only flight or only ship is used for transportation. As early as in the first year the gap increases greatly. The cost difference per year can be as much as €2.4 million per year (based on average of 10 tons through processing every working day, total of 240 working days).

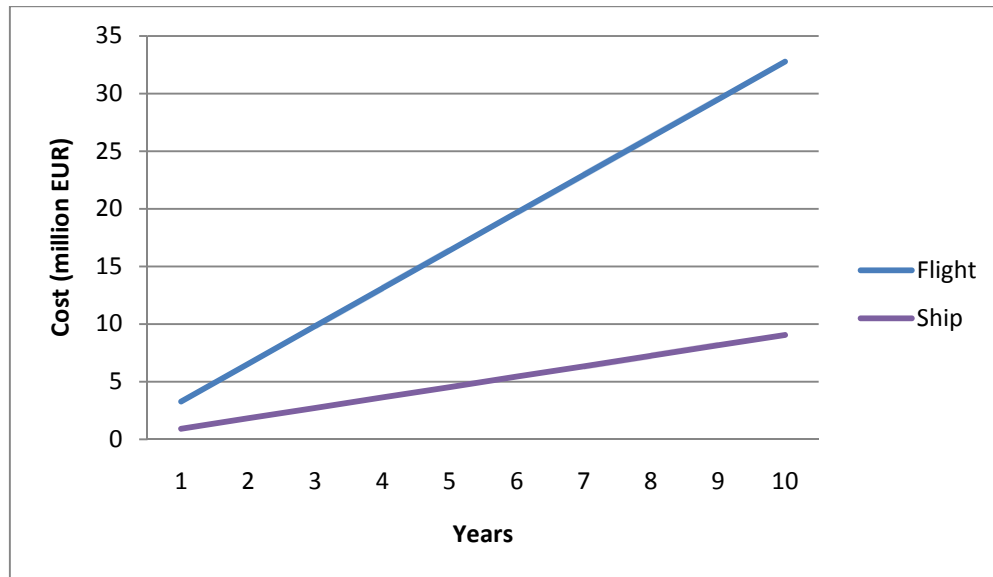


Figure 38. Accumulated transportation cost for 10 years.

7.8 Carbon footprint

Carbon footprint of sea, air and road transportation has been examined and calculated (Pablo, 2007). Of these three transportation modes, air transportation scores much higher in footprint than the others. Sea transportation is the lowest.

To find carbon footprint ton-kilometre is calculated. It is measured on the product of the transported mass in tons and the related distance performance and actually provided transport.

Figure 39 shows comparison between common journeys for exported fresh fish fillets.

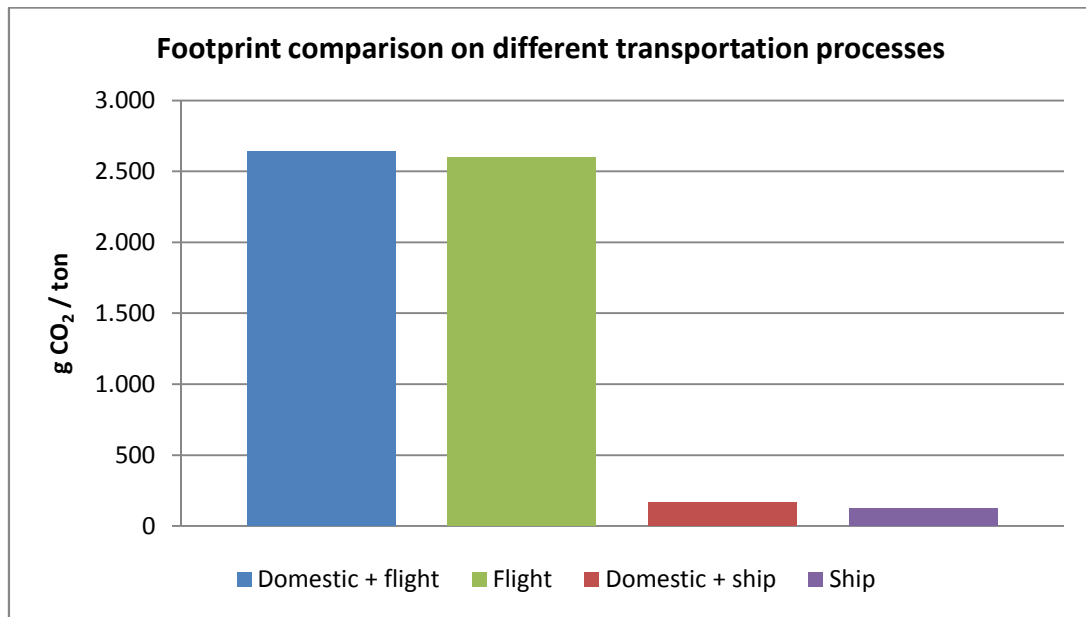


Figure 39. Comparison of total gCO₂/ton in different transportation journeys.

For one kilogram of good transferred 1 kilometre 0.1 g CO₂ is released into the air when transported by truck. When transported with airplane it is 1.3 g CO₂ and with ship it is 0.06 g CO₂. As stated above air transportation creates much more carbon footprints than ship, or 20 times more.

Some articles (Heap, 2010) argue that food mile is oversimplified assessment since there is no relation to leakage rates or energy efficiency, and use of food mile should therefore be avoided.

7.9 Location

The figure below shows cod catch per sea mile (ton/sea mile²) in the year 2007. The figure also shows where most valuable catching grounds of cod lie around Iceland. The most valuable sources are north of the Westfjords, close to Snæfellsnes, out of Reykjanesskagi and Lónsdjúp. Though these are the most generous areas cod can be caught around all of Iceland.

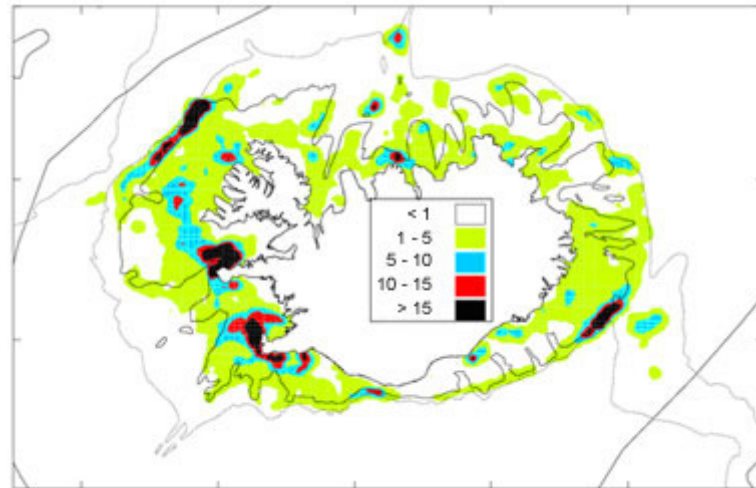


Figure 40. Cod catch per sea mile (ton/sea mile²) 2007 (Sigurðsson and Þórðarson, 2009).

Location of manufacturers can affect both the price and the shelf-life of the product. For example the transportation time is up to 2 days shorter for product exported from Vestmannaeyjar or Reyðarfjörður than from Ísafjörður or Dalvík. As seen in Figure 40, the cod catch is different between areas. Manufacturers are thus not only misfortune with the location since the catch can be returned to land earlier than otherwise. It would for example take long time to ship product from north-west of Iceland to Vestmannaeyjar. Figure 41 shows sailing schedule for one logistic company sailing two times per week from Reykjavík. When shipping from Iceland ship has two outgoing stops. Both Eimskip and Samskip sail through Vestmannaeyjar once a week and Reyðarfjörður once a week.

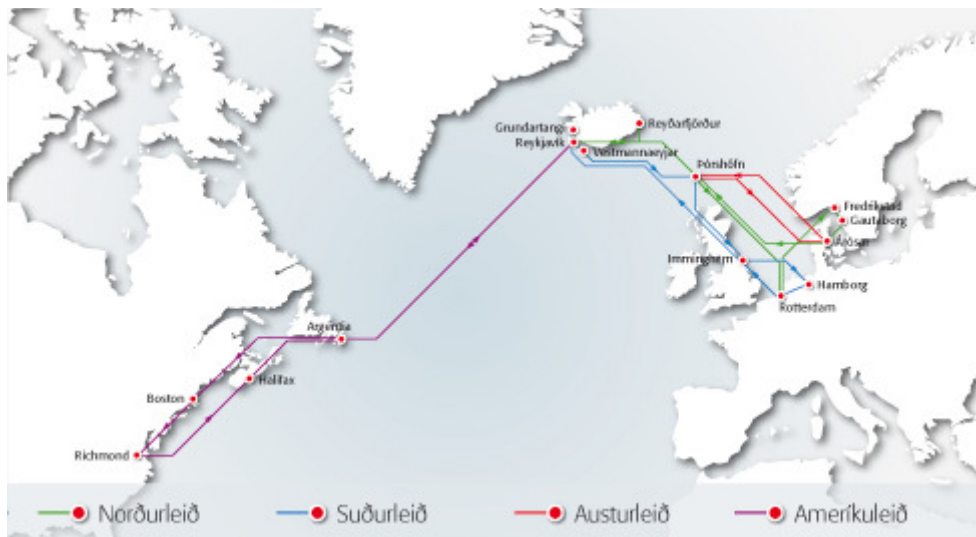


Figure 41. Sailing schedule for Eimskip.

8 Investments

8.1 Cooling equipment on board

8.1.1 Inputs and assumptions

Capital investment

The aim of this chapter is to make an economic analysis of cost factors for different cooling equipment on board, such as liquid ice system, fluid ice system and multi ice system. Additionally purchasing of crushed plate ice from retailer is possible. One cooling machine was chosen as representative for each technique available on the market. Outcome of this analysis should help for decision making in capital investment in cooling equipment used to improve and/or sustain quality and shelf-life of the product.

Table 9. Characteristics of three different liquid or slurry ice systems.

Machine	Production range	Ice concentration	Power consumption	Price
Optimar BP – 110 (liquid ice system)	460 L/h to 1120 L/h	40 % to 10 %	17 kW	€54,000
Skaginn FIS 110 (fluid ice system)	1250 L/h	30 %	65 kW	€160,000
STG MI 1060 (multi ice system)	650 L/h to 2600 L/h	40 % to 10 %	18 kW	€58,000

As mentioned in chapter 4 crushed plate ice can be used alone or to re-ice after 24 hours in liquid or slurry ice. When crushed plate ice (CPI) is used for cooling it can be bought from retailer at harbour before the ship goes out to sea. No capital investment is made for CPI. The price of crushed plate ice is based on price per each kilogram and is 2.8 ISK/kg or €0.018/kg. When ice is bought at the harbour and sailed out to sea it is estimated that 10% of it will melt before being used for cooling. It should be noted that the melting rate depends heavily on the ambient temperature and the insulation of the ship's hold.

In Icelandic regulations about handling, processing and distribution of fish catch and fish products (1999) it is stated that all fresh fish products should be kept in temperature equivalent to the melting point of ice. Manufacturers also know of possible risk of decrease in quality of the product when the raw material is not properly cooled or stored on board. Therefore all bigger manufacturers and ships cool the product on board.

Revenues

By using special cooling equipment on board manufacturers are doing their best to sustain the quality and shelf-life of the product. As mentioned earlier, proper cooling before processing is important for the future shape of fully processed product. Results from experiments do not show exact information on how much chilling on board brings the raw material in additional shelf-life. On the other hand it has been shown that appropriate chilling in the beginning is critical and can have great influence on the length in shelf-life. In chapter 5.5 experiments show one additional day in shelf-life when liquid cooling equipment is used in processing. In chapter 5.5.1 increase of one day in shelf-life is estimated as €0.2/kg. In the beginning it is assumed that the benefits of using liquid icing on board bring the product at least €0.2/kg of fully processed product. Since the product is not processed when cooled down on board and yield is about 55 %, the value for cooling system is €0.1/kg. Still, a large uncertainty is in the added value when the product is chilled and the added value is most likely different between different products. Without thorough experiment of the whole chain it is unknown how much temperature abuse in later stages of the process can spoil the benefits of cooling down the product in the beginning.

Operation cost

Energy cost is the biggest operational cost factor of an ice system. Energy cost is also an uncertainty factor due to changes in oil price and currency fluctuation.

Energy cost is based on how much ice is needed. Ice need is dependent of power consumption, ice concentration, oil price and the amount of product to be chilled.

When ice system is in use it is not expected to cut down salary costs, but it relieves work load on the employees and therefore increase the productivity of each employee.

To facilitate comparison for the three ice systems chosen, calculation for operation cost is based on flow of 20 tons of raw material per day, 20 days of the month, or in total 400 tons per month.

Table 10. Overview of operation cost of different cooling techniques.

Machine	Ice concentration	kg ice / kg fish	cost / kg
Optimar BP – 110 (liquid ice)	40 %	0.44	€0.013
Skaginn FIS 110 (fluid ice)	30 %	0.59	€0.009
STG MI 1060	40 %	0.44	€0.018
Crushed plate ice	100 %	0.18	-

Salvage value

Salvage value of the investments is estimated as zero after 10 years of average operational time.

Rate of return

Rate of return is determined by how the investment is financed. Rate of return used in this project is 11 %.

Service life

Average service lifetime is also around 10 years when the ice system is in use on board. 10 years is an estimation based of conversation with the manufacturers, but the ice system have not enough long experience to be able to claim exact lifetime.

Taxes

Taxes or tax benefits are not included in the project for now.

Depreciation

The ice system is fully depreciated in 10 years by the straight-line method mentioned in chapter 0. This is done on an accounting basis and has no direct effect on cash flow of the project.

8.1.2 Cost of capital

Internal rate of return (IRR)

Internal rate of return (IRR) is calculated as mentioned in chapter 3.4.1.

Since operation cost is relatively low compared to the amount of added value (€0.1 /kg) inner return rate of an investment in ice system is very high or over 250 % in all cases.

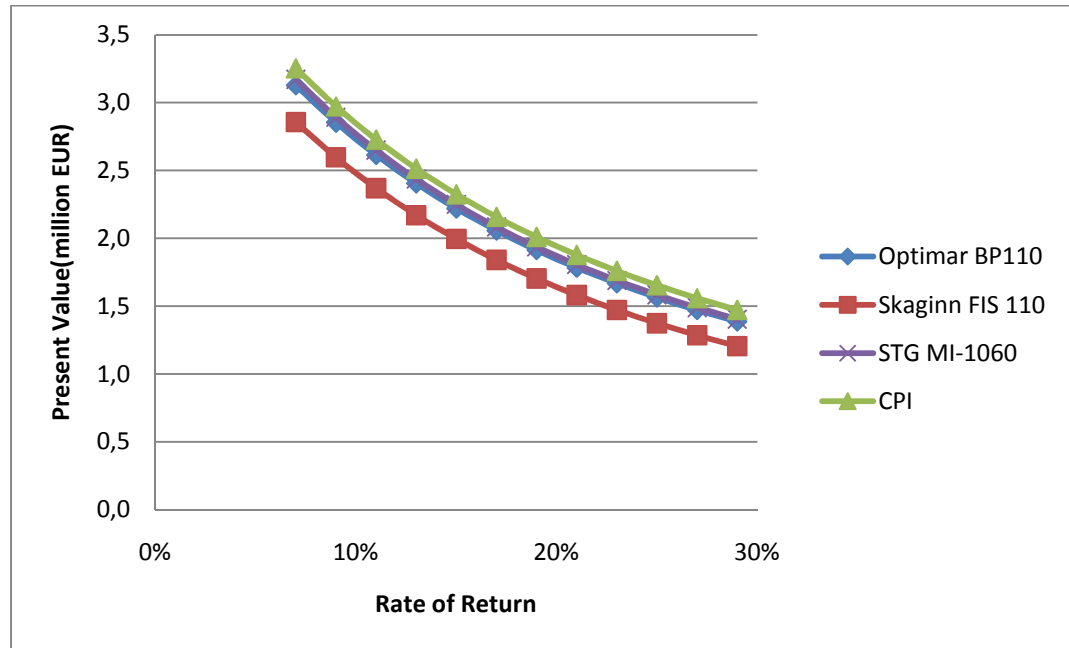


Figure 42. Net present value as a function of rate of return.

Figure 42 shows how all investment options analysed have similar results. Net present value is still positive with over 30 % rate of return.

8.1.3 Economical analysis

Break-even point analysis

Break-even point analysis estimates how long it will take for the investment until it is profitable or at what time-point the cash flow reaches zero (since the investment is negative cash flow).

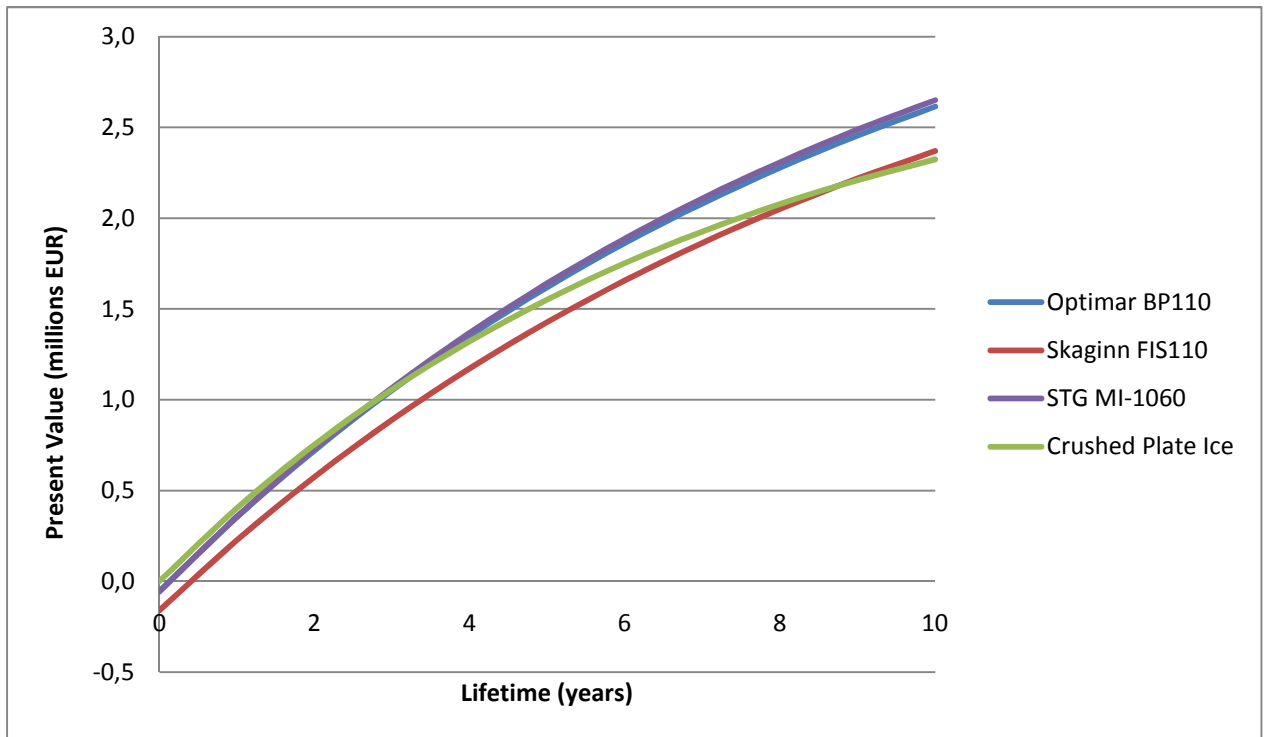


Figure 43. Net present value of different ice system options as a function of lifetime.

Figure 43 shows how the difference between chosen ice systems is very low. Net present value increases during the lifetime of the ice system. Since operation cost is very low the estimated revenues of the use of the liquid cooling systems is profitable very soon or within 6 months for each case. The figure also shows how the use of crushed plate ice is beneficial.

Net present value

Important parameters in the chilling process on board are the following: investment cost, oil price, capacity, energy price and efficiency of the ice system and the added value of chilling the product in the link of the chain from catch to processing. Following figures show the net present value of chilling machine as a function of different added value for every kilogram of fish being chilled.

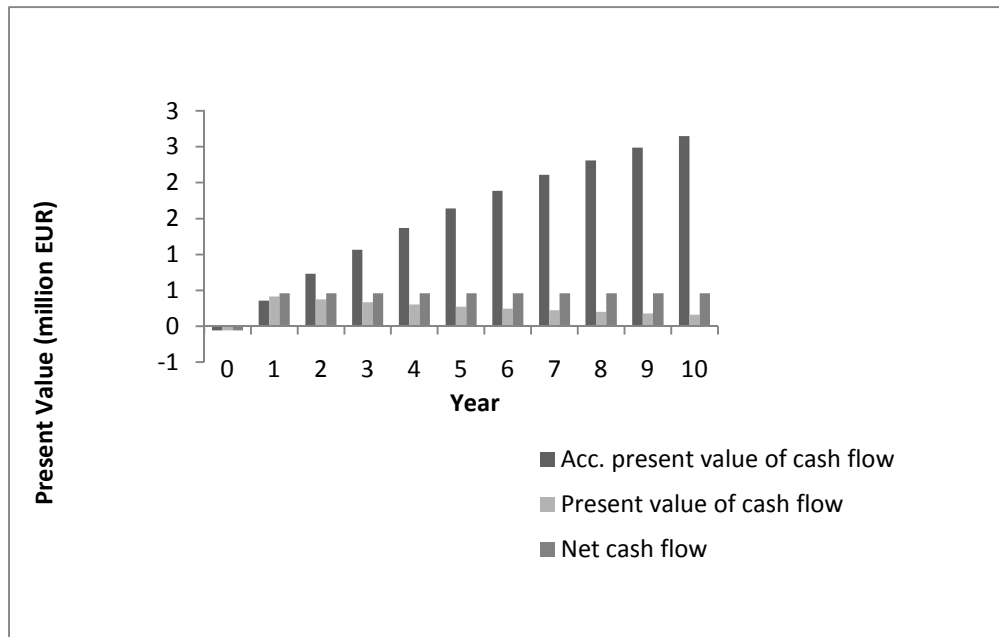


Figure 44. Accumulated net present value as a function of lifetime.

Figure 44 shows cash flow for the multi ice system, MI 1060 from STG. Results for other ice systems show similar results. It shows how the cash flow is negative in the first year. Since value-added revenues are quite high compared to both investment and operational cost, the investment returns profit very early and shows extremely positive results. Results for the two other ice systems can be found in Appendix A.

Annual equivalent worth

Since net present value is positive annual equivalent worth is also positive. Annual equivalent worth for the ice systems is as following:

Table 11. Annual equivalent worth calculations for different ice systems.

Machine	Annual equivalent worth
Optimar BP – 110 (liquid ice system)	€443,922
Skaginn FIS 110 (fluid ice system)	€402,351
STG MI 1060 (multi ice system)	€449,986

These results indicate that in all cases the investment should be accepted.

8.1.4 Sensitivity analysis

Trials were done with up to 50 % fluctuation on different parameters. The following figure shows the present value of each chilling technique based on variation from earlier given values of the parameters. Since all ice systems have similar outcome, sensitivity analysis is shown for Optimar BP-110 in Figure 45 and Figure 46. Changes in parameters have similar effect for each ice machine.

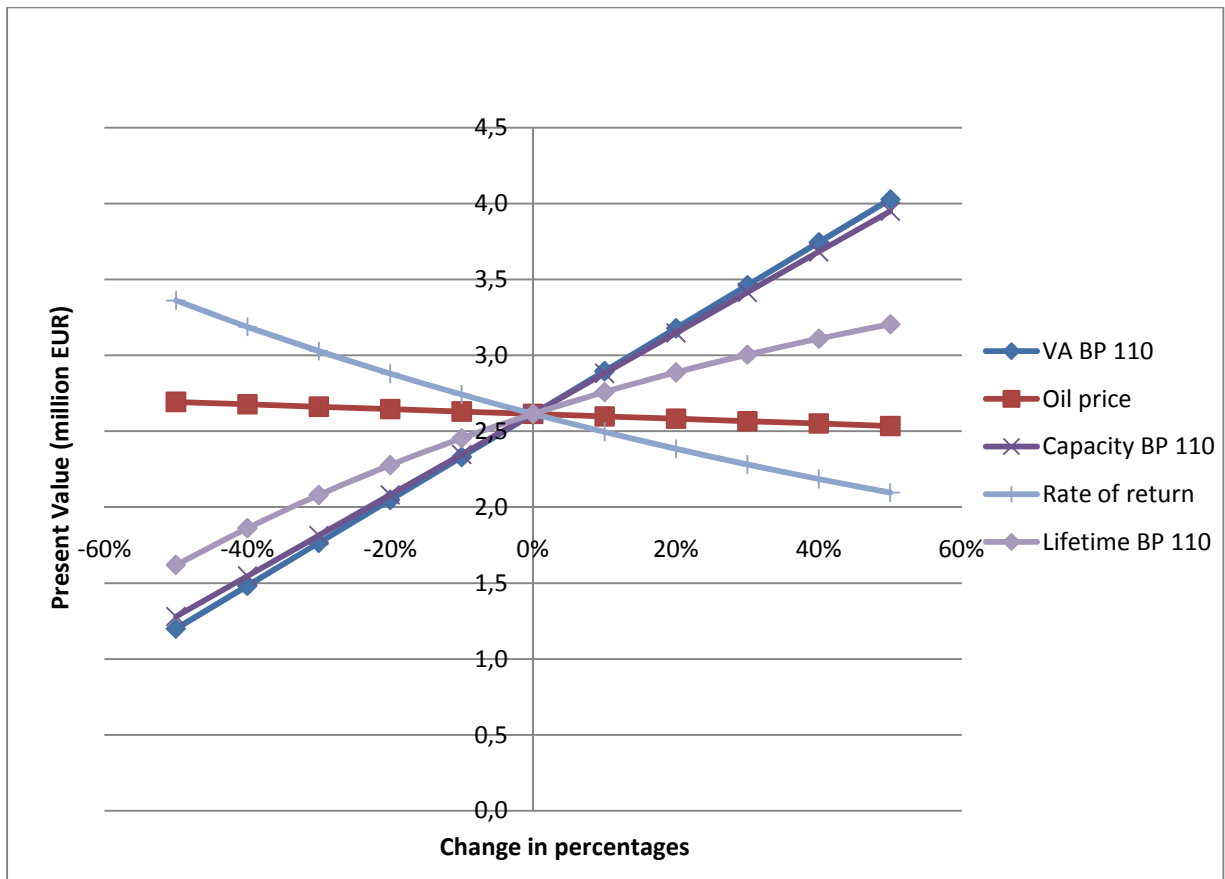


Figure 45. Sensitive analysis that shows change in net present value when parameters change.

Figure 45 shows that change in value adding revenues by adding chilling to the process and capacity of the ice machine have the biggest effect on the present value of the project. The net present value is also quite sensitive for a change in lifetime of the investment. Other parameters did not have significant impact on the net present value. But as can be seen decrease in parameters by 50 % does still not give negative present value of the investment.

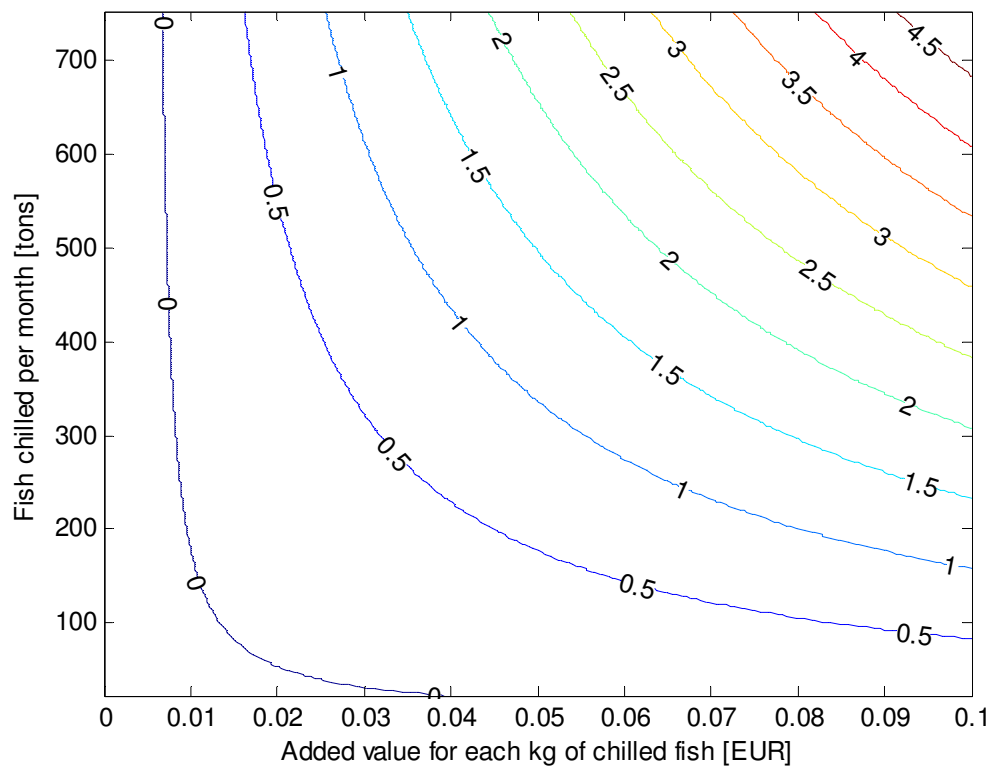


Figure 46. The net present value as a function of both amount processed per month and added-value per kilogram.

The contour lines in the above figure show clearly how the net present value increases when both added value and amount of fish chilled per month increases. Even very low amount in added value and low capacity shows positive results. Figures for other ice systems can be found in Appendix A.

Even though one ice system turns out to be a little bit more economical than other it should be considered how each of the chilling methods affects the product, for example: multi ice system might suit one product better than the other.

8.2 Cooling equipment in processing

8.2.1 Inputs and assumptions

Capital investment

As mentioned in chapter 5.4 the equipment analysed in this report is CBC chilling machine, (CBC stands for combined blast and contact). The machine is designed and produced by Skaginn, manufacturer located in Akranes, Iceland. Three different types are available. Each type has a different capacity range, 1,500 – 1,900 kg/hour. The most productive type will be analysed, which capacity is 1,900 kg/hour or around 90 fillets/min (assuming fillet size of around 350 g).

The CBC chilling machine consists of several units, cooling tank, in-feeding system, the chiller itself, and skinning system. Total price (refrigeration system and liquid cooler excluded) is € 764.000. Prices were obtained from Skaginn, offer was made in April 2009, but according to an employee of Skaginn these prices apply in 2010 also.

Liquid cooler used in the traditional processing method is also part of the processing process when CBC chilling machine is used. The investment cost for liquid cooling machine is the same as when using liquid cooling machine on board (same equipment), operational cost is though a little bit different. Capital investment in liquid cooler is various by producer, for example liquid cooler from Skaginn is €160,000 when liquid cooler from STG costs €58,000 and from Optimar around €57,000.

All calculations are based on 10 tons of fully processed product each working day, i.e. 10 tons of fillets or loins ready for export. Ten tons is not a great number and some large Icelandic processors put up to 50 tons through process in one day.

Funding

Since investing in CBC chilling machine is considered as high cost investment it is assumed that funding is needed. Usually 60 % funding is the maximum funding on behalf of lending institutions. Therefore contribution of the owner has to be at least 40 %. In calculations it is assumed that the equipment is financed with maximum loan, or 60 % of the total investment.

Interests

Based on average interest rate offered by banks for financing capital equipment it is assumed the interest rate is 10.10 % (June 2010).

Revenues

As mentioned earlier in this report experiments have shown that using liquid cooling in processing is worth one additional day in shelf-life. When using CBC chilling machine together with liquid cooling the shelf-life increases for 4 more days or 5 in total. It can be assumed that additional revenues related to longer shelf-life can be marked directly to the use of CBC. As listed in chapter 5.5.1 added-value per kg for each additional day in shelf-life is €0.20.

Operation cost

According to calculation made by Skaginn, done in April 2009, running cost for the chilling machine is €21.23/hour.

When CBC chilling machine is used it's primarily role is not to save job positions, it is mainly set up for more quality of the product. In the calculations it is assumed that operational cost includes one full time position.

Salvage value

Salvage value of the investments is estimated as zero after 10 years of average operational time.

Rate of return

As mentioned earlier the rate of return used in this report is 11 %.

Service life

Average service lifetime is around 10 years. 10 years is an estimate, but the CBC chilling machine has not enough life experience to be able to claim exact lifetime.

Taxes

Taxes or tax benefits are not included in the project for now.

Depreciation

The CBC chilling machine is fully depreciated in 10 years by the straight-line method. This is done on an accounting basis and has no direct effect on cash flow of the project.

8.2.2 Cost of capital

Internal rate of return (IRR)

Internal rate of return (IRR) is calculated as mentioned in chapter 3.4.1.

Since operation cost is relatively low compared to the amount of added-value inner return rate of an investment in ice system is very high or over 600 % for this investment.

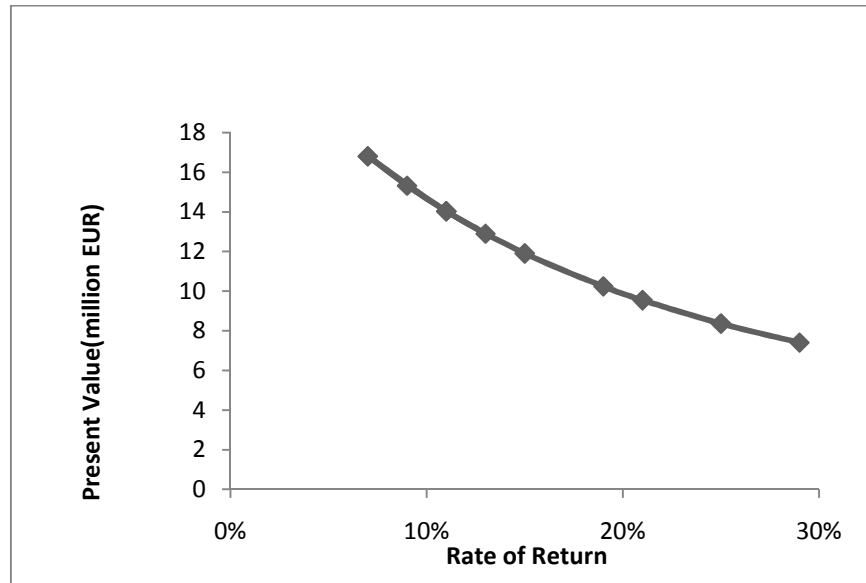


Figure 47. Net present value as a function of rate of return.

Figure 47 shows how net present value decreases as rate of return increases. Net present value is still positive with over 30 % rate of return.

8.2.3 Economical analysis

Break-even point analysis

Similar to chapter 0 break-even point analysis is applied to calculate how long it will take for the investment until it is profitable or at what time the cash flow reaches zero (since the investment is negative cash flow).

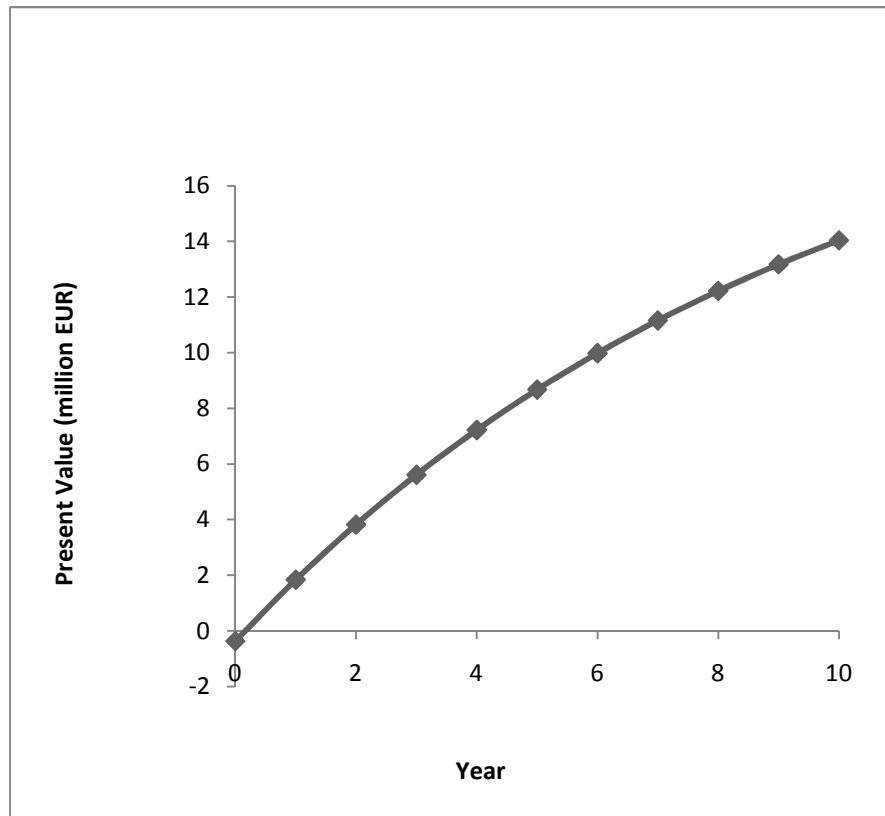


Figure 48. Net present value as a function of lifetime.

Figure 48 shows how the net present value of using CBC chilling machine together with liquid cooling machine increases as lifetime increases if added-value per kilogram of fully processed product is €1 (given that this processing method brings 5 days in additional shelf-life). Based on that value it is obvious that the investment is profitable within a few months. The added-value that makes the investment economical but not profitable is €0.08/kg (or €0.017/kg per day of increased shelf-life since the total shelf-life increase is approximately 5 days). These calculations are based on maximum of 10 tons per day going through processing, but as mentioned above 10 tons per day is far from being an overestimate.

Net present value

The most important parameters in the chilling process to calculate net present value of the investment are the following: investment cost, interest rate, added value (value that adds on the product when method is used), energy price and capacity.

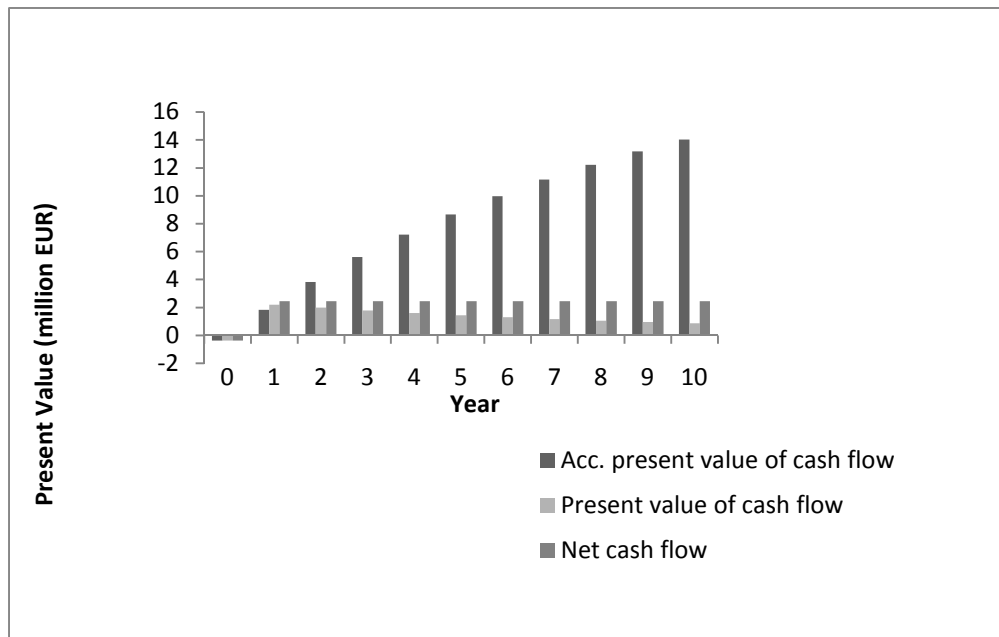


Figure 49. Accumulated net present value as a function of lifetime.

Figure 49 shows how the cash flow is negative in the first year. Since value-added revenues are quite high compared to both investment and operational cost, the investment returns profit very early.

Annual equivalent worth

Since net present value is positive annual equivalent worth is also positive. Annual equivalent worth for CBC chilling machine is €2,383,136.

This result indicates that the investment should be accepted.

8.2.4 Sensitivity analysis

Trials were done with up to 50 % fluctuation on different parameters. The following figure shows the present value when the most important parameters are changed. Present value is zero when estimated value-add is €0.08 /kg, or exactly the amount that the product has to gain in value when both liquid cooling and CBC chilling method are used in processing to become economical (accumulated net present value zero at the end of the lifetime). As mentioned before, the above mentioned chilling methods in processing bring the product up to 5 days of extra shelf-life.

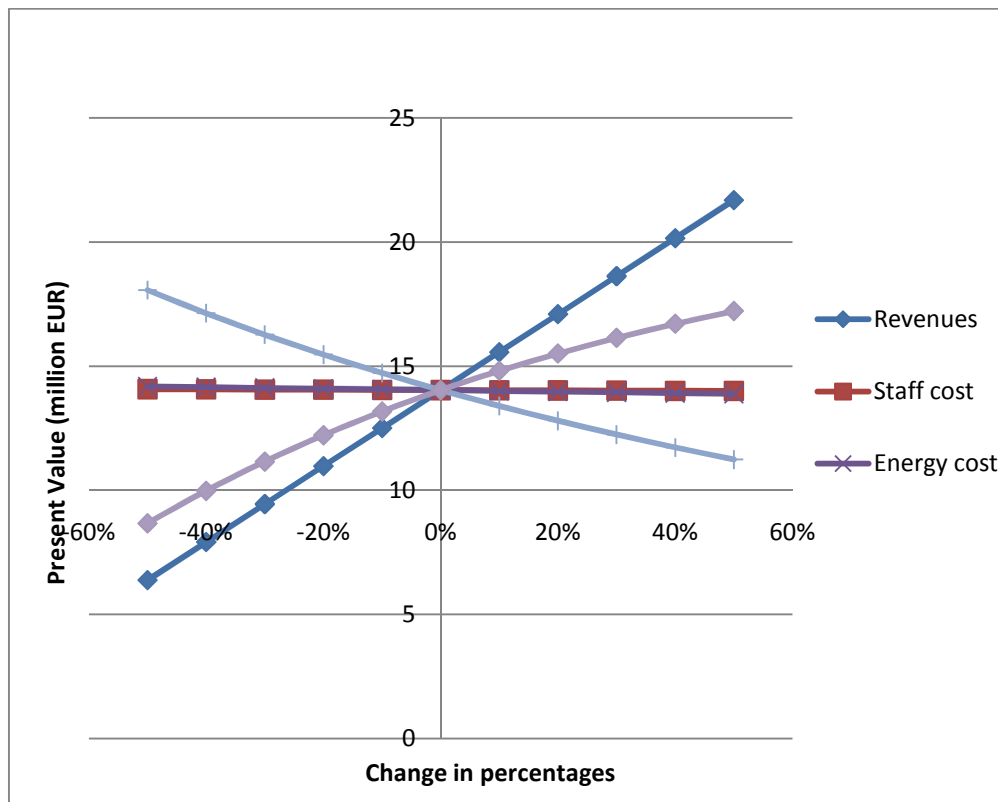


Figure 50. Sensitive analysis that shows change in net present value when parameters change.

Figure 50 shows that change in value-adding revenues has the biggest effect on the present value of the investment. The added-value is the biggest factor that can be managed by market forces and that is the factor that is most likely to fluctuate dramatically. As before mentioned added-value is total added-value per kilogram when both liquid cooling and CBC chilling method are used together.

Lifetime and interests have also great impact on how positive the present value of the investment is. But as the figure shows even though the parameters change up to 50 % it does not lead to negative present value.

Figure 51 shows net present value increases as added value increases or/and amount of processed product increases. The contour lines show net present value of the investment in millions of EUR.

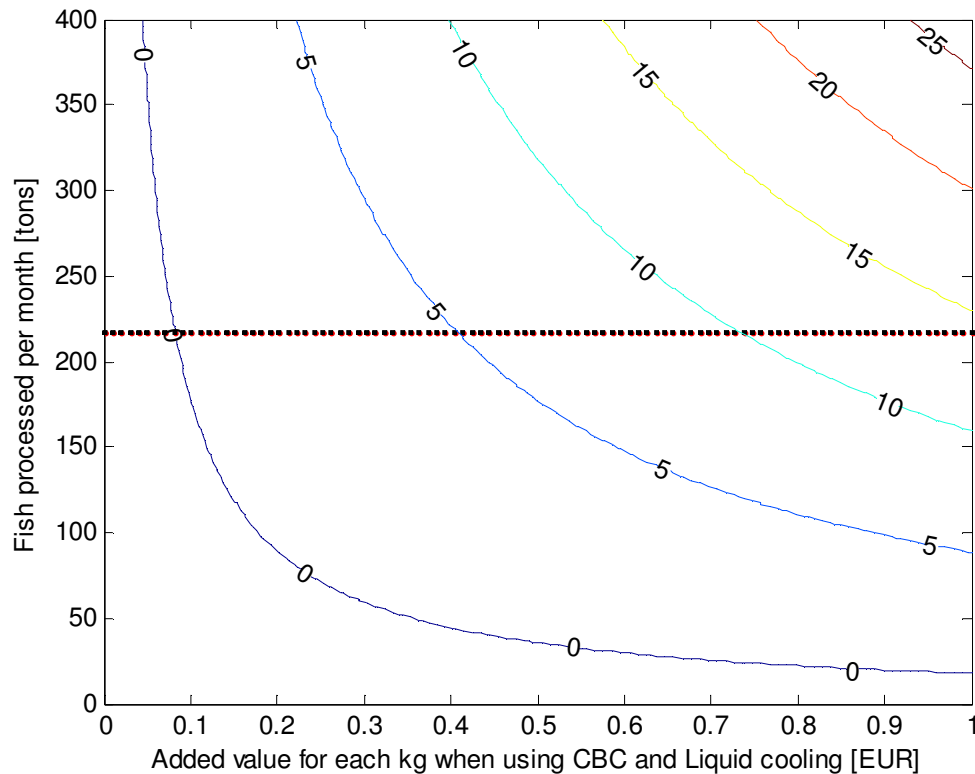


Figure 51. The net present value(million EUR) as a function of both amount processed per month and added-value per kilogram.

All results below or to the left of the zero line give negative results. That means the investment involves extra cost and is not profitable. The black line in the middle of the figure shows net present value based on 10 tons of processing per day. The added-value is total added-value, or how much the product has to increase in value based on 5 more days in shelf-life. As mentioned before 5 days should be the result of the use of liquid cooling and CBC chilling method as a combined solution. For example if the added value is evaluated to be approximately €1 per kilogram that is processed by this method and production is 10 tons per day, total net present value over 10 years brings up to €2.5 million per year.

9 Results and discussions

9.1 Catch

After catch it is important that the product is processed as soon as possible. A difference is though between farmed or wild fish whether the raw material should be processed as soon as one day after catch or whether processing should take place after rigor mortis.

Usually, the product is processed about three days after catch. Cooling after catch is a very important factor for future shelf-life of the processed product. It can minimise gaping in the flesh of the product. If the product was not handled right after catch it is very likely to have influence on whether methods like CBC cooling reaches its maximum effectiveness or not.

The results from sensitivity analysis, internal rate of return and net present value all show that investing in ice system for chilling on board is profitable in every alternative analysed in this report. When comparing each investment choice (as can be seen in Figure 43), it shows that all investment options give positive net present value within one year of each investment even though estimated added-value is quite low (€0.1/kg of chilled raw material).

The use of crushed plate ice turns out to be economical compared to no cooling, it requires no investment but if added value is slightly positive it gives positive results. Cooling on board is therefore in all cases an important link that should not be missing in the chain.

9.2 Processing

Two methods in processing were compared. The first method is when only liquid cooling is used in processing and then when liquid cooling is used together with CBC chilling machine.

Using liquid cooling as a standalone solution brings the product one extra day in shelf-life, or in total about 9 – 12 days of total shelf-life. On the other hand use of CBC chilling method gives up to 4 days increase in shelf-life and together with liquid cooling total shelf-life should be at least 14 days. It is though a predominant factor whether the product had appropriate handling from catching to processing (cooling with crushed plate ice, liquid ice or both and stored in ship hold/ chilled storage room before and after processing).

The investment cost of CBC chilling machine is about 4.8 times more expensive than liquid cooling machine so the result in increased shelf-life is in harmony with price difference. Since liquid cooling equipment is about 5 times less expensive than CBC chilling machine 1 day in shelf-life, compared to up to 4 additional days when CBC chilling machine is used, is an acceptable result in economical terms. The difference in operation cost between liquid cooling machine and CBC chilling machine is approximately five times higher for CBC which is also in consistence with both investment cost and physical benefits, i.e. gain in shelf-life.

Based on economical analysis the equipment analysed for chilling in processing (CBC chilling machine) is not expensive compared to possible benefits and when assumed 10 years of use. The cost per kilogram of processed product is only a fraction to the benefits of using it. Using LC and CBC together the benefits can be up to 5 more days in shelf-life and also an acknowledgment to buyers that the product has been treated and processed as quality product. Since the product gains five more days in shelf-life it becomes a tempting option to transfer with ship instead of airplane, because of massive price difference in transportation. Based on results and analysis stated in this report, use of liquid cooling and CBC cooling methods together is especially recommended.

9.3 Packaging

In this report the focus was on EPS, CP or MAP. Since MAP has not been used in export and no data available for real trials it is quite hard to compare MAP to the other two options.

When EPS and CP are looked into, EPS is both cheaper and gives more insulation throughout the transportation process. As stated in chapter 6.7.1 it gave much better results in trials and the use of EPS is especially recommended when there is a risk of temperature abuse in storage throughout the lifetime and during transportation.

The most surprising factor was though that EPS is cheaper than CP packaging, but other reports had claimed the opposite. EPS is more expensive in recycling and disposal but that is usually retailers or buyers problem, not the exporters.

9.4 Cooling in packaging

Two most common methods in cooling in packaging are putting icepacks into the packaging or dry ice. Both methods are effective in some conditions. Experiments show that if CBC chilling method is used in processing there is no need for extra cooling in packaging in ship transport or air transport. Buyers often insist that the product has been transported with extra cooling within the packaging and manufacturers sometimes use e.g. icepacks even though they know there is no need.

9.5 Transportation

From Iceland only two transport options are available for exporters, ship and air. Many exporters are located far from the capital and therefore have to transport the product long distances to harbour or airport, usually by trucks. According to results in experiments the first part of travelling by truck is not a problem. The trucks are in most cases refrigerated trucks and the temperature of the product is usually well managed and maintained.

When shipped the product is packed into a refrigerated container by the manufacturer and is not opened until at destination. That preserves the quality of the product when the process is well managed, such as no un-chilled storages or long time between loading and unloading. In experiments done by Matís that was usually not a problem and the temperature of the product did not rise in until after shipping.

In flight there were a few complications. The temperature is not as well manageable as in ship. The time between loading and unloading is critical and storages are sometimes not refrigerated. The flight has however the advantage over shipping that it takes only 20% of the shipping time. If the customer is ready to pay for the difference in transporting, flight is a substantial option since the price will never be as economic as when transporting by ship. The flight could even get more competitive by more effective temperature control both in storages and when the product is handled right on board of the plane.

In April 2010 the fresh fish exporters experienced some inconvenience due to the volcanic eruption in Iceland. Transportation by sea was the only option and exporters had to reschedule shipments or even freeze the product. This natural disaster reaffirms how important and steady ship transportation is.

Based on results, shipping is recommended to protect the quality of the product. On the other hand it is hard to evaluate buyers agenda on which is more important, stability in quality or number of days since catching. Sea freight has though been stable while flight freight has been decreasing and buyers probably accept that improvements in processing and increased stability during transportation return in more valuable product. Shipping has also the advantage of being about four times less expensive than flight.

9.6 Network flow

When facts in the network flow are considered as shortest path problem results indicate that liquid cooling and CBC chilling method in processing and transportation with air gives the best results regarding the time factor in the supply chain. The factor maximised in the model is time left in retail store after processing and transportation. The use of CBC chilling machines increases shelf-life for up to 5 days and together with air transportation the product has longer time in retail sale. Since MA packaging in destination country can bring the product up to 10 days (see chapter 6.6), MAP is always recommended in the solution.

When cost reduction is considered as main goal in the network the best result is to use shipping as transportation method instead of air, since air transportation is up to 4 times more expensive than shipping. The model is easily adjusted to new conditions such as change in lengthening of shelf-life for each link in the chain. And when e.g. domestic transport is necessary or CBC chilling machine is not available, the model can be adjusted for the respective parameters. The model can be seen in Appendix C.

9.7 Environmental issues

Green products are getting more space in the discussion. Therefore manufacturers should at least consider their processing methods, choice of packaging and transportation methods. As mentioned in chapter 0 the shipping is 20 times less polluting than air transportation. Regarding environmental factors shipping should be primary transportation method in all cases.

10 Conclusion

When both economical factors and quality aspects within the process of fresh whitefish after catch and until it has landed by a retailer a few factors have more influence on the final condition of the product than others. Some technology choices in the process are also more economical than others and at the same time they protect the product against abuse throughout the process from catch to retailer.

Exporters and processors have to consider many choices throughout the whole process, whether it is between transportation methods, processing methods, different packaging or different cooling methods on board. The most important factor throughout the whole chain is to keep the product within the recommended temperature range, or else it can have serious consequences of the shelf-life and final shape of the product. Processors should therefore select appropriate technology and methods to achieve success in every link of the chain.

The main objective of this thesis as mentioned in the introduction chapter was to investigate whether the value of raw material in export of fresh whitefish could be increased by choosing more economic and/or value adding processing and transportation methods in different links in the chain *from catch to retailer*. Results show that there is selection of options that brings the product both increased quality and are financially and/or environmentally economic.

Most important links in the supply chain regarding shelf-life are cooling on board and chilling in processing, these steps are ascendant factors in later health and quality of the processed product. Special equipment like CBC chilling machine has been showing very good results in experiments regarding increase of shelf-life.

According to economic analysis the operational cost and investment cost is only a fraction of possible revenues and benefits gained by the use of ice on board and special cooling equipment (like liquid cooling on board or CBC chilling machine in processing), both right after catch and in processing.

In the part from catch to processing the best combination is liquid/slurry ice cooling for 24 hours and then crushed plate ice until processing. In the processing phase, liquid cooling as a combined solution together with CBC chilling method shows very good results. The investment and operational cost is small compared to the benefits from the use of it. If the product is properly cooled down after catch and does not suffer from temperature abuse the use of this combination should bring the product up to 5 days in extra shelf-life and give an extra protection against thermal load during transportation. Regarding packaging, EPS packaging is especially recommended when the product is likely to suffer from temperature abuse during transportation. Results show that EPS boxes are more protective and better insulated than CP. Increased shelf-life gives exporters more alternatives in transportation. Sea transport is a good choice when CBC chilling method is used in processing.

Flight has the shortest travelling time which means that the product is very soon on the market. However, flight is an unstable part of a distribution chain and temperature abuse during travelling can have great impact on shelf-life of the product. Shipping on the other hand is a very stable chain but takes much longer time. During shipping both processor and buyer can in most cases rely on stable chain and therefore it can be assumed that the likelihood of temperature abuse is not high.

Regarding environmental factors shipping is the optimal transportation method. When carbon footprint is measured, air transportation creates much more carbon footprints than ship, or 20 times more.

Location of manufacturers has both advantages and disadvantages. When the location of one manufacturer has the effect of lengthening travelling time for one day it might be an advantage to be closer to the fishing ground and therefore speed the time from catching to processing. Processing the fish as soon as 2 days after catch can have great influence on shelf-life and bring the product this additional day lost in travelling and even more.

The decision-making process in the seafood industry is very complicated and all aspects could not be taken into account in this thesis (like some financial parameters such as housing, staff, administrative costs and others). Among areas worth further research and testing are e.g. field trials for the whole process, that is: temperature measuring both on ambient and product temperature from the beginning, right after catch and until the product has reached retailer store. Quality of the product like gaping, microbial growth and sensory aspects would have to be measured in later stages of the process. Experiments like this have to be well organized and controlled since the intention of the trials is to return valuable information without disturbing the natural process with additional handling.

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Appendix A

Assumptions and inputs for cooling equipment on board

LIQUID ICE MAKER OPTIMAR BP-110			FIS 110 - Skaginn			STG MI-1060		
Power consumption	17	kW	Power consumption	65	kW	Power consumption	18	kW
Electricity need per hour	17	KWh	Electricity need per hour	65	KWh	Electricity need per hour	18	KWh
Efficiency	100%		Efficiency	100%		Efficiency	100%	
Production capacity	460	kg/h	Production capacity	1250	kg/h	Production capacity	650	kg/h
kg liquid ice per kg fish	0,4436		kg ice per kg fish	0,5915		kg ice per kg fish	0,4436	
Max. capacity ice/month	331.200	kg	Max. capacity /month	900.000	kg	Max. capacity ice/month	468.000	kg
Max. capacity ice/hour	460	kg	Max. capacity/hour	1.250	kg	Max. capacity ice/hour	650	kg
Ice ratio	40%		Ice ratio	30%		Ice ratio	40%	
cost per hour	5,8	EUR/h	cost per hour	22,2	EUR/h	cost per hour	6	EUR/h
Time	720,0	h	Time	720,0	h	Time per month	720,0	h
Total price	4.185	EUR/month	Total price	16.000	EUR/month	Total price	4.431	EUR/month
Fixed amount per month	177.440	kg/liq. Ice	Fixed amount per month	236.600	kg/fl. Ice	Fixed amount per month	177.440	kg/mu. Ice
Cost per kg of liquid ice	0,013	EUR/kg	Cost per kg	0,018	EUR/kg	Cost per kg of liquid ice	0,009	ISK/kg

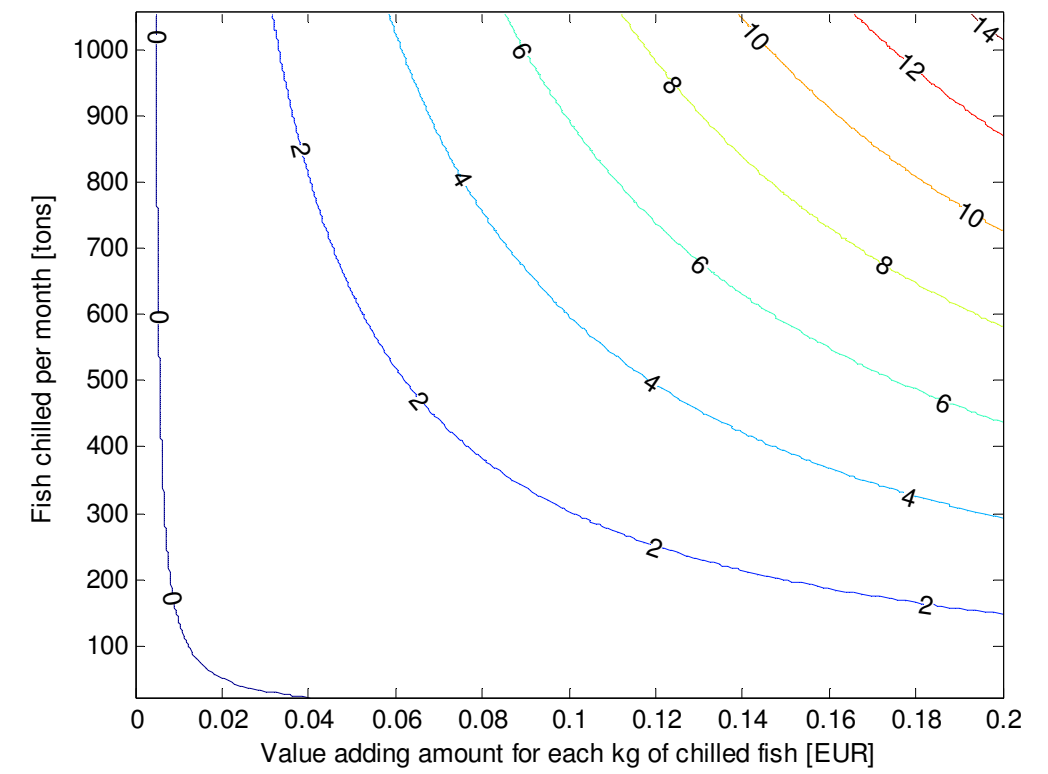
Screen shots of cash flow for cooling equipment on board

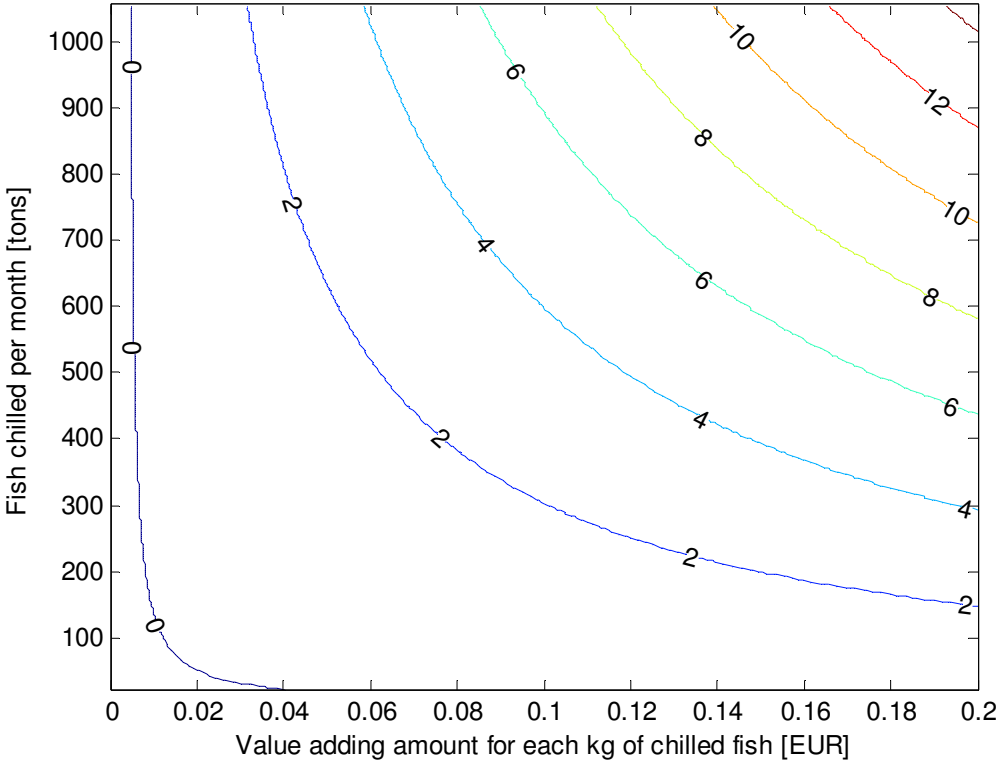
Optimar liquid ice maker BP - 110											
Year	0	1	2	3	4	5	6	7	8	9	10
Income statement											
Revenues		480.000	480.000	480.000	480.000	480.000	480.000	480.000	480.000	480.000	480.000
Expenses											
Depreciation		5.400	5.400	5.400	5.400	5.400	5.400	5.400	5.400	5.400	5.400
Operational cost		26.903	26.903	26.903	26.903	26.903	26.903	26.903	26.903	26.903	26.903
Taxable income		447.697	447.697	447.697	447.697	447.697	447.697	447.697	447.697	447.697	447.697
Income taxes (tax savings)											
Net income		447.697	447.697	447.697	447.697	447.697	447.697	447.697	447.697	447.697	447.697
Cash flow statement											
Operating activities											
Net income		447.697	447.697	447.697	447.697	447.697	447.697	447.697	447.697	447.697	447.697
Depreciation		5.400	5.400	5.400	5.400	5.400	5.400	5.400	5.400	5.400	5.400
Investment activities											
Investment	54.000										
Salvage value											0
Gains tax											
Working capital											
Net cash flow	54.000	453.097	453.097	453.097	453.097	453.097	453.097	453.097	453.097	453.097	453.097
Present value											
Present value of cash flow	-54.000	408.195	367.742	331.298	298.466	268.887	242.240	218.233	196.606	177.121	159.568
Acc. present value of cash flow	-54.000	354.195	721.937	1.053.235	1.351.701	1.620.589	1.862.829	2.081.062	2.277.668	2.454.789	2.614.357
Net cash flow	-54.000	453.097	453.097	453.097	453.097	453.097	453.097	453.097	453.097	453.097	453.097

Skaginn liquid ice maker FIS - 110												
Year	0	1	2	3	4	5	6	7	8	9	10	
Income statement												
Revenues		480.000	480.000	480.000	480.000	480.000	480.000	480.000	480.000	480.000	480.000	480.000
Expenses												
Depreciation		16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000
Operational cost		50.475	50.475	50.475	50.475	50.475	50.475	50.475	50.475	50.475	50.475	50.475
Taxable income		413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525
Income taxes (tax savings)												
Net income		413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525
Cash flow statement												
Operating activities												
Net income		413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525	413.525
Depreciation		16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000
Investment activities												
Investment	160.000											
Salvage value												0
Gains tax												
Working capital												
Net cash flow	160.000	429.525	429.525	429.525	429.525	429.525	429.525	429.525	429.525	429.525	429.525	429.525
Present value												
Present value of cash flow	-160.000	386.959	348.611	314.063	282.939	254.899	229.638	206.880	186.377	167.907	151.266	
Acc. present value of cash flow	-160.000	226.959	575.570	889.632	1.172.571	1.427.470	1.657.107	1.863.987	2.050.364	2.218.271	2.369.537	
Net cash flow	-160.000	429.525	429.525	429.525	429.525	429.525	429.525	429.525	429.525	429.525	429.525	429.525

STG multi ice maker MI - 1060												
Year		0	1	2	3	4	5	6	7	8	9	10
Income statement												
	Revenues		480.000	480.000	480.000	480.000	480.000	480.000	480.000	480.000	480.000	480.000
	Expenses											
	Depreciation		5.800	5.800	5.800	5.800	5.800	5.800	5.800	5.800	5.800	5.800
	Operational cost		20.159	20.159	20.159	20.159	20.159	20.159	20.159	20.159	20.159	20.159
	Taxable income		454.041	454.041	454.041	454.041	454.041	454.041	454.041	454.041	454.041	454.041
	Income taxes (tax savings)											
	Net income		454.041	454.041	454.041	454.041	454.041	454.041	454.041	454.041	454.041	454.041
Cash flow statement												
	Operating activities											
	Net income		454.041	454.041	454.041	454.041	454.041	454.041	454.041	454.041	454.041	454.041
	Depreciation		5.800	5.800	5.800	5.800	5.800	5.800	5.800	5.800	5.800	5.800
	Investment activities											
	Investment	58.000										
	Salvage value											0
	Gains tax											
	Working capital											
	Net cash flow	58.000	459.841	459.841	459.841	459.841	459.841	459.841	459.841	459.841	459.841	459.841
Present value												
	Present value of cash flow	-58.000	414.270	373.216	336.229	302.909	272.890	245.846	221.482	199.532	179.758	161.943
	Acc. present value of cash flow	-58.000	356.270	729.486	1.065.716	1.368.624	1.641.514	1.887.359	2.108.841	2.308.373	2.488.131	2.650.074
	Net cash flow	-58.000	459.841	459.841	459.841	459.841	459.841	459.841	459.841	459.841	459.841	459.841

Graphs for cooling equipment on board
Skaginn FIS 110





Appendix B

Assumptions and inputs for CBC chilling machine and Liquid ice machine in processing

General information CBC					General information Liquid Cooler				
Investment			€	764.045	Investment		€	160.000	
Owners contribution		40%	€	305.618	Owners contribution	40%	€	64.000	
Loan		60%	€	458.427	Loan	60%	€	96.000	
Interests				10,10%	Interests			10,10%	
Operational cost					Operational cost				
Staff cost daytime	ISK/hour	939	€/hour	5,99	Power consumption		kW	65	
Staff cost overtime	ISK/hour	1.690	€/hour	10,79	Electricity need per hour		KWh	65	
Energy cost			€/hour	21,23	Efficiency			80%	
Hours per day				8	Production capacity		kg/h	1250	
Working days per month				21,67	kg ice per kg fish			0,5915	
Hours per month				173,33	Needed ice/month		kg	128.154	
					Cost per kWh	ISK OR.IS 1.1.10		7,85	
Daytime per month				173,33	Ice ratio			30%	
Overtime per month				0,00	cost per hour		EUR/h	3,26	
					Time			173,3	
Depreciation		10%	€	76.405	Total price per month			565	
					Price per kg fish		EUR/kg	0,003	
Maximum capacity			kg/hour	2.300	Depreciation	10%	€	16.000	
			kg/month	398.654					
Assumed max. 10 tons per day			max kg/month	216.660					
Revenue increase for 1 day in shelf life			€/kg	0,20					
Total increase in shelf life (CBC and LQ)			days	5					
ISK/EUR (isb.is 9. 6.10)				156,67					

Screen shots of cash flow for CBC chilling machine

CBC chilling machine and liquid cooling machine												
Year		0	1	2	3	4	5	6	7	8	9	10
Income statement												
	Revenues		2.599.920	2.599.920	2.599.920	2.599.920	2.599.920	2.599.920	2.599.920	2.599.920	2.599.920	2.599.920
	Expenses											
	Depreciation		92.405	92.405	92.405	92.405	92.405	92.405	92.405	92.405	92.405	92.405
	Operational cost		63.397	63.397	63.397	63.397	63.397	63.397	63.397	63.397	63.397	63.397
	Debt interest		55.997	52.500	48.650	44.412	39.745	34.607	28.949	22.721	15.863	8.313
	Taxable income		2.388.121	2.391.618	2.395.468	2.399.707	2.404.374	2.409.512	2.415.169	2.421.398	2.428.255	2.435.805
	Income taxes (tax savings)											
	Net income		2.388.121	2.391.618	2.395.468	2.399.707	2.404.374	2.409.512	2.415.169	2.421.398	2.428.255	2.435.805
Cash flow statement												
	Operating activities											
	Net income		2.388.121	2.391.618	2.395.468	2.399.707	2.404.374	2.409.512	2.415.169	2.421.398	2.428.255	2.435.805
	Depreciation		92.405	92.405	92.405	92.405	92.405	92.405	92.405	92.405	92.405	92.405
	Investment activities											
	Investment	-924.045										
	Salvage value											0
	Borrowed funds	554.427										
	Principal repayment		-34.621	-38.118	-41.968	-46.207	-50.874	-56.012	-61.669	-67.898	-74.755	-82.306
	Net cash flow	-369.618	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904
Present value												
	Present value of cash flow	-369.618	2.203.517	1.985.149	1.788.422	1.611.190	1.451.522	1.307.676	1.178.086	1.061.338	956.159	861.404
	Acc. present value of cash flow	-369.618	1.833.899	3.819.048	5.607.470	7.218.660	8.670.181	9.977.857	11.155.943	12.217.281	13.173.440	14.034.843
	Net cash flow	-369.618	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904	2.445.904

Appendix C

Model for shortest path problem

Node	Description
1	Catch
2	Liquid/slurry ice
3	Chrushed plate ice
4	No cooling
5	Liquid cooling
6	CBC cooling
7	No cooling
8	MAP
9	ESP
10	CP
11	Ice mats
12	No cooling
13	Dry ice
14	Domestic transp.
15	Ship
16	Air
17	Map
18	Retailer

10 days are put in the beginning since that is average shelf-life for fresh fish traditionally processed (8 days when no cooling in processing since results show bad handle in beginning has bad results on shelf-life). Other numbers in the time column stand for increase or decrease in life time when respective node in the network flow is chosen.

Grey colored fields are manually input

	Origin	Destination	Time	Flow
Before transportation	1	2	10	0
	1	3	10	1
	1	4	8	0
	2	3	0	0
	2	5	1	0
	2	7	0	0
	3	5	1	1
	3	7	0	0
	4	5	1	0
	4	7	0	0
	5	6	4	1
	5	8	0	0
	5	9	0	0
	5	10	0	0
	6	8	0	0
	6	9	0	0
	6	10	0	1
	7	8	0	0
	7	9	0	0
	7	10	0	0
	8	11	0	0
	8	12	0	0
	8	13	0	0
	9	11	0	0
	9	12	0	0
	9	13	0	0
	10	11	0	0
	10	12	0	0
	10	13	0	1

Transportation phase	11	14	-1	0
	11	15	-7	0
	11	16	-4	0
	12	14	-1	0
	12	15	-7	0
	12	16	-4	0
	13	14	-1	0
	13	15	-7	0
	13	16	-4	1
	14	15	-4	0
	14	16	-7	0
	15	17	7	0
	15	18	-2	0
	16	17	6	1
	16	18	-2	0
	17	18	-2	1

			Total shelf life	15
			Days until transportation	4
			Days in transportation phase	0
			Time left in retail store	11

Flow balance constraints

<i>Node</i>	<i>Net outflow</i>		<i>Required net outflow</i>
1	1	=	1
2	0	=	0
3	0	=	0
4	0	=	0
5	0	=	0
6	0	=	0
7	0	=	0
8	0	=	0
9	0	=	0
10	0	=	0
11	0	=	0
12	0	=	0
13	0	=	0
14	0	=	0
15	0	=	0
16	0	=	0
17	0	=	0
18	-1	=	-1