Thesis for the Degree of Doctor of Philosophy

Enhancing quality management of fresh fish supply chains through improved logistics and ensured traceability

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ABSTRACT

The aim of the project was to enhance product quality management in fresh fish supply chains through improved logistics management and ensured traceability effectiveness. The study provides insights into seafood companies' perspectives on the benefits of implementing traceability. Knowledge on the net benefits of implementing traceability and the distribution of costs and benefits among actors can support decision making. Comprehensive literature review on the necessary components to ensure traceability and a framework developed to assess traceability system effectiveness enable researchers and practitioners in the food/seafood sector to locate problems and take necessary actions to ensure effective traceability. In addition, more efficient use of recorded data provides an approach to enhance quality management. Data on ambient temperatures during logistics steps can be used to calculate the product warm up time. The results on temperature profiling pinpointed several hazardous steps in air transportation related to handling, storage and transport operations. Pros and cons of two transport modes, air vs. sea, were analysed. Several factors were found to influence product temperature and shelf life during logistics processes, namely, presence/absence of precooling, mode of transport, product location and logistics length. These findings help to improve logistics management as well as to make decisions on transport alternatives so as to improve quality management. The new photochromic time-temperature indicator (TTI) was found to give reproducible responses and reflect well the temperature conditions of fresh fish supply chains. The results show that a right charging time could be defined to suit the shelf life of the fresh fish product concerned. The TTI of a right charging level placed on the bottom surfaces of fresh cod retail packs was found to reflect well the temperature conditions of the product and the shelf life declared by sensory evaluation, except for the case of severely superchilled conditions, and other methods of quality control. The results indicate the potential of using the new TTI to continuously monitor product temperature history, quality and shelf life in fresh fish supply chains.

Keywords: fresh fish supply chain, traceability, logistics, air freight, sea freight, temperature mapping, quality, shelf life, time-temperature indicator.

ÁGRIP (ABSTRACT IN ICELANDIC)

Markmið verkefnisins var að efla gæðastjórnun á ferskum fiski með betri skipulagningu og endurbættum rekjanleika, allt frá veiðum til neytenda. Hluti af rannsóknunum var að fá yfirlit yfir þekkingu forstöðumanna fyrirtækja sem tengjast sjávarútvegi á rekjanleika og kostnaðarmeðvitund þeirra á vali flutningaleiða og umbúða við ákvörðunartöku um val á flutningaferlum fyrir sjávarafurðir. Greining flutningaferla var nauðsynlegur hluti verkefnisins til þess að fá heildaryfirlit yfir stöðu greinarinnar og flutningaferlanna. Niðurstaða greiningarinnar leiddi í ljós hvaða hlekki aðfangakeðjunnar væri hægt að bæta m.t.t. geymsluþols, verklags, búnaðar, umhverfisáhrifa o.fl. Í verkefninu var rannsakað hvernig hitastig þróast í gegnum flutningakeðjuna bæði fyrir flug- og sjóflutninga; flakavinnslu, forkælingu, áhrif mismunandi umbúða, - virkni geymslna og gáma og einnig við tilfærslur vöru í keðjunni. Niðurstöður þessara verkþátta verkefnisins voru notaðar til að meta hitaálag, sem afurðirnar urðu fyrir í ferlunum og nota þá til að spá fyrir um geymsluþol. Afrakstur verkefnisins verður notaður við að taka ákvarðanir um hvaða ferla eigi að lagfæra í aðfangakeðjunni svo að það komi að mestu gagni við bestun á heildarferlinu.

Kostir og gallar flug- og sjóflutnings fyrir ferskan fisk voru greindir. Niðurstöður hitakortlagningar sýndu fram á mun stöðugra hitastig í gámaflutningi með skipum en með flugflutningi. Einkum er hætta á hitaálagi í flugflutningskeðjum þegar vara flyst milli ólíkra hlekkja kælikeðjunnar. Aðrir þættir aðfangakeðjunnar, sem geta haft áhrif á gæði og geymsluþol ferskfisks er forkæling fyrir pökkun, staðsetning kassa á bretti í tilfelli illa hitastýrðra kælikeðja og lengd keðjanna.

TTI (Time Temperature Indicators) var einnig greint í verkefninu þar sem búnaður var prófaður fyrir ferskar fiskafurðir og notkun hans til að meta gæðamörk afurða. Gerðar voru prófanir á TTI í geymslutilraunum til að sannreyna hvort hraði gæðabreytinga afurða væru í samræmi við virkni TTI búnaðarins.

Lykilorð: Ferskur fiskur, rekjanleiki, vörustjórnun, flutningaferlar, skipaflutningar, flugflutningar, geymsluþol, hitaskráning, TTI-vöktun.

LIST OF ORIGINAL PAPERS

This thesis is based on the following papers, referred to in the text by their respective Roman numerals:

I. Mai, N., Bogason, S. G., Arason, S., Árnason, S. V., and Matthíasson, T. G. Benefits of traceability in fish supply chains - case studies. British Food Journal. Accepted for publication 19th October 2009.

II. Mai, N. T. T., Margeirsson, S., Stefansson, G. and Arason, S. 2010. Evaluation of a seafood firm traceability system based on process mapping information - More efficient use of recorded data. *International Journal of Food, Agriculture & Environment*: 8(2), 51-59.

III. Mai, N. T. T., Margeirsson, B., Margeirsson, S., Bogason, S. G., Sigurgísladóttir, S. and Arason, S. 2010. Temperature Mapping of Fresh Fish Supply Chains - Air and Sea Transport. *Journal of Food Process Engineering*. In press.

IV. Mai, N., Margeirsson, B. and Stefansson, G. (2010). Temperature controlled transportation alternatives for fresh fish – air or sea? In J. S. Arlbjørn (Ed.), *Logistics and Supply Chain Management in a Globalised Economy. Proceedings of the 22nd Annual NOFOMA (The Nordic Logistics Research Network) Conference*, June 10-11, 2010. (pp. 147-162). Kolding, Denmark: Department of Entrepreneurship and Relationship Management, University of Southern Denmark.

V. Mai, N., Audorff, H., Reichstein, W., Haarer, D., Olafsdottir, G., Bogason, S., Kreyenschmidt, J. and Arason, S. Performance of a new photochromic time-temperature indicator under simulated fresh fish supply chain conditions. Submitted to International Journal of Food Science & Technology, May 2010.

VI. Mai, N. T. T., Gudjónsdóttir, M., Lauzon, H. L., Sveinsdóttir, K., Martinsdóttir, E., Audorff, H., Reichstein, W., Haarer, D., Bogason, S. G. and Arason, S. Continuous quality and shelf life monitoring of retail-packed fresh cod loins in comparison with conventional methods. Submitted to the journal of Food Control, May 2010.

Abbreviations

ANOVA	Analysis of variance
CBA	Cost-benefit analysis
CBC	Combined blast and contact (cooling)
CFU	Colony-forming unit(s)
EAN.UCC	European Article Number and Uniform Code Council
EPC	Electronic product code
EPS	Expanded polystyrene
GS1	Global Solutions/Global Solutions One
GLN	Global location number
GTIN	Global trade identification number
ID	Identification
LU	Logistic unit
NPV	Net present value
PCA	Principal component analysis
QDA	Quantitative descriptive analysis
RFID	Radio frequency identification
Rf-TTI	Coupled radio frequency and time temperature indicator
RRS	Relative rate of spoilage
RSL	Remaining shelf life
RSS	Reduced space symbology
SSCC	Serial shipping container code
SSO	Specific spoilage organisms
SV	Square value
SVo	Initial square value
TMA	Trimethylamine
TRU	Traceable resource unit
TTI	Time-temperature integrator/indicator
TU	Trade unit
TVB-N	Total volatile basic nitrogen
TVC	Total viable counts

TABLE OF CONTENTS

1 INTRODUCTION

Global demand and consumption of fresh fish have increased (FAO, 2009; Vannuccini, 2004; World Fishing Net, 2010), for instance a significant growth in fresh fish market has been observed in the United Kingdom (UK) during recent years (Seafish, 2010). The world production of fresh seafood has gradually grown from about 45.4 million tons in 1998 to 54.6 million tons in 2007; Of the fish destined for human consumption in 2007 48.1% was in live and fresh form (FAO, 2007). Iced fish export from Iceland has been increasing in recent years, a rise of 43.3% in volume and 37.3% in value in 2008 compared to 2007 (Statistics Iceland, 2009), amounting to about 111.7 thousand tons in 2008 (Statistics Iceland, 2009; Statistics Iceland, 2010). Export of fresh cod and haddock fillets and portions from Iceland was about 11.5 thousand tons in 2008 (Statistics Iceland, 2009), of which about 9 thousand tons were to the UK (Seafish, 2010). Export of fresh fish fillets to the UK almost tripled from 1999 to 2004 for cod and quadrupled from 2003 to 2008 for haddock (Seafish, 2010). All these facts indicate that the supply of fresh fish is increasingly important.

A common (fresh) fish supply chain is shown in Figure 1. The chain is seen as integrated from farm to fork with flows of materials and information.

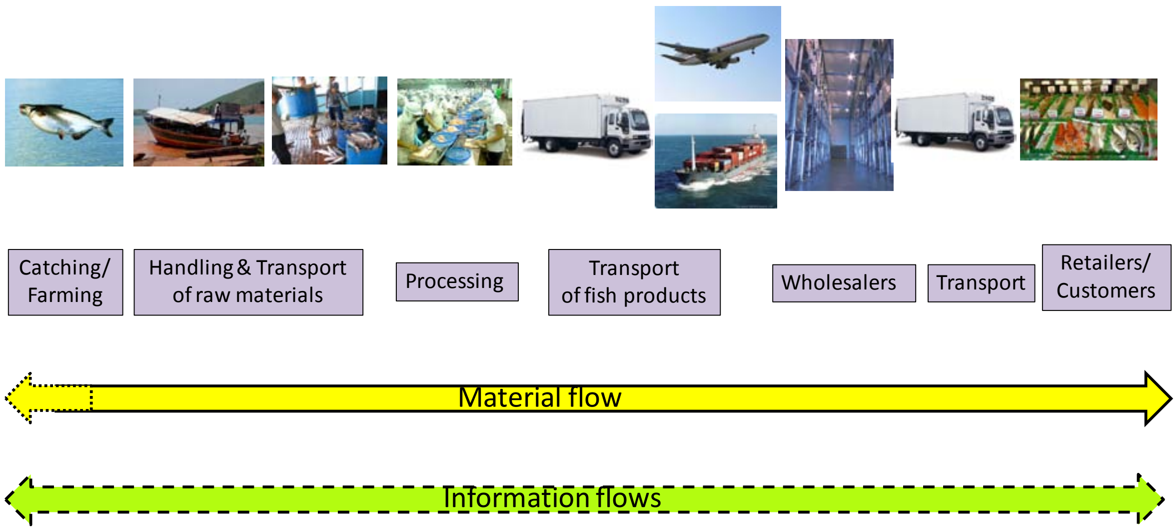

Figure 1. Integrated (fresh) fish supply chain (Adopted and modified from Coyle *et al.* (2003); EAN, (2002)).

From a supply chain management point of view, material flow is an important focus of *logistics* (Coyle *et al.*, 2003), where *quality* of products delivered to the immediate and/or final customers is emphasised. Once a product does not meet market requirements, standards or regulations, it can be rejected (Nunes *et al.*, 2003), returned (Coyle *et al.*, 2003) or even recalled in case of a food safety problem (Buhr, 2003; McEntire *et al.*, 2010). *Fish quality* is a complex concept, which for the consumer may include safety; nutritional and eating quality; freshness; obvious physical attributes of the species, size and product type; convenience and integrity; and availability (Olafsdottir, 2005; Olafsdóttir *et al.*, 1997). *Quality management* (quality assurance), defined as "all the activities and functions concerned with the attainment of quality in a company", would include the technical, managerial and environmental aspects (Huss & Ryder, 2003). The technical aspect is the main focus of quality management in the seafood industry, which includes the management of safety, freshness, shelf life and authenticity (Huss & Ryder, 2003).

Information flow is vital in supply chain management (Coyle *et al.*, 2003). It is a fundamental factor to enable product *traceability*, required by legislations (e.g. EU Regulation 178/2002 and US Bioterrorism Act PL107-188) and markets, tracking and tracing the material flow and history (EAN, 2002). It is also important to fulfil the information requests of actors and consumers in the chain related to product *quality,* e.g. information on the quality itself or on the product origin and/or handling conditions/techniques which affect the quality (Olafsdottir, 2005).

These above facts raise a need for better understanding how traceability and logistics in a fresh fish supply chain are practised, in relation to quality management, and what can be done to improve them. This study focuses on fresh fish export chains from Iceland (cod loins and haddock fillets) and, to a lesser extent, from Vietnam (*Pangasisus* fillets) which have been among the most important chains for the seafood sectors in both countries. Emphasis was to ensure the traceability effectiveness and to improve logistics management of fresh fish by more efficient use of recorded information and continuous monitoring of product temperature conditions along the chain(s) so as to enhance product quality management regarding freshness and shelf life.

1.1 Food traceability

Traceability has emerged as an important concept in food safety since the breakout of the Bovine Spongiform Encephalopathy (BSE) and dioxin crises in Europe in the last decade.

In the fields of animal health and food safety, various definitions of traceability can be found, both in legal and standard texts. *Traceability* is defined by the International Organisation for Standardisation (ISO) as "the ability to trace the history, application or location of that which is under consideration" (ISO 9000:2000 - Part 3.4.2). The term ''ability to trace and follow" is used in the European Union (EU) Regulation 178/2002 (EC, 2002b), while ''ability to follow" is present in Codex standards (CAC, 2008) or ''the creation and maintenance of records" in Bioterrorism Act 2002 of the United States of America (PL107-188, 2002). The ability to trace the product information within a company is referred to as *internal traceability*; while *external/chain traceability* is the ability to trace the product information through the links in a supply chain, or the product information a company gets and gives away (Moe, 1998).

Traceability can be divided into tracing and tracking. *Tracing* (backward or upstream) is the ability to find the origin, attributes, or history of a particular traceable item or product from given criteria, through records, upstream in the supply chain; used to find the source of the problem. *Tracking* (forward or downstream) is the ability, at every point of the chain, to find the products' localisation from given criteria; used in case of product recall and to find the cause of the problem (Bechini *et al.*, 2005; Deasy, 2002; Dupuy *et al.*, 2005; Olsson & Skjöldebrand, 2008; Schwägele, 2005).

In traceability, information accessibility is considered at four main levels: *breadth* or the amount of information the traceability system records, *depth* or how far upstream or downstream in the supply chain the system tracks, *precision* or the system assurance degree of pinpointing the movement or characteristics of a particular product, and *access* or the speed of communicating and disseminating requested information to chain actors or public health officials (McEntire *et al.*, 2010).

1.1.1 Regulations and standards on traceability

EU Regulation 178/2002, US Bioterrorism Act 2002, the 2002 and 2008 US Farm Bills - legislations on traceability of the two most important markets, the EU and the US, for agrifood and particularly seafood products - stipulate “one step back - one step forward” traceability. The regulations require food business operators to be able to know where their supplies come from and to whom their products are sent (EC, 2002b; McEntire *et al.*, 2010; PL107-188, 2002). These and other traceability-related regulations, such as EU Council Regulation 104/2000 (EC, 2002a) and EU Commission Regulation 2065/2001 (EC, 2001a), require identifying and labelling the products by lots. Furthermore, having product recall procedures in place is compulsory for a food business operator in the EU (EU Regulation 178/2002 (EC, 2002b) and Directive 2001/95/EC (EC, 2001b)) while it is voluntarily required in the US (Subpart C of Part 7 of FDA regulations 21 CFR 7.40-59 (FDA, 2003)).

In international standards such as Codex and ISO 22000:2005, traceability is also required at one step up - one step down level and considered as a tool to enable targeted product recall or withdrawal in case of a food safety problem (CAC, 2006; McEntire *et al.*, 2010).
ISO 22005:2007 presents the principles and basic requirements for the design and implementation of a food and feed traceability system. It requires that the organisation should define the information to be obtained from suppliers, to be collected concerning the product and processing history, and to be provided to its customers and/or suppliers (CampdenBRI, 2009).

The GS1 Global Traceability standard (GS1, 2009), a voluntary globally recognised standard, describes the creation of accurate records of transactions to meet the core legislative and business need for one step up-one step down traceability at any point along the supply chain and is compatible with ISO 22000:2005 for product tracing. The GS1 Traceability standard is applied using various GS1 Standards such as Global Trade Item Number (GTIN), Global Location Number (GLN), Serial Shipping Container Code (SSCC), GS1-128 Bar code, Reduced Space Symbology (RSS), Data Matrix and Electronic Product Code (EPC).

TraceFish standard (CEN, 2003; EAN, 2002) was developed by TraceFish, the European Commission funded concerted action project “Traceability of Fish Products”, as a voluntary traceability standard for the fisheries sector, providing separate standards for captured and farmed fish. The standards relate to the information that should be recorded at each stage of the supply chain in order to maintain traceability, such as information on the distribution chain and technical specification for the electronic encoding of data, based on the EAN.UCC (European Article Number and Uniform Code Council)/GS1 numbering system.

More information on traceability regulations and activities in a number of regions and countries as well as other traceability-related standards can be found elsewhere, e.g. in a recent publication of McEntire *et al.* (2010).

1.1.2 Benefits - Incentives for traceability

Food traceability has been perceived and proven to bring both *social* and *industrial* benefits. From the public or social point of view, good traceability practice in food supply chains reduces risks and costs associated with outbreaks of food borne diseases (Hobbs, 2003), e.g. reduce their occurrence magnitude and possible health impact, reduce or avoid medical costs, reduce labour productivity losses, or reduce safety costs arising from a widespread food borne illness (Can-Trace, 2007). Furthermore, readily verifiable traceability information can reduce the costs for consumers in verifying the information associated with food quality (Hobbs, 2004; Hobbs, 2003).

From the industrial perspective, traceability can result in the following benefits:

Market benefits: By implementing traceability, actors of supply chains are able to comply with laws and regulations of the markets and to meet the demands of their customers, which in turn will help them to retain and extend their markets (Leat *et al.*, 1998; McEntire *et al.*, 2010; Olsson & Skjöldebrand, 2008; Smith *et al.*, 2005; Sparling *et al.*, 2006; Wang *et al.*, 2009a). In addition, traceability helps to expand sales of high-value products or products with credence attributes (Golan *et al.*, 2004). Traceability is also found to be beneficial in terms of reducing costs associated with maintaining or enhancing consumer or market confidence in a product (Alfaro & Rábade, 2009; McEntire *et al.*, 2010; Pouliot & Sumner, 2008; Umberger *et al.*, 2003; van Rijswijk *et al.*, 2008; Wang *et al.*, 2009b; Ward *et al.*, 2005).

Benefits from recall savings: Implementation of traceability is considered as a measure to save costs associated with product recalls due to improved recall management efficiency

(Banterle & Stranieri, 2008; Buhr, 2003; Chryssochoidis *et al.*, 2009; Frederiksen *et al.*, 2002; Golan *et al.*, 2004; Hobbs, 2004; Olsson & Skjöldebrand, 2008; Poghosyan *et al.*, 2004; Smith *et al.*, 2005; Sparling *et al.*, 2006).

Benefits from reduction of liability claims and lawsuits: Another economic reason for adopting traceability systems is to reduce liability risks associated with unsafe food problems (Hobbs, 2004; McEntire *et al.*, 2010; Poghosyan *et al.*, 2004; Pouliot & Sumner, 2008; Sparling *et al.*, 2006) which are the penalties, loss of trade, damage to reputation, or loss of a brand name that may result (Frederiksen *et al.*, 2002; Poghosyan *et al.*, 2004).

Benefits from process improvements: Traceability, particularly electronic-based, has the potential to improve supply chain and company management (Poghosyan *et al.*, 2004; Smith *et al.*, 2005; Wang *et al.*, 2009a), increase production and process efficiency (Alfaro & Rábade, 2009; Buhr, 2003; Kim & Sohn, 2009), improve planning and lower cost of distribution systems (Alfaro & Rábade, 2009; Golan *et al.*, 2004) and improve inventory management (Alfaro & Rábade, 2009; Chryssochoidis *et al.*, 2009; Karkkainen, 2003; McEntire *et al.*, 2010). Sharing traceability information along with other relevant information throughout the value chain, e.g. in the cod industry, could improve the catch management and production planning, as well as optimise yields and overall profits (Margeirsson, 2007).

In addition, applying electronic-based traceability systems can also *save in labour costs* compared to paper-based systems (Alfaro & Rábade, 2009; Buhr, 2003; Chryssochoidis *et al.*, 2009).

Cost-benefit analysis (CBA) is necessary to quantitatively estimate the net benefits of traceability. So far, there has not been any scientific publication on the CBA of adopting traceability system(s) in the seafood industry.

1.1.3 Types of traceability systems

Information transfer in traceability can be conducted by several technologies which apply different media and infrastructure. The simplest type of traceability systems is paper-based. Bar codes are also commonly used and radio frequency identification (RFID) is a more recent medium. Besides there are other potential media such as vision/imaging systems, dot peening and laser etching (McEntire *et al.*, 2010).

McEntire *et al.* (2010) have reviewed the advantages and limitations of different types of traceability systems; a summary is presented in Table 1.

Table 1. Advantages and limitations of various traceability system types (Adopted from McEntire *et al.*, 2010).

Type of traceability system	**Advantages**	**Limitations**
1. Paper-based	Low cost	Potential illegibility, transposition, language barriers, fading and other physical damage
2. Barcode-based	A substantial amount of information can be contained in the bar code Relatively inexpensive Globally accepted	Need printer and reader/scanner Line-of-sight access to the bar code is required for scanning
3. RFID-based	Line of sight to the tag is not required Multiple tags can be read virtually simultaneously Labour cost savings No manual screening, variable memory Tag memory can be rewritten or appended	May be too expensive for low cost commodities Tags may interfere with recycling and biodegradation processes Radio interference
3a. Active RFID tags Internal battery powered Either transponders or beacons	Range: 1000-1100 m	More expensive, $10 to 50 Limited battery life
3b. Passive RFID tags Tags powered solely by radio frequency No battery, transmitter	Low cost (20-40 cents) No maintenance Can operate at low, high and ultra-high frequencies	Range: several meters
3c. Semipassive RFID tags Internal battery can power sensors	Relatively low cost compared to active tags	Range: several meters Limited battery life

It is worth noting that the type of media for transmitting information is totally independent from the type and quality of information conveyed, meaning that using an advanced medium such as RFID does not guarantee effective traceability if the information is lacking standardisation allowing interoperable exchanges of relevant information along the chain. Regardless of the type of medium selected, the information transmitted along the supply chain needs to be standardised (McEntire *et al.*, 2010).

1.1.4 Traceability effectiveness

Effectiveness of a traceability system is considered as its ability to collect the necessary information (Bertolini *et al.*, 2006).

In general, current traceability regulations (e.g. EU General Food Law Regulation 178/2002 and US Bioterrorism Act of 2002) and standards (e.g. Can-Trace Canadian Food Traceability Data Standard (CFTDS) version 2.0, TraceFish standard, etc.) stipulate one-up-one-down model for traceability. Therefore relevant data must be *collected, kept and shared* by all the participants in the food supply chain to accomplish this.

Three basic elements of chain traceability are (Can-Trace, 2010; CEN, 2003; Derrick & Dillon, 2004; Donnelly *et al.*, 2009; EAN, 2002; ECR, 2004; McEntire *et al.*, 2010):

- *Product, party and location identification*: Every food component from harvest, from farm or sea, and through every stage of its transformation or packaging to a finished consumer product must be uniquely identified at each stage of transformation or possession and these identifiers must be linked.
- *Recording of information*: Effective traceability requires standardising the information that needs to be recorded through each step of the food supply chain. It is required that linkages are maintained, allowing a product to be traced through the supply chain. Each time a lot number is changed, the original and resulting lot numbers must be recorded. If a lot number is unchanged, but the product moves between facilities, this must be recorded in order to follow the path of the product.
- *Linking of information*: Each business operator must transfer information about the identified lot or product group to the next partner in the supply chain or to a central data base or registry to enable information retrieval when necessary. This is to ensure a continuous flow of traceability information.

Mandatory data elements required for traceability are sender identifier, lot number, product description, product identifier, quantity, unit of measure, shipment identifier, ship from and to location identifiers, ship date, receiver identifier and receipt date. There are two types of mandatory data: master and transactional. *Master Data* is information that seldom changes and applies to product, party and location information, including information such as product description, buyer identifier and location. *Transactional Data* is unique to each individual transaction, including information such as quantity, lot number, shipment identifier and shipment date (PMA & CPMA, 2006).

Optional data elements are for enhanced traceability and include information such as best before date, contact information, country of origin (province/state), logistics provider identifier, pack date, receiver name, sender name, shipping container serial number and vehicle identifier (PMA & CPMA, 2006).

As a best practice, the lot number and name of the manufacturing facility should appear on each case of product; and the lot number(s), quantity and shipping location should appear on invoices and bills of lading (McEntire *et al.*, 2010).

The three basic traceability elements are practised with four key traceability principles which are *unique identification* of products, logistics units and locations; traceability *data capture and recording*; *links management* and traceability data retrieval; and traceability *data communication* (ERC, 2004).

To meet the chain traceability requirement, all actors in the chain have to practise well their own traceability. Information related to history (e.g. temperature record, information related to production process), application (e.g. information related to property: weight, species, fat content, etc.) and location (e.g. distribution route) should be recorded and linked to a traceable unit. Each actor is required to record identifications (IDs) of suppliers and transporters of received trade units (TUs) and IDs of buyers and transporters of dispatched TUs. Internal traceability requires all transformations during the production to be recorded (Donnelly *et al.*, 2009; Senneset *et al.*, 2007). For instance, a complete bill of lots of resources contributing to the composition of a product batch has to be registered (Kelepouris *et al.*, 2007). It can be summarised that there are three basic operation types to obtain internal traceability: *recording the unique IDs of traceable resource units (TRUs)*, e.g. IDs of batches of raw materials or ingredients; *assigning unique IDs to new TRUs*, e.g. IDs for products; and *linking* a set of input unique IDs to one or more sets of output unique IDs, e.g. *recording transformations* of raw materials to final products (Derrick & Dillon, 2004; Donnelly *et al.*, 2009; Lindh *et al.*, 2008; McEntire *et al.*, 2010; Senneset *et al.*, 2007; Thompson *et al.*, 2005). Recording of process and transformation information is considered as routine procedures of an internal traceability system (Senneset *et al.*, 2007).

A *traceable resource unit (TRU)* is defined as a batch of any resource (Kim *et al.*, 1999; Thakur & Donnelly, 2010). *Batch* is often synonymous with *lot* (ECR, 2004; Olsen &

Karlsen, 2005) which is a definite quantity of some commodity produced, manufactured or packaged under uniform conditions (Bechini *et al.*, 2005; McEntire *et al.*, 2010).

1.2 Logistics of fresh food, particularly fresh fish; Effect of logistics practice on the product quality

Temperature is considered to be the main factor that affects the quality and safety of perishable food products (Jedermann *et al.*, 2009), particularly fresh fish (Olafsdottir, 2005). Abusive and/or fluctuating temperature accelerates the growth of specific spoilage organisms (SSO) as well as pathogens (Jol *et al.*, 2005; Raab *et al.*, 2008; Rediers *et al.*, 2009), causing quality and safety problems and thus economic losses.

Fresh fish is often stored and/or shipped at melting ice temperature (ATP, 2007; Einarsson, 1992; Einarsson, 1994; Panozzo & Cortella, 2008; Pawsey, 1995) or even below 0 °C, at superchilled temperatures (Olafsdottir *et al.*, 2006; Sivertsvik *et al.*, 2003) to keep it good and safe for a certain period of time. However, the fresh fish supply chains may face certain hazards when the requirements are not fulfilled.

The transportation of perishable products such as fresh fish is very common by air as it is rapid (James *et al.*, 2006; Simpson *et al.*, 2003). However, during loading, unloading, truck and air transportation, storage and holding the product is normally subjected to temperature abuse at un-chilled conditions (Brecht *et al.*, 2003; Nunes *et al.*, 2003), which means that much of its journey, up to 80%, is un-protected (James *et al.*, 2006). The temperature of the hold during flight is normally 15-20 °C (James *et al.*, 2006). Therefore, air freight of perishable food requires some form of insulation around the products as well as precooling/cooling of the products before transportation (James *et al.*, 2006; Laurin, 2001).

Fluctuating and/or high temperatures even for a short time were reported to cause the rejection of a whole strawberry load (Nunes *et al.*, 2003). Results from a study on chilled modified atmosphere packaged (MAP) Pacific hake shows that even a small fraction of storage time (4.3%) at abusive temperature can cause a significant reduction in shelf life (25%) of the product (Simpson *et al.*, 2003).

Another mean of transporting fresh fish is by sea where the product is containerised (Seafish, 2010) in refrigerated containers to maintain the required low temperature for the whole voyage. This mode of transportation, however, takes much longer time compared to air freighting. It is worth noting that the quality of perishables is reduced as time elapses even at optimum conditions of handling (Pawsey, 1995).

The importance of having the food at the correct temperature before loading it into transport containers has been emphasised as refrigeration systems in the containers are designed to maintain the temperature of the load, but not to extract its heat (James *et al.*, 2006).

Air freight has been dominant for fresh fish fillets or portions while container shipping is more common for whole gutted fish (Seafish, 2010). This is because fillet products are more susceptible to microbiological spoilage than whole fish due to the microbial contamination of fish flesh during and after filleting (Einarsson, 1992). However, recently it has been observed that technical developments have also made container transport a feasible option for fillets (Seafish, 2010).

Several studies on the effect of different factors, such as product locations on a pallet, presence of insulating covers and precooling methods, in the cold chains on the temperature distribution and quality of food products have been conducted. Rediers *et al.* (2009) mapped the temperature of fresh cut endive from the point of harvest through the distribution chain to restaurant storage and found that the position of the product on the pallet influenced its temperature, product on the top of the pallet responded more rapidly to environmental temperature changes than those in the middle or at the bottom of the pallet. Similar results were found by Raab *et al.* (2008) during a temperature mapping of a chilled chicken breast supply chain, product temperature at the top level of the pallet was more influenced by surrounding temperature fluctuations than at the middle or bottom of the pallet. Moureh & Derens (2000) have studied and modelled the temperature evolution of frozen fish product at different positions on a pallet during transport, the results of which support previous findings that products/boxes which have more free surfaces to the surroundings, e.g. at the top corners of a pallet, are more sensitive to changes in temperature. Moureh *et al.* (2002) also found that the top corners of a pallet were the most sensitive regions to the surroundings as they had three free surfaces; and studied the use of insulating pallet covers for shipping heat-sensitive foodstuffs in ambient conditions. Laurin (2001) found that precooling methods affected quality of air transported asparagus. Heat transfer models developed by Moureh and Derens (2000) and Moureh *et al.* (2002) can be used to evaluate the product tolerable time for transport and improve packaging design in order to decrease the negative effects of ambient temperature fluctuations on product temperature.

Trade-off between modes of transportation should be made based on the quality and safety perspectives regarding time-temperature history, customer requirement on delivery time, economic efficiency related to cost of transport, cost of more efficient packaging and weighed against the resulting overall environmental impacts. Air transportation is quick, but expensive (Simpson *et al.*, 2003) and with several hazardous steps during ground and flight operations regarding temperature abuse. During passenger flights fish boxes are more exposed to the environment due to the splitting up of pallets. Freighter flights are more fuel efficient than passenger flights, but more affected by fuel prices than passenger flights since their fuel cost is a much larger part of total expenses (Morrell, 2008). Sea transportation is considered to be a cheaper mean of transport. The product temperature is well-controlled during the whole logistics inside refrigerated containers (James *et al.*, 2006). While air transport has several strong, but short lasting, effects on the global temperature, shipping emissions have a cooling effect on climate that lasts 30-70 years due to very high emissions of SO_2 and NO_x, but also with dominating warming effect in the long term because of significant amounts of CO_2 emitted (CICERO, 2008). By optimizing the logistic chain, energy and environmental benefits can be obtained (Panozzo, 1999).

1.3 Time temperature indicators to continuously monitor the quality of food

Time-temperature indicators (TTIs) are small devices that can be attached to the food or the food package which is in close contact to the food. They show an easily measurable, time temperature dependent change which must be irreversible and easily correlated to the food deterioration process and remaining shelf life (Taoukis & Labuza, 1989a).

TTIs have shown a great potential to continuously monitor temperature conditions throughout a chain from packaging to consumption (Kreyenschmidt *et al.*, 2010; Riva *et al.*, 2001; Taoukis & Labuza, 1989a; Tsironi *et al.*, 2008), to indicate the abuse (Labuza & Fu, 1995), as well as to replace direct temperature recordings (Riva *et al.*, 2001).

The operation of a TTI is based on mechanical, chemical, electrochemical, enzymatic or microbiological reaction systems that change irreversibly after being activated (Fu & Labuza, 1992; Giannakouroua *et al.*, 2005; Kreyenschmidt *et al.*, 2010; Labuza & Fu, 1995; Taoukis *et al.*, 1999; Taoukis & Labuza, 1989a; Wells & Singh, 1988). The change rate increases at higher temperatures similarly to most chemical reactions. The change is usually expressed as a visible response, such as colour development and/or colour movement or mechanical deformation.

Some types of TTIs are “partial-history” indicators, responding only after a predetermined threshold temperature has been exceeded (Wells & Singh, 1988); some are “abuse” indicators, showing whether the product was exposed to unacceptably high temperatures (Taoukis & Labuza, 1989a); and many others are full time-temperature history integrators, responding to all temperature conditions (Taoukis & Labuza, 1989a; Wells & Singh, 1988).

1.3.1 Kinetic approach to apply TTI for monitoring food quality

Taoukis & Labuza (1989a) developed kinetic models which allowed the correlation of the response of certain TTI types to the quality change and the remaining shelf life of a product that had undergone the same temperature history (Figure 2).

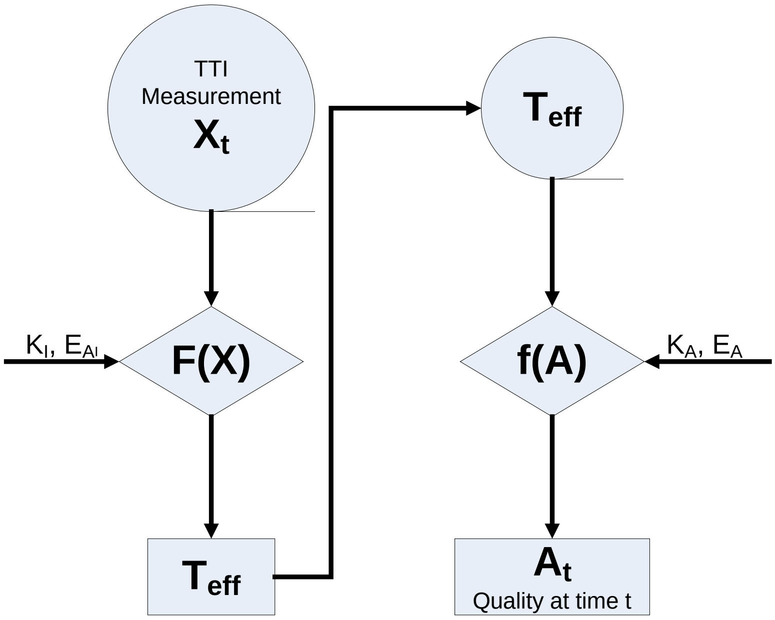

Figure 2. Kinetic approach for applying TTIs to monitor food quality (Adopted from Taoukis & Labuza (1989a)) (see explanations in the text).

A simple form of the quality function showing the change with time of a quality parameter A of a food (such as physical, chemical, microbiological or sensory indices) during a known variable temperature exposure T(t) can be expressed by Eq. 1:

$$f\left(A\right)_t = \int_0^t k dt = k_A \int_0^t \exp\left[\frac{-E_A}{RT\left(t\right)}\right] dt \tag{1}$$

where $f(A)_t$ is the quality function of the food; k the reaction rate constant, an exponential function of inverse absolute temperature, T, given by the Arrhenius expression, $k = k_A \exp\left(-E_A / RT\right)$, k_A a (pre-exponential) constant, E_A the activation energy of the reaction controlling quality loss, and R the universal gas constant. The activation energy of chemical and enzymatic reactions, as well as microbial growth in food is within the range of 10-120 kJ/mol (Taoukis *et al.*, 1998; Taoukis & Labuza, 1989a).

Introducing the term effective temperature T_{eff}, which is defined as the constant temperature that results in the same quality value $f(A)_t$, as the variable temperature distribution over the same time period, $f(A)_t$ can be expressed as:

$$f\left(A\right)_t = k_A \exp\left(\frac{-E_A}{RT_{eff}}\right)t \qquad (2)$$

The same kinetic approach can be used to model the measurable change X of the TTI with a response function $f(X)_t$. When the TTI is exposed to the same temperature history T(t) as the food product, the response function can be expressed by Eq. 3 using the effective temperature concept:

$$f\left(X\right)_t = k_I \exp\left(\frac{-E_{A_I}}{RT_{eff}}\right)t \qquad (3)$$

where k_I and E_{AI} are Arrhenius parameters of the indicator (TTI).

As seen in Figure 2, if the change value X of the TTI at time t is measured, the value of the response function can be calculated. By solving Eq. 3, T_{eff} is then derived. With the T_{eff} and the quality loss parameters of the food (k_A and E_A) known, the quality function f(A) is calculated from Eq. 2 and from there the value of the quality index A_t at time t is found. This allows the remaining shelf life of a product to be calculated at any assumed average temperature of downstream distribution and to better manage product quality.

For this effective temperature approach, there is an important underlying assumption, i.e. $T_{eff(food)} = T_{eff(TTI)}$, for a given temperature distribution. This is only true when $E_A = E_{AI}$ and when the temperature is constant throughout the distribution. The smaller the difference in the activation energy of food and TTI, the more accurately the TTI indicates actual shelf life of the food product (Taoukis & Labuza, 1989a). Therefore, the TTI manufacturers are more likely to produce TTIs with appropriate compositions and temperature sensitivities to match the activation energy value of food quality changes.

1.3.2 Applicability of TTIs for monitoring quality of different food products

The applicability of TTIs for safety and quality management and for decision making in meat cold chains has been studied to improve distribution management as well as to replace the current "First In First Out" (FIFO) practice (Oliva & Revetria, 2008). Least Shelf Life First Out (LSFO) TTI-based systems were proposed for chilled (Taoukis *et al.*, 1998) and frozen (Giannakourou & Taoukis, 2003) food products.

Numerous studies have been carried out on the application of different TTI types to monitor the quality and shelf life of various food products such as refrigerated dairy products (Fu *et al.*, 1991), fresh tomatoes and naked wrapped lettuce (Wells & Singh, 1988), chilled Russian and eggplant salads (Taoukis *et al.*, 1998), frozen green peas and white mushrooms (Giannakourou & Taoukis, 2002), MAP fresh pork cuts (Taoukis, 2006), chilled Mediterranean fish boque (*Boops boops*) (Taoukis *et al.*, 1999) and fresh farmed turbot (*Psetta maxima*) packed in PVC film (Nuin *et al.*, 2008).

Kinetic models of various TTI types have been developed to correlate with the quality changes and the remaining shelf life (RSL) of a product, which has undergone the same temperature history (Giannakourou & Taoukis, 2002; Nuin *et al.*, 2008; Shimoni *et al.*, 2001; Taoukis *et al.*, 1998; Taoukis *et al.*, 1999; Taoukis & Labuza, 1989a, 1989b; Tsironi *et al.*, 2008; Yan *et al.*, 2008).

Recently, Kreyenschmidt *et al.* (2010) studied the kinetic behaviour of a novel photochromic OnVu™ TTI at isothermal conditions from 2 to 15 °C. They developed a contour diagram used for defining the right charging level of the TTI labels to suit the shelf life of a product under the same temperature conditions. The new TTI was found to produce reproducible responses under the studied conditions and, therefore, constitute a reliable tool to monitor the cold chains of food products (Kreyenschmidt *et al.*, 2010).

1.3.3 OnVu™ time temperature indicator

The newly introduced printable OnVu™ 197 TTI - Patent EP 1049930 B1 (Ciba Specialty Chemicals & Freshpoint, SW) is a solid state reaction TTI, based on the inherent reproducibility of reactions in a crystal phase. Photosensitive compounds are excited and coloured into dark blue by exposure to low wavelength (such as UV) light. This coloured state will reverse to the initial colourless state at a temperature depended rate (Galagan &

Su, 2008; Kreyenschmidt *et al.*, 2010) (Figure 3). The visual end point can be set by comparison to a light blue printed reference. By controlling the type of the photochromic compound and the length of UV light exposure during activation, the length and the temperature sensitivity of the TTI can be set. To prevent the re-activation of a charged label, an UV-Vis filter is applied on the surface of the label (Figure 4).

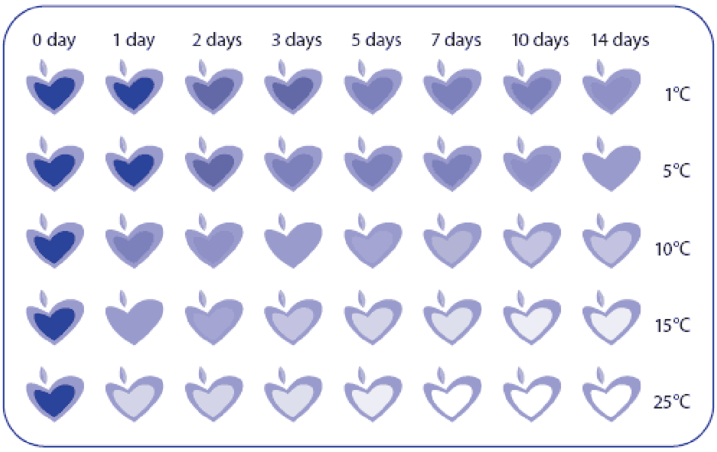

Figure 3. Discolouration process of OnVu^{TM} labels at different temperatures (http://www.onvu.compictureshow_works_large.gif).

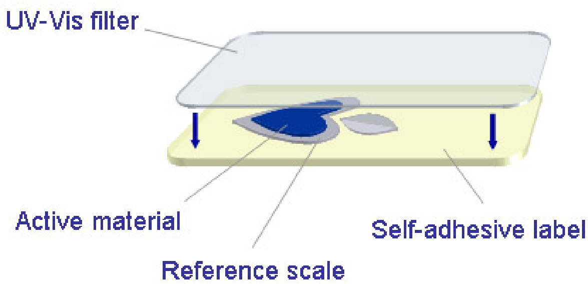

Figure 4. Structure of an OnVu^{TM} label (http://www.onvu.com/pictures/Processes/TheStrucktureOfAnOnvuLabel.jpg).

2 AIM OF THE PROJECT

Though traceability has been practised for several years in response to legislative and market requirements, its effectiveness has not been observed for all companies in the food industry (Levinson, 2009). A framework for self assessment of traceability system effectiveness is therefore important for companies in a food/seafood supply chain so as to enable them to take necessary actions to ensure traceability. Furthermore, little knowledge on the seafood industrial benefits of traceability and lack of systematic approach for decision making on implementing traceability may restrict actors in a seafood supply chain from adopting a more advanced traceability system or solution. Detailed information of traceability benefits in the seafood sector and cost-benefit analyses are necessary to bridge the gap here. Compliance and efficiency of quality control and full traceability at plants can only be achieved by fully integrating laboratory data with the movements of materials, production, final products, shipping and customer information (Deasy, 2002). However, available data on quality, process control and process parameters are normally not efficiently exploited by companies. Therefore, it is desirable to explore a more efficient use of recorded data to improve quality and supply chain management.

Despite the availability of scientific and practical knowledge on the effect of different factors in cold chains on the temperature distribution and quality of food products, detailed information of temperature evolution, as the main factor affecting fish freshness, during the logistics of fresh fish with regard to different modes of transport (air vs. sea), precooling practice and product location is not sufficiently researched and reported and thus requires further study. This is to find out hazardous steps in the chain to improve logistics management and quality management of fresh fish products. Automatic and continuous monitoring of the temperature history of fresh food throughout the distribution chain by time-temperature indicators is a promising alternative in freshness control (Olafsdottir, 2005; Olafsdóttir *et al.*, 1997). The applicability of a newly introduced photochromic TTI for chilled fish products under dynamic conditions of real supply chains requires further research.

The aim of the project was to:

- Investigate the qualitative and quantitative benefits of traceability and the net benefits of adopting a new traceability system for the seafood industry through cost-benefit analysis which can be used as a decision support tool;
- Develop a framework to evaluate the effectiveness of traceability systems of food/seafood producers;
- Explore the temperature evolution of fresh fish products during logistics processes as affected by modes of transport (air vs. sea freighting), precooling (with/without), and product location in relation to the product shelf life so as to improve logistics management;
- Explore the applicability of a novel photochromic time-temperature indicator to continuously monitor the temperature history, quality and shelf life of fresh fish products under dynamic temperature conditions in a supply chain context, in comparison with other methods of quality control.

The focus of the studies described in this dissertation will be on fresh fish export chains from Iceland (cod loins and haddock fillets) and Vietnam (*Pangasius* fillets) to the European market. These chains are among the most important ones in the seafood sectors in the two countries. The findings can potentially be extended to other fresh fish chains.

Specific research questions of the project were as follows:

- What are the benefits of traceability? What are the net benefits of adopting new traceability system(s) for the seafood industry? How are the costs/benefits of implementing new traceability system(s) distributed among the actors in a chain? (Paper I)
- What are the main components to ensure traceability? How is traceability practised at a seafood processing company? What kinds of data are recorded and how? Does such traceability system meet the TraceFish standard? How can the effectiveness of traceability systems at food/seafood producers be evaluated? How can recorded data be used more efficiently? (Paper II)
- How does the temperature of fresh fish evolve during the logistics from processing to market as affected by modes of transport (air vs. sea freighting), presence/absence of precooling and locations of products? What are the pros and

cons of each mode of transport? How is the shelf life of fresh fish affected by logistics? What can be done to improve the logistics? (Papers III and IV)

- How does the novel photochromic OnVu^{TM} time-temperature indicator perform under dynamic temperature conditions in a fresh supply chain context? Is it applicable to continuously monitor the temperature of fresh fish products? Can the kinetic model, developed for isothermal conditions at 2-15 °C, be applied for lower temperatures? How should the charging level(s) be chosen to suit the shelf life of the fresh fish products concerned? (Paper V)
- Where should TTI labels be placed on retail packs of fresh fish? Is it possible to use the novel OnVu^{TM} TTI to continuously monitor the temperature history, freshness and shelf life of fresh fish (cod loins in retail packs) as an alternative to other conventional methods of quality control such as sensory, chemical and microbiological analyses or to replace direct temperature recordings? (Paper VI)

The results will provide insights into seafood companies' perspectives on the benefits of adopting new traceability system(s) or solution(s) and knowledge on the net benefits of the project(s) and on the distribution of costs and benefits among the actors, which support decision making. A framework to assess traceability system effectiveness will help food/seafood companies to locate problems and take necessary actions to ensure an effective traceability. Further, the results on temperature profiling will identify hazardous steps, allowing business operators in fresh fish supply chains to improve their logistics as well as to make decision on transport alternatives so as to improve quality management. Additionally, the results will allow choosing suitable activation levels and correctly placing the TTI to monitor the quality and shelf life of the fresh fish products concerned.

Altogether the outcomes of this study will provide a necessary basis to enhance quality management at a firm level in terms of improved logistics management and ensured traceability effectiveness. The information gained is not only of academic interest, but also of great practical importance for the fish industry in general and fresh fish supply chains in particular.

3 MATERIALS AND METHODS

In this chapter an overview of the materials and methods used in the thesis is given. The samples and experimental procedures are described in more detail in the original papers I-VI.

3.1 Study design

The thesis is based on the studies described in papers I-VI. An overview of the study design is illustrated in Figure 5. The study focused on the two main pillars of a fresh fish supply chain – *traceability* and *logistics*, among others (e.g. initial quality of raw materials and ingredients and their handling process and processing technology), which affect the *quality* of a product delivered to the customer(s).

Initially, a literature review and surveys were carried out to estimate the qualitative and quantitative benefits of traceability. The inputs from the surveys were then used to perform cost-benefit analyses of adopting new traceability systems to estimate the net benefits and cost/benefit distribution among actors in the chain (I). Furthermore, a literature study and process mapping were conducted on the necessary components to ensure traceability and recorded information at a firm. The outcomes were used to develop a framework for evaluating traceability system effectiveness as well as suggestions for more efficient use of recorded data (II). In paper III, temperature mappings were done for several fresh fish supply chains transported by air and sea. Hazardous steps were pinpointed, the pros and cons of each transport mean were analysed, and improved practices were proposed (III, IV). Papers V and VI focused on investigating the performance and applicability of the novel OnVu™ time-temperature indicator to continuously monitor temperature conditions, quality and shelf life of fresh fish in a supply chain context. This was to find out the reliability (V), and the right placement and charging level(s) of the TTI for monitoring purposes (V, VI).

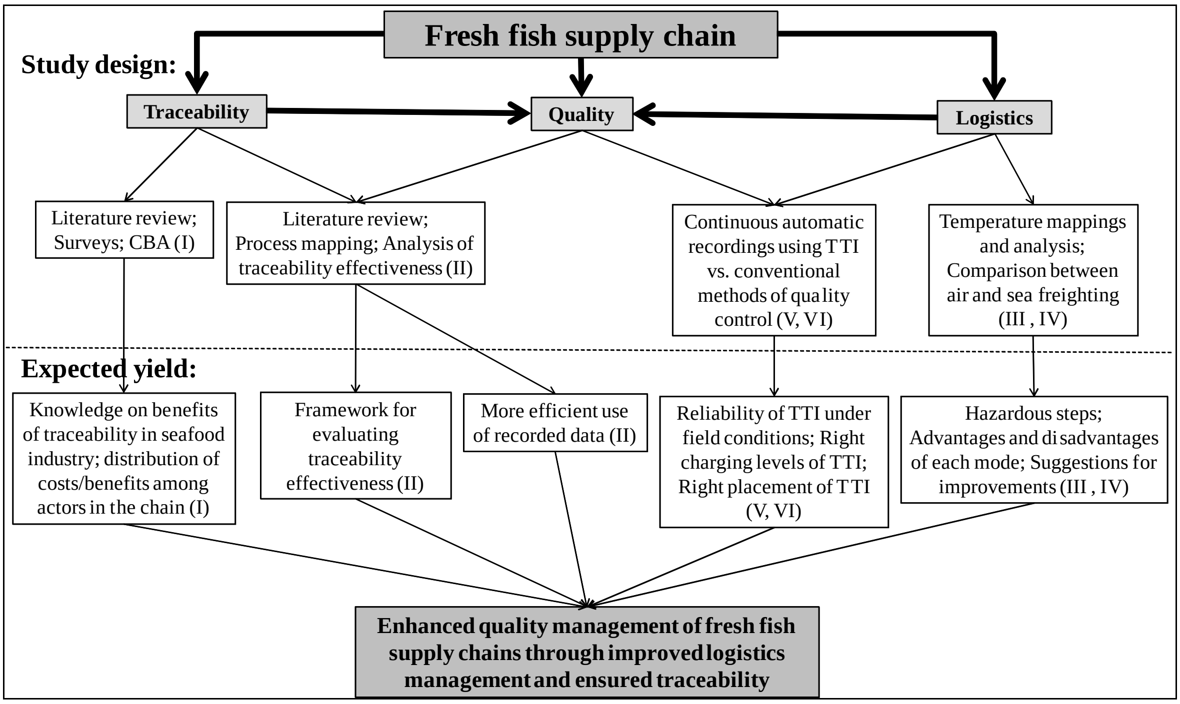

Figure 5. Overview of the study design. Paper numbers are shown in parentheses.

3.2 Surveys

To investigate the seafood companies on their attitudes toward traceability implementation and benefits, an on-line questionnaire using a 5-point Likert scale (from 1 = "very unlikely" to 5 = "very likely") was used. The questionnaire was adopted and modified from the one used for the Chinese seafood industry (Wang *et al.*, 2009a). In one part of the questionnaire, the companies were asked how they qualitatively perceived benefits of the implementation of traceability systems by rating their answers. The studied groups were seafood companies, located in European Economic Area (EEA), Vietnam and Chile, involved in one or more steps of seafood supply chains, namely, traders, processors, suppliers, importers and exporters (I).

To obtain quantitatively perceived benefits of implementing traceability and adopting new traceability system(s) or solution(s), a questionnaire with 7 sections and 21 questions was used for interviewing seafood companies. The first section of the questionnaire asked for general information about the companies and their attitude toward a new traceability system or solution. In the second to the sixth sections, the interviewees were asked to quantitatively estimate their perceived benefits of a specific new traceability system or solution with regard to market, recall, liability, process improvements and labour cost savings. The last section asked about company size and yearly turnover. The interviewees were either chairmen or managerial staff of the companies who know their production and business well. The questionnaire was emailed about one month in advance to the companies for preparation. Each interview took about 45-60 minutes (I).

The costs of implementing a traceability system or solution were obtained from another type of questionnaire to technology developers where they asked to itemise and monetise all the opportunity costs together with the lifespan, if applicable, of each item needed (I).

All the questionnaires were developed or adopted based on the results from the literature review and expert suggestions and tested with some volunteer companies for improvements/modifications before their actual use.

3.3 Cost-benefit analysis

Ex ante cost-benefit analyses (CBAs) of adopting new traceability system(s) were based on the calculation of net present value (NPV) (Eq. 4, I) as described by Boardman *et al.* (2006).

$$NPV = \sum_{t=0}^{n} \frac{NB_t}{(1+r)^t} \tag{4}$$

where t is the time of the cash flow; n the lifetime of the project; r the discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk); NB_t the net benefits at time t, $NB_t = B_t - C_t$, B_t the benefits arise at time t; and C_t the costs arise at time t (I).

Costs associated with permanent structures were not included in the calculation. Furthermore, before-tax real Euro and real discount rates were used as the analyses were assumed to reflect the gross benefits accruing to the processor and trader. In addition, it was assumed that implementation of the project would not affect the market price of inputs used due to its small size (Bell and Devarajan, 1983; Dreze and Stern, 2001).

The calculations were based on the following assumptions:

- A real discount rate of 4.5% was used for base-case scenario; sensitivity analysis was performed with discount rates currently used in EU countries between 2.4 and 7.0% (Evans and Sezer, 2005);
- The time frame of the system was five years, based on the survey responses of the technology developers;
- The first cash flow occurred at the end of each year from the first year;
- As the system was composed of relatively short lifetime items, depreciation was assumedly ignored;
- The scrap value of system items equalled zero.

In the conducted cost-benefit analyses, three scenarios were considered: base-case, worst-case and best-case. In the base-case scenario, discount rate was 4.5%; costs were the average estimated; and benefits were assigned with two values "Low" or lower bound of estimated benefits and "High" or upper bound of estimated benefits. In the worst-case scenario, discount rate was 7.0%; costs were the maximum estimated; benefits were the lower-bound estimated. For the best-case scenario, discount rate was 2.4%; costs were the minimum estimated; and benefits were the upper-bound estimated.

3.4 Process mapping

Process mapping was based on a method and structured tables of questionnaires described by Olsen & Karlsen (2005) and Olsen & Aschan (2010). The questions aimed to find out the flow of materials and information within and through the studied company, the traceable units, unit identifications (identifiers), transformation points of the processes, the presence or absence of the links/recorded relationships between the identified units and the ability to track and trace through a company. The mapping included a backward factory walk through; in-depth interviews (1-2 hours each) with the quality control (QC) manager, production manager and laboratories' staff; and a document analysis on traceability, quality, process control and other recorded files (II).

3.5 Temperature mapping

Temperature mappings were performed with the help of temperature data loggers, which were configured in the way that temperature changes at different positions inside a box and on box surface, and at different positions of boxes on a pallet could be sufficiently monitored. For each studied box, loggers were placed at the bottom, middle and top height levels inside the box, and another logger was placed outside on the (top or side) surface (II, III, IV). On each studied pallet, temperatures of three (sometimes four) boxes positioned at bottom corner, middle side, top corner, and sometimes top middle of the pallet were mapped. In each study set, one or two pallets were investigated (III, IV).

DS1922L temperature loggers iButton® (Maxim Integrated Products Inc., CA, USA) were used for mapping the temperature inside the boxes, with temperature range -40 °C to 85 °C, resolution 0.0625 °C, accuracy ± 0.5 °C and ± 1 min/wk. Recording intervals were set at 2-10 min. TBI32-20+50 Temp Data Loggers Onset® (Onset Computer Corporation, Southern MA, USA) were used for the measurement of ambient temperature on the box surfaces, with temperature range -20 °C to +50 °C, resolution 0.3 °C, accuracy ± 0.4 °C and ± 1 min/wk. Recording intervals were set at 1-5 min. All loggers were calibrated in thick mixture of freshly crushed ice and water before use (II, III, IV).

3.6 Laboratory reference methods

3.6.1 Sensory evaluation

The Quantitative Descriptive Analysis (QDA) introduced by Stone and Sidel (1985) and a freshness score sheet modified from the Torry scale originally described by Shewan *et al.* (1953) were used to assess the cooked samples of cod loins (VI).

3.6.2 Chemical measurements

Total volatile basic nitrogen (TVB-N) and thrimethylamine (TMA) was performed by the methods described by Malle & Tao (1987) (VI).

3.6.3 Microbiological analysis

Total viable psychrotrophic counts (TVC) and counts of H_2S-producing bacteria (black colonies) were done on iron agar (IA), modified from Gram *et al.* (1987) by using 1% NaCl and no overlay. Plates were spread-plated and incubated at 17°C for 5 days. Enumeration of presumptive pseudomonads was performed using modified Cephaloridine Fucidin Cetrimide (mCFC) agar as described by Stanbridge & Board (1994). *Pseudomonas* Agar Base (Oxoid) with CFC selective Agar Supplement (Oxoid) was used and the plates were incubated at 22°C for 3 days.Counts are reported as logarithmic average values ($\log_{10}$ colony-forming units (CFU)/g) (VI).

3.7 TTI experimental set up

3.7.1 TTI activation

The OnVu™ TTI B1+090807 (Ciba Specialty Chemicals & Freshpoint, Basel, Switzerland) were activated in an automated UV light charger GT 240 Bizerba (Bizerba GmbH & Co. KG, Balingen, Germany) with a speed of 10 labels/min and covered after charging with an UV-filter Thermal Transfer Ribbon TTR 70QC 53141 to prevent any further light-induced reactions. The charging was done under stable ambient (temperature and relative humidity) conditions (V, VI).

3.7.2 TTI discolouration measurements

TTI colour changes were measured with Gretag Macbeth OneEye spectrophotometer (X-Rite, Regensdorf, Switzerland) at D65 illumination and 2° observation angle conditions. The measurements were done in the laboratory at an ambient temperature of 6-7 °C. The square value (SV) in CIE-Lab space (Eq. 5) was used to characterise the TTI-charging and discolouration process:

$$SV = \sqrt{L^2 + a^2 + b^2} \tag{5}$$

where L represents the lightness of the labels; a represents their redness and greenness; and b represents their yellowness and blueness. The reference scale corresponds to a measured SV value of 71, which is regarded as the end of a charged OnVu label's shelf life (Kreyenschmidt et al., 2010) (V, VI).

3.7.3 TTI kinetic model fitting

The square values (SV) of the non-abused labels were fitted with a sigmoidal function (Eq. 6) (Kreyenschmidt et al., 2010):

$$SV(t) = \frac{d}{1 + e^{-k(t-c)}} \tag{6}$$

where d is the amplitude of the colour change; c is the reversal point; k is the rate constant of the colour change, which is temperature-dependent; and t is the storage time (V, VI).

3.8 Data analysis

Microsoft Excel 2003 or 2007 (Microsoft, Redmont, WA, USA) was used to calculate means, standard deviations and ranges for all measurements and to generate graphs (I-VI).

Analysis of variance (ANOVA) was used to test whether groups were significantly different with regard to temperatures at different locations on a pallet or inside a box and at different steps of a fresh fish supply chain (III), or at plate/tray surfaces and within the product (V, VI) with post hoc Tukey and Bonferroni correction; TTI response (V, VI); and sensory attributes with Duncan's multiple comparison test (VI). T-test was applied if there were only 2 groups (V, VI). For variables on ordinal scales and/or in cases when sample numbers in each group were ≤ 6, a non-parametric Wilcoxon W test was used (I, V, VI). All tests except on QDA data were performed using the software SPSS version 16.0 (SPSS, Chicago, Il, USA) (I, III, V, VI). QDA data were corrected for level effects, caused by level differences between assessors and replicates, by the method of Thybo & Martens (2000) and ANOVA was carried out on QDA corrected data using the statistical program NCSS 2000 (NCSS, Utah, USA) (VI). All tests were performed with a significance level of 0.05 (I, III, V, VI).

Multivariate analysis was performed using the Unscrambler version 9.0 (CAMO Process AS, Norway). The main variance in the data set was studied using principal component analysis (PCA) with full cross validation. Data were autoscaled prior to the PCA, that is, first centred by subtracting the column average of elements from every element in the column; and then each element was scaled by multiplying with the inverse standard deviation (1/STDEV) of the corresponding variable, to handle the model offsets and to let the variance of each variable be identical initially (Bro and Smilde 2003) (III).

The Seafood Spoilage and Safety Predictor (SSSP) software version 3.0 (DTU Aqua, Denmark) was used to predict the effect of time-temperature combinations on the RSL based on the recorded temperature profile. Recorded product temperature data were fitted into a square-root model for relative rate of spoilage (RRS) of fresh seafood from tropical (II) or temperate waters (III, VI). In SSSP, RRS is defined by the ratio of sensory shelf life at a reference temperature, normally 0 °C, to the sensory shelf life of the product under evaluation at T °C (Dalgaard, 2002) (II, III, VI).

Origin 7.5 (OriginLab, Northampton, MA, USA) was used to fit the TTI data and to build graphs (V, VI).

4 RESULTS AND DISCUSSION

4.1 Benefits of traceability

Benefits of traceability in the food industry can be categorised into qualitative (intangible) and quantitative (tangible) groups (Table 2, I). *Qualitative* benefits here are those that are infeasible or difficult to be quantified and assigned monetary values; *quantitative* ones, in the other hand, can be monetised (Boardman *et al*., 2006). Quantitative benefits in turn are classified into five subgroups: market benefits, savings on recall costs, savings on liability costs, savings on process improvements and labour cost savings (various sources, e.g. Can-Trace, 2007; Chryssochoidis *et al.*, 2009; Golan *et al.*, 2004; Hobbs, 2004; McEntire *et al.*, 2010). A survey conducted in Beijing, China showed that 60.1% of the consumers were willing to pay a price premium, about 6% in average and up to 10%, for traceable fish products to increase safety (Wang *et al.*, 2009b). Navobi calf-milk replacer manufacturer through its traceability information system was able to save over $100,000 in recalls and recovery costs from a *Salmonella* outbreak (Buhr, 2003). Gilde Norge, a Norwegian slaughtering plant, has incorporated an electronic traceability system with a visual grading system and obtained an increase of 5-7% in the final meat yields (Buhr, 2003). Margeirsson (2007) indicated that traceability led to transparency in the cod value chain and that sharing of traceability information (such as origin) along with other relevant information (such as catching method, grading, fillet yield, gaping and parasite) could help managing the catch (fishing ground and volume) and organising the processing. More examples on the benefits of traceability are given in the following subsections.

Table 2. Summary of traceability benefits based on a literature survey (I).

	Benefit categories					
	Qualitative (intangible)	*Quantitative (tangible)*				
		Market	*Recall*	*Liability*	*Process*	*Labour*
Market recovery improvement		x				
Market and revenue growth		x				
Product price premium		x				
Less frequent recalls			x			
Less severe recalls			x			
Better management of recalls			x			
Less frequent claims & lawsuits				x		
Less severe claims & lawsuits				x		
Liability insurance cost reduction				x		
Inventory turnover improvement					x	
Spoilage/out of date cost reduction					x	
Yield improvements					x	
Labour cost savings						x
Regulatory & legislative compliance	x					
National security	x					
Enhanced customer confidence/trust	x					
Litigation risks mitigation or elimination, e.g. ability to shift the responsibility to other(s)	x					
Resolution of track trace data gaps	x					
Company reputation - customers	x					
Company reputation - consumers	x					
Company reputation - government & public	x					
Improved customer service	x					
Company reputation - suppliers	x					
Being technological proficient and an industry leader in new technologies and processes	x					

Variuos sources (among others): Buhr, 2003; Karkkainen, 2003; Can-Trace, 2004; Poghosyan *et al.*, 2004; Sparling *et al.*, 2006; Pouliot and Sumner, 2008; Chryssochoidis *et al.*, 2009; Wang *et al.*, 2009a.

4.1.1 Qualitative benefits of traceability

Seafood companies in the studied groups consider improving supply chain management as the most important benefit of traceability (Figure 6, I). Other perceived benefits are the increase of the ability to retain existing customers, product quality improvement, product differentiation and reduction of customer complaints. The results here are similar to the findings of Wang *et al.* (2009a) on the perceived benefits of traceability by Chinese seafood enterprises, which are, in general, the improvement of product quality and improvement of management style. Overall, the Vietnamese and EEA companies perceive that traceability can reduce liability claims and lawsuits, while the Chilean firm does not have the same perception. The EEA companies' group and the Chilean firm also see traceability benefits in the reduction of product spoilage. These benefits have also been considered and/or reported in other food sectors, e.g. improvement of supply management (Golan *et al.*, 2004), increase of product quality (Chryssochoidis *et al.*, 2009; Poghosyan *et al.*, 2004), retaining of existing beef markets in those countries which require traceability (Souza-Monteiro & Caswell, 2004) and product differentiation in the fresh fruit and vegetable industry (Golan *et al.*, 2004) and the dairy-processing sector (Sparling *et al.*, 2006).

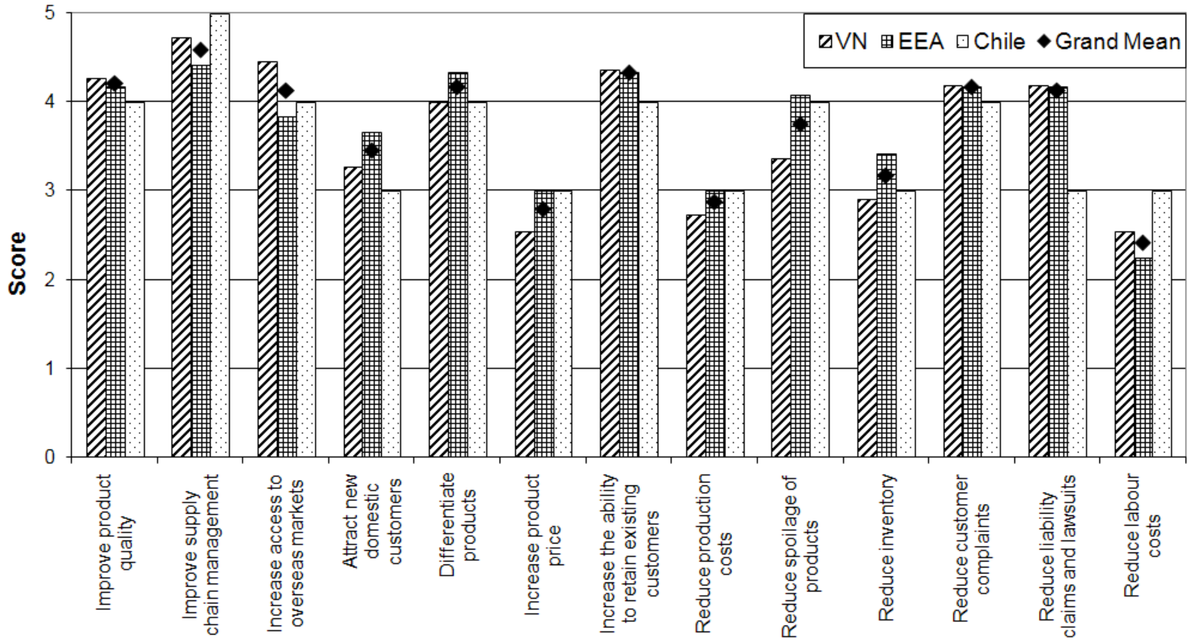

Figure 6. Qualitative peceived benefits of traceability from the industrial perspectives. The mean scores across the companies of the same region are given for 11 Vietnamese (VN) and 12 European Economic Area (EEA) firms; single values of scores are shown for the Chilean (Chile) company. The average score across 24 companies is also shown as grand mean (I).

Surprisingly, other benefits of traceability highlighted in the literature, such as reduction of inventory costs (Can-Trace, 2004), reduction of production costs, increase of product price (e.g. positive consumer willingness-to-pay) (Hobbs, 2003; Hobbs *et al.*, 2005) and saving of labour costs (Buhr, 2003; Chryssochoidis *et al.*, 2009) are considered of minor importance by the companies-respondents. No significant difference ($p > 0.05$) of perceived benefits was found between the Vietnamese and EEA companies' groups.

4.1.2 Cost-benefit analyses of adopting advanced traceability systems

Present and net present values of benefits of 5-year lifetime of two RFID-based traceability systems were calculated and are presented in Table 3 (I). The three scenarios included the effects of uncertainty related to the discount rate (2.4, 4.5% and 7.0%) and future benefits (lower bound and upper bound). As shown in Table 3, in the seafood processing company case, aiming to use passive RFID tags Rf-TTI (coupled radio frequency and time temperature indicator) on all master boxes, the net present value (NPV) of the lower-bound base-case scenario, where the benefits of recall reduction have not been perceived, is negative. Contrastingly, when the recall is expected to be reduced from 0.25 ("unlikely") level with the current traceability to 0.1 ("very unlikely") with the new system (see Paper I), the NPV becomes positive. The NPV in the trading company case, aiming to use one active RFID tag on each pallet, is always positive; and the benefits by far outweigh the costs (16-252 times). Although not all the scenarios of the seafood processing company case appear to be beneficial in monetary terms, it is worth noting that the new traceability solution in this case is aimed at a more detailed level (master boxes) than in the trading company case (pallets).

Table 3. Present values of benefits and net benefits of implementing new traceability solutions (€ thousand) (I).

Benefit components	*Processing company case*				*Trading company case*			
	Worst	*Best*	*Base*		*Worst*	*Best*	*Base*	
			Low	*High*			*Low*	*High*
Market growth benefits [a]	0.0	0.0	0.0	0.0	18,691.6	39,062.5	19,138.8	38,277.5
Recall reduction [b]	0.0	1,164.8	0.0	1,097.5	0.0	0.0	0.0	0.0
Savings from clams & lawsuits	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Labor cost savings [a]	93.5	195.3	95.7	191.4	37,383.2	58,593.8	38,277.5	57,416.3
Savings from process improvements [a]	0.0	48.8	0.0	47.8	0.0	0.0	0.0	0.0
Total benefits	*93.5*	*1,408.9*	*95.7*	*1,336.7*	*56,074.8*	*97,656.3*	*57,416.3*	*95,693.8*
NPV	*-6,952.6*	*1,191.1*	*-749.4*	*491.7*	*52,648.8*	*97,270.2*	*56,615.4*	*94,892.9*

[a] Assume that benefits occur once at the end of the first year. [b] Assuming yearly benefits, from the end of the first year. NPV is net present value.

Because the two case studies are not of the same supply chain and aimed at different traceability solutions (rf-TTI vs. active RFID tags) and precisions (boxes vs. pallets), the CBA results are not comparable. However, they have strengthened the argument on costs shifting among the stakeholders in a supply chain. It was shown that the seafood processing company paid much for what was needed, resulting in some negative NPVs, while the trading company could expect steady benefits. In order to implement new traceability solution(s), e.g. RFID-based, at the supply chain level, it is suggested that the price of intermediate products would go up, which is a way that trading companies could entice or persuade food producers to put new traceability system(s) in place. The findings support the need for an open discussion between different actors in a food supply chain on the distribution/redistribution of costs and benefits of implementing traceability (Can-Trace, 2004).

4.2 Traceability effectiveness in the fresh fish supply chain and more efficient use of recorded data

4.2.1 Effective traceability framework

Main components to ensure traceability at a food/seafood processing firm can be summarised as follows: registration of unique IDs for all resources' batches, registration of unique IDs for all newly formed batches, recording of all relevant product and process information and linking it to the batches' IDs, and transferring all traceability relevant information of the inputs (e.g. relevant batches IDs and associated information) with the product to the next step (e.g. next production step or next link of the chain) (Can-Trace, 2010; CEN, 2003; Derrick & Dillon, 2004; Donnelly *et al.*, 2009; EAN, 2002; Kelepouris *et al.*, 2007; Lindh *et al.*, 2008; McEntire *et al.*, 2010; Senneset *et al.*, 2007; Storøy *et al.*, 2007; Thompson *et al.*, 2005). Based on these, a framework to assess the effectiveness of a company traceability system was developed and is presented in Table 4 (II). A traceability system is effective if all the assessed questions can be answered in the affirmative (YES), if not required actions (RA) need to be taken to ensure traceability effectiveness. Detailed required actions or modifications to a seafood firm traceability system to ensure traceability should be consulted elsewhere, e.g. the traceability guide of Derrick & Dillon (2004).

Table 4. Framework for evaluating the effectiveness of a food processing company's traceability system and necessary modification to ensure traceability (II).

Question No.	Category of traceability information	Question	Possible answer and next action	Required Action (RA)
Ia	**Resource ID registration**	**Ia.** Are all batches of resources (e.g. raw materials and ingredients, etc.) registered with unique IDs?	- YES → Go to **Ib** - NO → Go to **RA-Ia**	**RA-Ia.** Register all batches of resources with unique IDs. Go to **Ib**.
Ib	**Resources' information**: associated/ relevant resources' information other than IDs	**Ib.** Is all traceability relevant information of resources' batches (e.g. suppliers' IDs, date of reception, quantity, grade, quality, etc.) provided and/or recorded, kept, and linked to batches' IDs?	- YES → Go to **II** - NO → Go to **RA-Ib**	**RA-Ib.** Develop procedure(s)/method(s) to obtain, keep, and link all traceability relevant information of resources' batches to their IDs. Go back to **Ib**.
II	**Transformation information**	**II.** Are all relevant resource, product, and process information (e.g. bill of lots) recorded and linked to resources' IDs or product IDs?	- YES → Go to **III** - NO → Go to **RA-II**	**RA-II.** Record all relevant resource, product, and process information and link to batches' IDs. Go to **III**.
III	**Product ID registration**	**III.** Are unique IDs assigned to all newly formed batches (e.g. product) and are these records kept?	- YES → Go to **IV** - NO → Go to **RA-III**	**RA-III.** Assign unique IDs to all newly formed batches and keep records. Go to **IV**.
IV	**Transferred information**	**IV.** Is all traceability relevant information of the input(s) (e.g. relevant IDs of the input(s) and associated information) transferred with the output (e.g. product) to the next step (e.g. next production step or next link of the chain)?	- YES → Go to **Conclusion** - NO → Go to **RA-IV**	**RA-IV.** Develop procedure(s)/method(s) to transfer all relevant IDs of input(s) and associated information with the output to the next step. Go back to **IV**.
		Conclusion: Traceability system is effective		

4.2.2 Traceability practice at a seafood processing company-a case study

Results from analyzing the traceability system at a Vietnamese *Pangasius* processing company using the proposed framework (Table 4, II) show that all the answers are YES which indicate a sufficient traceability system. Details on the IDs' configuration, product and process information inputs, and how the associated IDs are linked are presented in Paper II. Figure 7 shows traceability information flow at the company, indicating the link between associated IDs as well as between unit IDs and their associated product and/or process information.

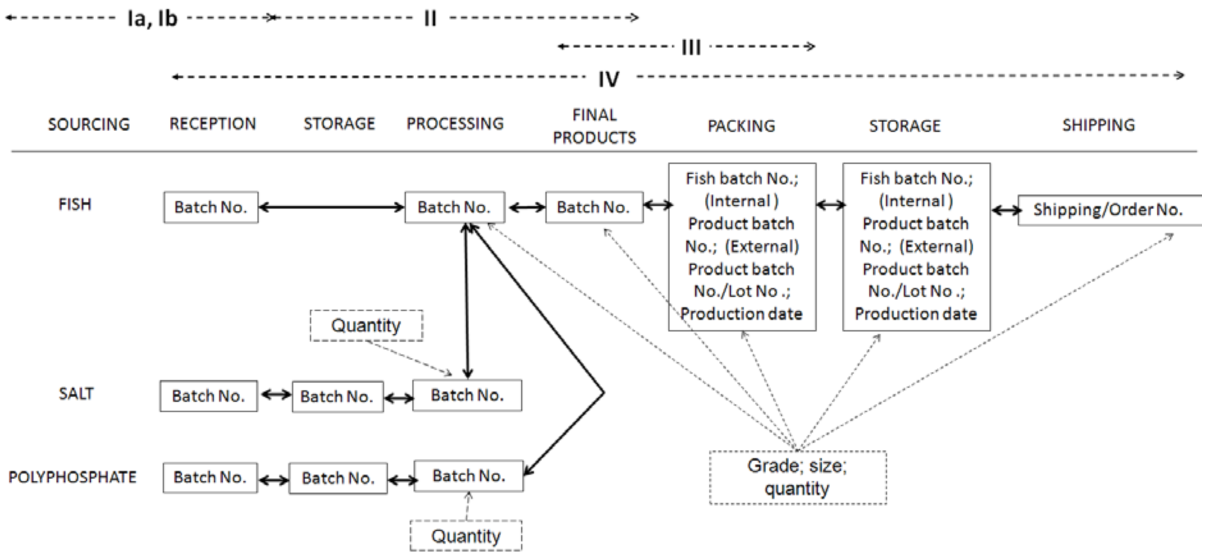

Figure 7. Traceability information flow at the processing plant. Frame boxes = IDs of the units; Two-way arrows = links between the units; Dash boxes = associated information; Dash one-way arrows = link of associated information to unit IDs. The dash two-way arrows with Roman numerals show the mapped areas with respective assessed questions for evaluating the effectiveness of the traceability system (II).

At the studied company, for each of all incoming batches of raw materials and ingredients, the IDs of suppliers and transporters are recorded in the reception form (II). For every dispatched batch of product, the IDs of buyers and transporters are recorded in the shipping form (II). This is in accordance with good traceability practice concerning information transfer for chain traceability (Storøy *et al., 2007*).

The current traceability system is effective because the codes of incoming resources (i.e. fish and ingredients' batch numbers) are associated uniquely to the final product (i.e. internal product batch number) and the codes of final product are also linked to the lot numbers (i.e. external product batch number) which are used for logistics and distribution (Bertolini *et al.*, 2006). All the data of the current system conform to mandatory data list of food traceability as described by Folinas *et al.* (2006). The studied system also meets the fundamental structure of a traceability system proposed by Moe (1998).

4.2.2.1. Ability to trace

Tracing back from the distributor through the company can be practised using the information on the box labels about the *production date* and the *external product batch number* which is uniquely assigned to each *product batch* defined as a certain type of product (e.g. fresh *Pangasisus* fillets) produced from the same fish raw material batch in the same production shift, date and workshop (II). Batch number of fish raw material (or *fish batch No.* for short) is uniquely assigned a three-digit ordinal number for each production year to the raw material from the same pond received at the processing plant during the same day. The company is then able to trace the origin of their products up to aquaculture pond level using an internal code system. Each product batch is uniquely assigned an *internal product batch number*, indicating the processing workshop; the shift; production date and the farming pond code uniquely given by the company (II).

Other ingredients can be traced back through the company to a delivery batch of a supplier. This is because a delivery of the resource from a certain supplier is uniquely assigned an *ingredient batch number* which is indirectly linked to the product batch number through the fish batch number. However, sometimes a product batch is produced from one fish batch and more than one batch of an ingredient, meaning that sometimes the traceability level is at a group of two continuously received ingredient batches (II).

4.2.2.2. Ability to track

Tracking forward through the company is possible using the same set of identifiers-numbers as when tracing back. Tracking of fish raw material is rather simple as there is no mixing of the resource from a pond throughout the production and to the customer. Concerning the other ingredients, e.g. a delivery of polyphosphate is normally used for 15 days of production. Therefore, if a recall (although very unlikely) of a delivery batch is issued by its supplier, a half month production of fish would have to be recalled (II). Frederiksen *et al.* (2007) have indicated that material identity with the longest time in production, e.g. polyphosphate in this case, has to be very well controlled, as it affects many product lot identities. The willingness to improve the precision of ingredients' traceability depends on the recall risks of each resource and the final product, detail level of information required by the customers and associated costs (Donnelly *et al.*, 2009; Kelepouris *et al.*, 2007; Moe, 1998; Randrup *et al.*, 2008). This is an area for future research.

4.2.2.3. Compliance with regulation and standard

The company meets with 178/2002 European Common Food Law requirements (EC, 2002b) for traceability which consider one step forward - one step backward traceability. However, the traceability system does not meet with TraceFish requirements (CEN, 2003) because globally unique identifiers, identified by Global Trade Item Numbers (GTIN), are not used (II).

4.2.3 More efficient use of recorded data

Connecting traceability with the whole documentation and control system represents an effective mean to improve the consumers' perception on food safety and quality (Moe, 1998). Along with traceability information, lot of information on process parameters and on quality is recorded and kept at the company, mainly in paper form and most of them for internal use only (II). These facts restrict the company from using the available data in an efficient manner. These data could be entered into computer system for faster access. Data on ambient temperature during logistics steps can be used to calculate the product warm up time (Margeirsson, 2009) (II). Furthermore, with the correlation between ambient and product temperatures, the remaining shelf life of a product can be estimated, using available software such as SSSP (DTU Aqua, Denmark) (II). These thus help to improve the management of product quality as well as improve the supply chain management (II).

4.3 Logistics of fresh fish: air versus sea transport. Measures for improvements

4.3.1 Air transport

Results from temperature mappings of air cargo and passenger freights for fresh cod loins and haddock fillets in expanded polystyrene (EPS) boxes from producers in Iceland to customers in the UK are shown in Figures 8 and 9. There are several critical steps found in air freighting, especially in the passenger flight, including the flight itself, loading/unloading operations, land transport and holding storage at un-chilled conditions (III, IV). Similar hazardous operation steps of air transport have been reported by Brecht *et al.* (2003); James *et al.* (2006); and Nunes *et al.* (2003). These cause fluctuation and/or rise of product temperature inside boxes, especially in those with more free sides such as at top corners of the pallets (III, IV). Position of the product on a pallet influences the product temperature evolution: middle boxes are the most resistant while top and bottom corner boxes are more sensitive to environmental temperature changes (III, IV). Other authors (Moureh & Derens, 2000; Moureh *et al.*, 2002; Raab *et al.*, 2008; Rediers *et al.*, 2009) have also found that products in the middle of a pallet are less affected by the ambience than those on top level, which is explained by better insulation of the middle part. All these authors have, however, found that the top corner boxes are the most influenced by the environment while it is not always the case in this study where bottom corner boxes are sometimes the most sensitive. This difference might be caused by different positioning of the pallets in relation to the cooling units and/or door.

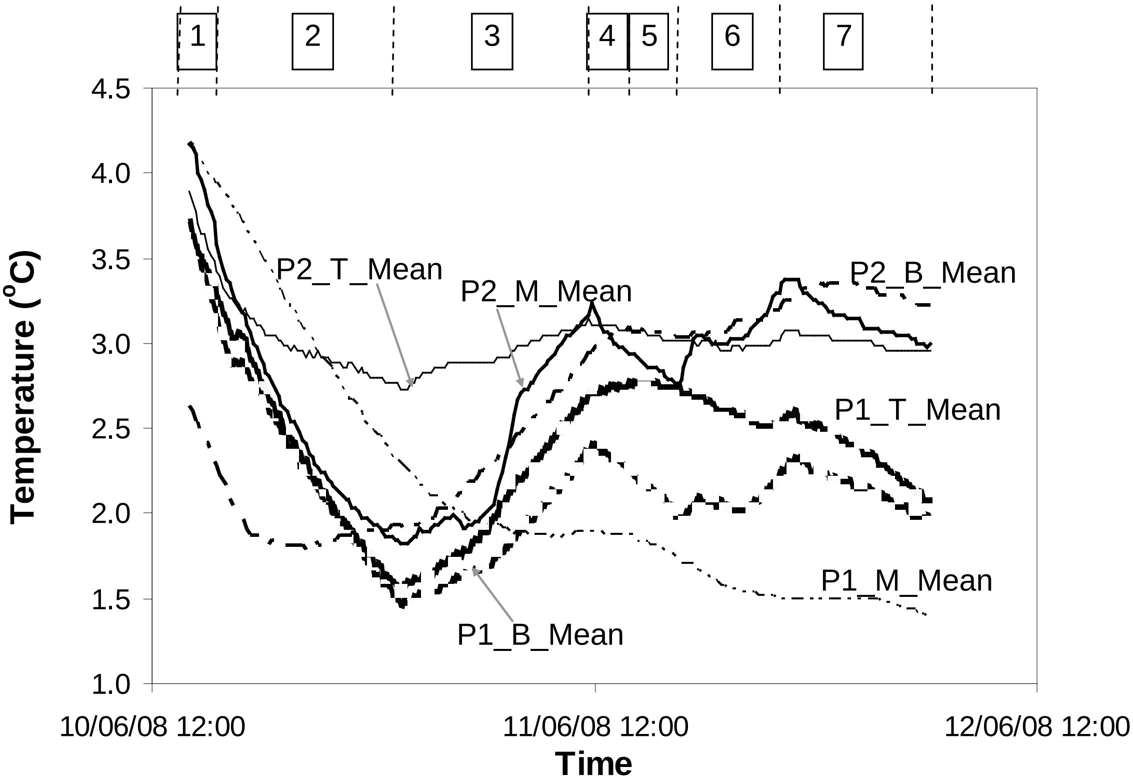

Figure 8. Average product (cod loins in 3-kg EPS boxes) temperature (_Mean) on two pallets during a cargo air freight study. P stands for pallet. T, M and B indicate top corner, middle side and bottom corner boxes on a pallet. Numbers in squared boxes indicate steps in the supply chain: 1 = Cold storage after packing at the producer (Dalvik); 2 = Loading truck and transportation to Reykjavik (RVK), 3 = Un-chilled storage over night in RVK, 4 = Transportation in refrigerated truck to Keflavik (KEF), 5 = Chilled storage at KEF airport, 6 = Loading at KEF and flight from KEF to Nottingham (UK), 7 = Transportation from processor storage (III).

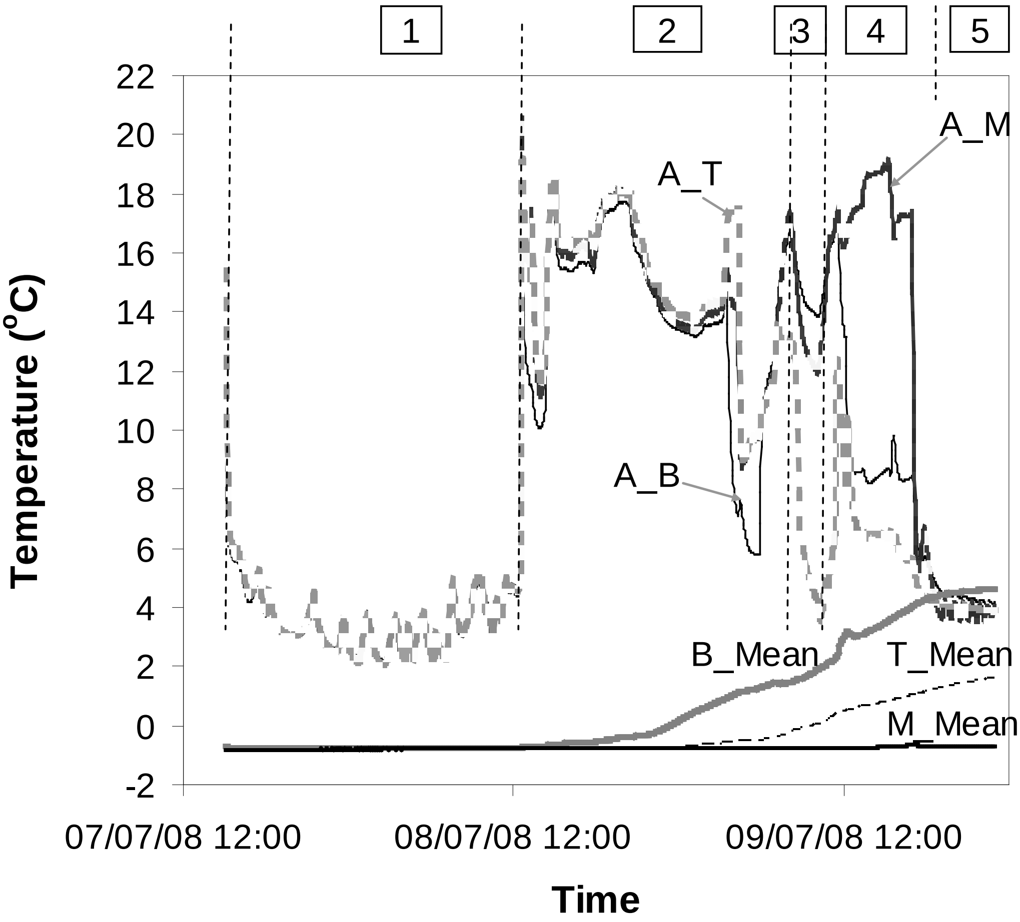

Figure 9. Box surface (A_) and average product (haddock fillets in 12-kg EPS boxes) (_Mean) temperatures during a passenger air freight study. T, M and B indicate top corner, middle side and bottom corner boxes on a pallet. Numbers in squared boxes indicate steps in the supply chain: 1 = Chilled storage at the producer in Hafnarfjordur (IS) after packaging; 2 = Transport from Hafnarfjordur to some storage at KEF, 3 = Flight duration, from taking off to landing, 4 = Storage at London Heathrow airport (LHR, UK), 5 = Land transport in refrigerated truck to the secondary producer in Plymouth (UK) (III).

The greater the temperature fluctuation around the boxes, the larger the temperature range inside the packaged product becomes (III). Temperature on top of the product inside the EPS boxes is more sensitive to ambient changes than those deeper in the box (III). Giannakourou *et al.* (2005) have also shown that there is a difference in temperatures between top and middle levels inside transported Styrofoam ice boxes of chilled gilt-head seabream during most abused/fluctuated periods.

Furthermore, precooling reveals an important operation before loading for transportation. Those products which were precooled resulted in lower temperature at the end of the logistics compared to those without precooling (III, IV). This is in accordance with the recommendation to precool product before transportation (James *et al.*, 2006).

4.3.2 Sea transport

In contrast to air transport, temperature mapping for sea freighting (Figure 10, III, IV) shows very stable temperatures of both the ambience and product since in the sea freight chain the boxes were kept in a refrigerated container for the whole trip from the processor to the final destination. Furthermore, the product temperature difference between locations inside a box is small (≤ 0.2 °C most of the time) thanked to the pre -cooling (by liquid and combined blast and contact (CBC) cooling) before skinning and adding of ice on top of the fillets when packing into the EPS boxes. Product temperature was maintained well below 0 °C as normally stated in contracts (III, IV).

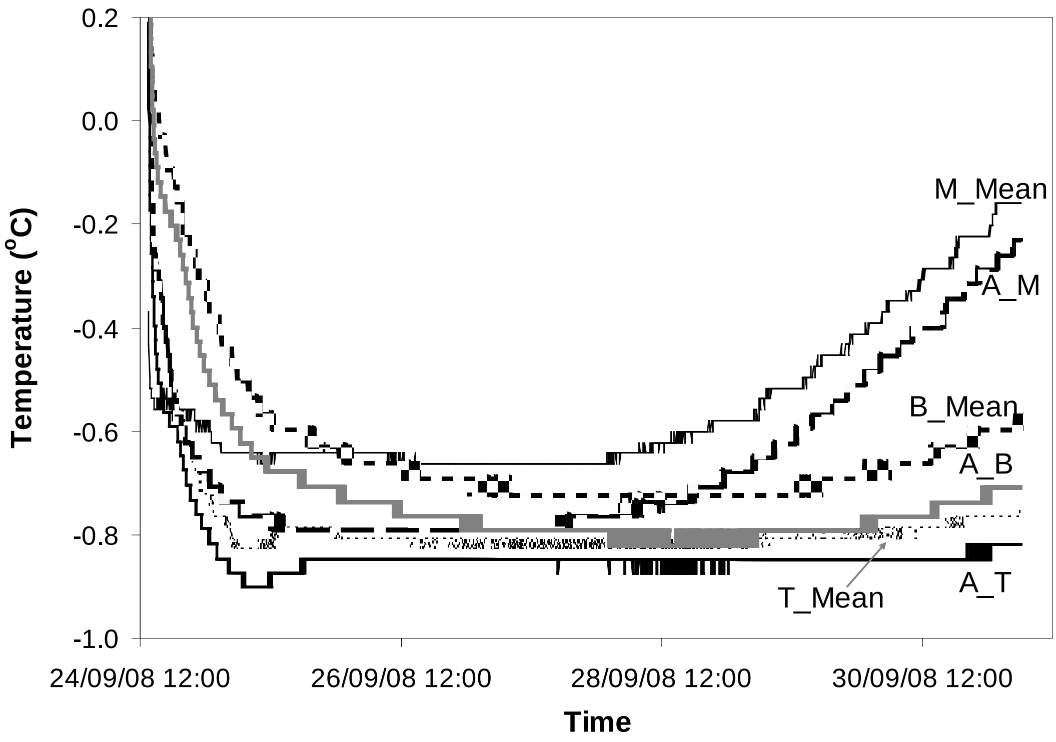

Figure 10. Box surface (A_) and average product (cod loins in 5-kg EPS boxes) (_Mean) temperatures of the top corner (T), bottom corner (B) and middle side (M) boxes on a pallet during a sea transport study (III, IV).

4.3.3 Influence of logistics on the product shelf life

Figure 11 gives an overview on three air and one sea trips regarding total used time (length of the logistics plus three days from catch), predicted remaining shelf life (RSL), and (average) temperatures of product and box surface. The product RSL is affected by the length of the logistics, presence/absence of precooling, mode of transport as well as product location (III, IV).

Length of the logistics (time from packaging to delivery at customers, e.g. retailers, including handling, storage and transport processes): Longer logistics result in shorter remaining shelf life as seen in the cases of the air freight in September 2007 and sea freight in September 2008 compared to other cases despite the fact that the temperature was well controlled in sea transport (III). This verifies an earlier observation that even under optimal conditions the quality of a perishable product apparently decreases with time (Pawsey, 1995).

Presence/Absence of precooling: Precooling helps to lower the initial temperature of the product, reduce the temperature heterogeneity between different height levels inside a box, and increase the RSL as in the case of air passenger transport in July 2008 even though the pallet was split up (III). This reveals the importance of precooling the product before packing as stated by others (James *et al.*, 2006).

Mode of transport affects the logistics length and ambient temperatures (Figure 11, III), meaning that transport mode affects the product time-temperature history, and consequently influences on the product shelf life (III). It is understandable as temperature and time are the key factors affecting the product degradation process (Jol *et al.*, 2005; Olafsdottir, 2005; Pawsey, 1995; Raab *et al.*, 2008; Rediers *et al.*, 2009), thus its RSL.

Product location: Products at different locations on a pallet and inside a box experience different degrees of environmental temperature changes and their temperatures evolve differently (Figures 8-10, III, IV), which in turn affects the RSL (III).

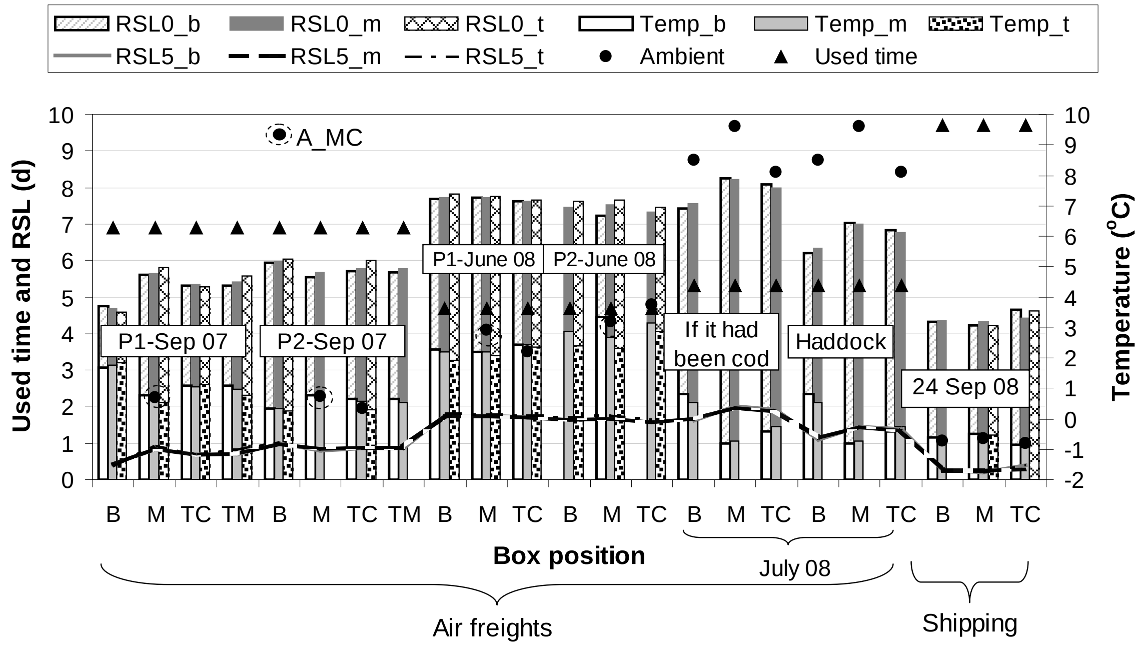

Figure 11. Total used time from catch and predicted remaining shelf life (RSL) of product at 0 °C (RSL 0) and 5 °C (RSL 5). The average ambient (Ambient) and product (Temp_) temperatures over the whole logistics from different pallets (P1, P2), box positions on a pallet (B = bottom, M = middle side, TC = top corner and TM = top middle) and locations inside a box (b = bottom, m = middle height and t = top) are also shown. A_MC means the temperature on the side of a pallet. The 3 lines of predicted RSL at 5 °C (RSL 5_b, _m and _t) are almost identical on the graph (III).

4.3.4 Improvement of logistics management in fresh fish supply chains

Air freight transportation has several critical steps, including pre and post transportation and the flight itself (*transportation*), loading/unloading operations (*handling*), and holding storage at un-chilled conditions (*storage*). The single process contributing to the highest rise in product temperature in the current study turned out to be the storage process. This indicates that most potential for improvements is during this process, which would in most cases require access to a cool storage within the airport area, where products can then be moved fast to the airplanes for loading and further transportation to distributors or retailers (IV).

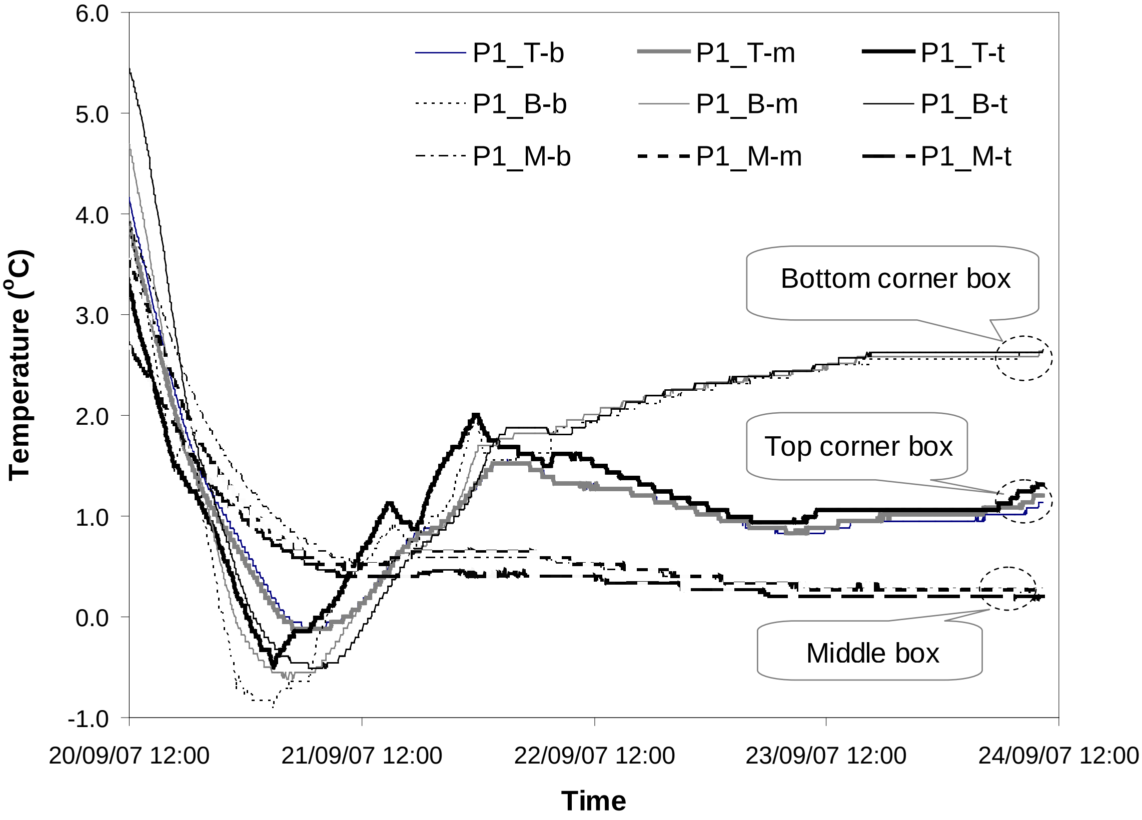

Figure 12. Product temperature at different locations on a pallet and inside the boxes during the air cargo study in September 2007. P stands for pallet; T indicates top corner box; B is bottom corner box; and M is middle side box of a pallet; t is top; m is middle height; and b is bottom product inside a box (III, IV).

Heterogeneity in temperature of product at different locations on a pallet indicates that it is possible to group the boxes according to their positions on pallets and collect boxes with similar temperature evolution during the pallet unloading (Figure 12, III, IV). This would potentially increase the market duration and possible shelf life of the products which have been exposed to lower ambient temperatures (III, IV). Jedermann *et al.* (2009) have also mentioned about grouping product items with equal temperature behaviour in batches.

Furthermore, precooling is recommended to lower the product initial temperature and reduce the temperature gradient between product levels inside a box so as to withstand the temperature fluctuations and/or abuse as well as long duration of the logistics (III, IV). This is in accordance with suggestions of precooling the product stated elsewhere (James *et al.* 2006).

Overall, the temperature mapping and predicted RSL results (Figures 8-12) support the need to continuously monitor time and temperature history of products (Giannakourou *et al.*, 2005). Long exposure to high temperature also facilitates pathogen to growth (Raab *et al.*, 2008) which causes food safety problems. To better manage fish quality including safety, it is useful to apply some technology such as temperature data loggers, time temperature indicator (TTI) labels, radio frequency identification (RFID) tags with the temperature sensor and time recorder or other similar equipment on or inside the packaged product. Heat transfer modelling of individual and palletised EPS boxes containing fresh fish, similar to the modelling of frozen fish pallets by Moureh and Derens (2000) and Moureh *et al.* (2002), would be useful to predict product temperatures under dynamic ambient conditions as described in the current study.

4.4 Continuous monitoring of quality and shelf life of fresh fish in comparison with conventional methods

The newly introduced printable photochromic OnVu™ TTI has been tested for its reliability under the fresh fish supply chain temperature conditions (V) as well as its applicability for quality and shelf life monitoring of fresh cod loins in retail packs compared to conventional methods of quality control (VI).

4.4.1 Performance of the new photochromic OnVu™ TTI under nonisothermal conditions of fresh fish supply chains

The reliability of a TTI is an important issue to enable the application of the TTI in cold chain management (Shimoni *et al.*, 2001; Kreyenschmidt *et al.*, 2010). Reproducible charging process and responses of the TTI under the conditions concerned are therefore of great importance.

4.4.1.1. Reliability of the new TTI

The investigation results show that the new TTI has produced reproducible responses right after charging and during the whole discolouration process both under isothermal temperatures below 2 °C and nonisothermal conditions simulating real fresh fish supply chains. The discolouration of the TTI reflected well its undergone temperature conditions. Some activation levels of the TTI were found to give similar lifespan of the TTI as that of air packed fresh fish products (cod fillets) under the same temperature conditions. All these indicate the potential to use the new TTI for continuous monitoring of the temperature history, quality and shelf life of fresh fish products (V).

4.4.1.2. Model validation and correlation between charging levels and the lifespan of the TTI

The kinetic model developed for the new TTI under isothermal conditions at temperature range 2-15 °C (Kreyenschmidt *et al.*, 2010) works well for non-abused temperature conditions below 2 °C (V). This indicates the possibility to extend the contour diagram of Kreyenschmidt *et al.* (2010), which presents the TTI lifespan as a function of charging levels and storage temperatures, to temperature regions below 2 °C to define suitable charging levels of the TTI to suit the shelf life of the fresh fish/food products concerned under the same low temperature conditions.

Alternatively, the choice of the right charging level(s) to suit the shelf life (lives) of fish product(s) of the same storage conditions can be done using the correlation of TTI lifespan and charging level (SVo) at specific temperature conditions as shown in Figure 13 (V).

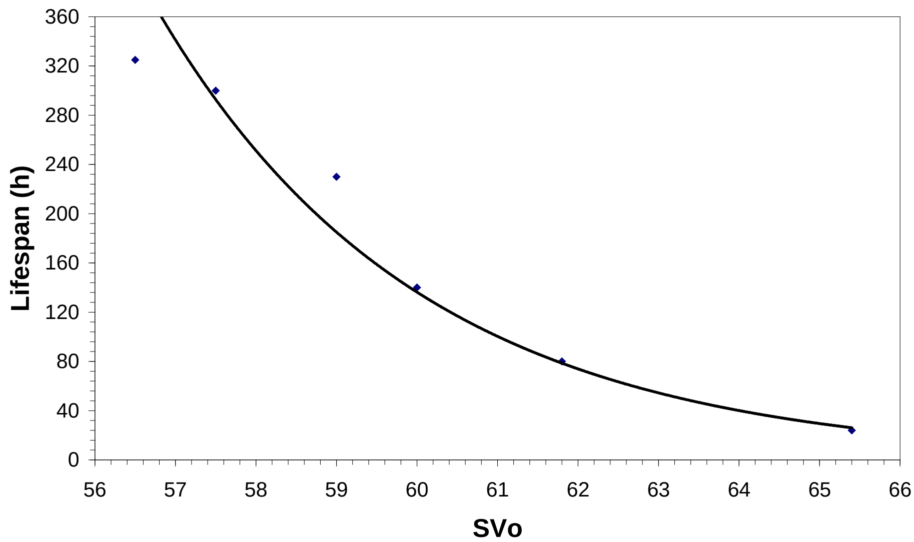

Figure 13. Lifespan of the TTI with different charging levels/initial square values (SVo) at a storage temperature of 0.5 °C. Experimental data and fitted curve by an exponential decay function (V).

4.4.2 Applicability of TTI to monitor the quality and shelf life of fresh fish in comparison with conventional methods

Product shelf life given and predicted by TTI placed on the bottom surfaces of retail trays agrees well with the one derived from TVB-N level and predicted based on product temperature history by the relative rate of spoilage (RRS) model, for both chilled and superchilled storage cases (Table 5, VI). It is also in accordance with the product shelf life declared by sensory evaluation in the case of chilled storage. However, the TTI indicates a much longer shelf life than sensory shelf life in the case of severely superchilled storage, which causes negative effects on the sensory attributes of the product (Table 5, VI). The ST group, stored at undesirable conditions (product temperature -2.8 ± 1.2 °C), was described with more dark colour, precipitation and discolouration, more rubbery texture and less tender, flaky, soft and mushy texture than the TT group (product temperature -0.2 ± 0.4 °C from day 6) (VI). Superchilled storage delayed the growth of specific spoilage organisms (SSO), H_2S-producing bacteria and Pseudomonads, in supechilled (ST) group compared to chilled (TT) samples (Table 5, VI). This explains the lower concentration of TVB-N and TMA in ST samples (VI) as H_2S-producers along with some other psychrotrophic species, such as *Photobacterium phosphoreum,* contribute to the formation of these volatile compounds (Koutsoumanis & Nychas, 2000; Olafsdottir et al., 2006). The results are in a good agreement with other studies that the proliferation rate of these bacterial species is lower at superchilled storage conditions compared to chilled storage for aerobically packed cod fillets (Olafsdottir *et al.*, 2006) or loins (Wang *et al.*, 2008). Lower TVC and SSO counts in the superchilled samples agree with the slower colour changes of the TTI in the ST group compared to the TT group (VI).

Table 5. Product (cod loins in airtight retail packs) shelf life (days from processing) given by sensory evaluation, TVB-N level, TTI discolouration, and square-root spoilage model in SSSP; and values of TMA, TVC and specific spoilage organisms, initial and at sensory rejection (VI).

		Initial values	ST		TT	
			Non-abused	Abused	Non-abused	Abused
Sensory shelf life (d)			11		10-11	
TVB-N based shelf life (d)			> 15		10-11	
Shelf life based on TTI_top (d) [a]	Measured		> 15.9	9.8	12.7	8.7
	Simulated		15.9 [b]		12.7 [b]	
Shelf life based on TTI_bottom (d) [a]	Measured		> 15.9	10.1	10.7	8.5
	Simulated		> 15.9 [b]		10.7 [b]	
SSSP, RRS model (SL) (d)			> 15.3	10.8	10.2	8.8
TMA (mg N/100 g)			< 1.1 ± 1.2		1.6 ± 0.2	
TVC (log CFU/g)		5.3 ± 0.2	< 6.6 ± 0.1		7.2 ± 0.1	
H_2S-producer counts (log CFU/g)		2.3 ± 1.0	< 4.6 ± 0.9		5.5 ± 0.5	
Pseudomonad counts (log CFU/g)		3.5 ± 0.1	< 5.4 ± 0.6		6.6 ± 0.1	

[a] Charging time of TTI labels at 7 °C were 650 ms (SVo 59) on day 0 (packaging day, i.e. 3 days from catch) for ST samples and 450 ms (SVo 61) on day 6 for TT samples; [b] Simulated using Eq. (6). ST = superchilled retail trays of cod loins stored at set -1 °C without abuse (ST, Non-abused) or with abused on day 8 (ST, Abused); TT= chilled retail trays of cod loins stored at set 0.5 °C without abuse (TT, Non-abused) or with abused on day 8 (TT, Abused); TTI_top = TTI placed on top surfaces of retail packs; TTI_bottom = TTI placed on bottom surfaces of retail packs; SL = shelf life; RRS model = relative rate of spoilage model.

Temperature recordings on the top and bottom pack surfaces as well as in the product show that the temperature on the bottom surface is not significantly different ($p > 0.05$) from the product temperature; while this is not always the case between temperatures on the top surface and in the product (VI). TTI placed on the bottom of the packs can therefore be used to monitor temperature conditions of fresh fish products. The findings strengthen the aim to use TTI to replace direct temperature recordings in the fresh food supply chains of Riva et al. (2001). Further, with a suitable activation level, TTI placed on the bottom of retail packs, can potentially be used to monitor the quality and shelf life of chilled fish products.

5 CONCLUSIONS

The studies carried out provide better understanding on the benefits, both qualitative and quantitative, of traceability in the seafood industry. The findings offer practical evidence in support of the traceability drivers mentioned in the literature which are market benefits, savings related to product recalls, savings associated with liability issues, savings from process improvements and savings from labour costs with electronic based systems. *Ex ante* cost-benefits analyses of adopting new and more advanced traceability systems provide initial knowledge on the net benefits of such projects and the distribution of costs and benefits among actors in seafood supply chains. The financial burden of implementing traceability systems may be borne by the processing firms, while gains are reaped by firms in the distribution business closer to the end consumer. This could provide a partial explanation why traceability has been slow to gain ground as a visible value adding marketing tool, and is mainly being driven by food safety regulations. The findings highlight the need for an open discussion between different actors along the chain on the distribution/redistribution of costs and benefits of implementing traceability and support the argument for cost shifting among stakeholders. In order to implement more advanced traceability system(s) or solution(s) at the supply chain level, it is suggested that the price of intermediate products would go up, which is a way that trading companies could entice or persuade food producers to put new traceability system(s) in place.

The framework developed in this study for evaluating the effectiveness of traceability at seafood companies might also potentially be useful for food producers to evaluate the effectiveness of their existing traceability systems based on process mapping information. The case study performed at a *Pangasisus* fish processing company in Vietnam supports the validity of the framework. Further, the framework could be used to locate problems of traceability systems so that the actors can take timely necessary actions to ensure traceability.

A more efficient way of using available quality and process parameters' information, routinely recorded at companies, helps to improve the management of product quality as well as improve the supply chain management (e.g. optimise shipping destination and stock rotation). It is suggested to key these data into computer system for faster access. Data on ambient temperatures during logistics steps can be used to calculate the product warm up time. Furthermore, with the correlation between ambient and product temperatures, the remaining shelf life of a product can be estimated from the ambient temperature history.

Temperature mapping studies provide insights into how fresh fish kept cool throughout logistics processes, from packaging to markets. Several critical steps were pinpointed in air transport, especially in a passenger flight, including ground transportation and the flight itself (*transportation*), loading/unloading operations (*handling*), and holding storage (*storage*) at un-chilled conditions. Abusive temperature during air freighting causes fluctuation and/or rise of product temperature inside boxes, especially in those with more free sides such as at the top corners of the pallets. The greater the temperature fluctuation around the boxes, the larger the temperature range inside the packaged product becomes. Temperature on top of the product inside the EPS boxes is more sensitive to environment changes than those deeper in the box. Thus, grouping products according to their positions during transportation is useful for further management of the resource. Temperature during sea transportation in refrigerated containers is well maintained at low temperature. However, long shipment time causes a relatively short remaining shelf life of a product in sea freighting. Precooling product before transportation reveals an important step to help withstanding the temperature fluctuations, abuse and duration of the whole logistics. Further, the studies indicate that most potential for improvements in airfreight is during *storage* process, which would in most cases require access to a cool storage within the airport area, where products can then be moved fast to the airplanes for loading and further transportation to distributors or retailers. The results also show a need for continuous monitoring of the product temperature history throughout the supply chain, from the point of packaging to retailers, and further down to end consumers with the implementation of some technology, such as time-temperature indicators (TTIs).

The study on the behaviour of the new OnVu^{TM} TTI under simulated field conditions of chilled fish products has showed that the TTI presented a good reliability under different temperature conditions as it gave reproducible responses right after charging as well as during the discolouration process. The TTI reflected well the temperature conditions of the simulated field scenarios, which indicates its potential use to monitor the cold chains of fresh fish. The existing kinetic model worked well with data from non-abuse storage at temperatures below 2 °C, which indicates the potential to extend the quality contour diagram to low temperatures so that a charging level can be defined to suit the shelf life of a product stored under the same conditions. The charging levels can also be chosen based on the correlation between the charging levels and lifespan of the TTI found in this study.

The TTI placed on the bottom of the packs were found to effectively reflect the temperature conditions of the product and could therefore be used to monitor the abuse and fluctuations in temperatures during storage of fresh cod loins in retail packs. In general, the TTI of a suitable charging level can potentially be used to continuously monitor the quality and shelf life of chilled product(s). However, severely superchilled conditions, which cause negative effects on the sensory attributes of the product, other than those induced by microbial spoilage, might influence the precision of shelf life estimation by the TTI. The findings support the idea to use TTI to replace direct temperature recordings in the fresh food supply chains.

6 FUTURE PERSPECTIVES

Market drivers for traceability in relation to environment, sustainability, carbon footprint/Food miles and similar issues needs to be further explored. Furthermore, though *ex ante* cost-benefit analysis of adopting new traceability solution(s) is useful for decision making, *in medias res* and/or *ex poste* CBA(s) is desirable to re-evaluate the net benefits of implementing new traceability solution(s) and learn about the efficiency of the *ex ante* CBA.

Precision of traceability of a product is highly affected by the traceability of ingredients involved in the bill of lots to make the product. It is very common in practice that a lot of an ingredient relates to more than one lots of dispatched product. Improvement of the precision of ingredients' traceability depends on the recall risks of each ingredient and the final product, detail level of information required by the customers and associated costs. This is an area for future research.

Study on improvement of fresh fish quality concerning improved packaging (e.g. packaging material, size and thickness, and pallet cover), optimising cooling and/or precooling techniques to reduce the effect of ambient changes on the product temperature during the logistics is another interesting research area.

Heat transfer modelling is desirable to correlate ambient temperature and fresh fish product temperature under specific conditions, which enables shelf life prediction of the product concerned and/or calculation of product warm up time based on the ambient temperature history. The knowledge of the product shelf life and/or warm up time would be helpful for producers and other downstream actors in product distribution planning.

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PAPER IV

Temperature controlled transportation alternatives for fresh fish – air or sea?

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IV

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Temperature controlled transportation alternatives for fresh fish – air or sea?

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ABSTRACT

Purpose of this paper

The importance of stable low temperature during the transportation of fresh fish is critical to ensure the quality of the products and thereby the remaining shelf life after delivery. In this study, processes in air and sea transportation are analysed and by using real life temperature measurements, the activities that contribute to temperature augments during transport operations are identified.

Design/methodology/approach

Building on a previous work on temperature measurements of fresh cod loins during long distance transportation, a full scale process mapping and analysis has been done to identify the processes that are included and are causing undesirable rise in temperature.

Findings

The major finding of this work is that air transportation results in serious temperature fluctuations due to loading, unloading, and waiting times compared to sea transportation using temperature controlled containers.

Practical implications

The practical implications of this work is that sea transportation using temperature controlled containers is a serious alternative for transportation of fresh fish, even if up to four days of transportation is added to the total transit time.

What is original/value of paper

The originality of the paper is that real life temperature measurements have been used to prove that more fluctuations are found in air transportation compared to sea transportation chains. In addition, the processes that cause the fluctuations are identified and analysed.

Keywords: Chilled food transportation, air transportation, sea transportation, temperature control, logistics

1. INTRODUCTION

Consumption of fresh fish has been growing worldwide (Vannuccini 2004; FAO 2009) and the importance of the transportation and logistics activities dealing with fresh fish has increased (Mai et al. 2010). The world production of fresh seafood has grown from around 30,000,000 tons in 1994 to around 50,000,000 tons in 2002 (Vannuccini 2004). The attention the transportation and logistics activities draw is not the least due to the fact that temperature is considered as the main factor that affects the safety and quality of perishable products such as fish. Abusive and/or fluctuating temperature accelerates rapid growth of pathogens and specific spoilage organisms (Jol et al. 2005; Raab et al. 2008), causing safety problems and economic losses. Fresh fish is often stored and transported at melting ice temperature (Pawsey 1995; ATP 2007) or even at super-chilled temperature (below 0 °C) (Olafsdottir et al. 2003) to maintain its safety and quality for a certain period. However, the fresh fish supply chains may face certain hazards when the desired/required conditions are not met.

Air freight is a very common mean of transport for perishable products such as fresh fish since this is the fastest transportation mode. However, during logistics operations such as loading, unloading, truck and air transportation, interim storage and holding the product is often subjected to temperature abuse and/or fluctuations (Brecht et al. 2003; Nunes et al. 2003), meaning that the products are un-protected during much of their journey (James et al. 2006). Even short time temperature abuse and/or fluctuations might cause severe damage to the products, leading to a significant reduction in the product shelf life, e.g. in a case of chilled modified atmosphere packaged Pacific hake (Simpson et al. 2003), or the rejection, e.g. of a whole strawberry load (Nunes et al. 2003).

Another mean of fresh fish transport is sea freight where the product temperature is well controlled in refrigerated containers during the whole voyage (Mai et al. 2010). This mode of transportation, however, consumes more time than air freighting, which may reduce the quality of perishables even at optimum conditions of handling (Pawsey 1995; Mai et al. 2010). The quality of the fish when delivered at customer site is directly related to its shelf life which is very important as it indicates the marketing life span left for the product.

The purpose of this work is to identify the logistics processes that contribute to most temperature increase within a supply chain of fresh fish, from producer to distributor, during a relatively long transportation period using two different transportation modes. To do so, the temperature changes of the surroundings were measured as well as the temperature of fresh cod loins themselves inside expanded polystyrene (EPS) boxes. Even though packaging with less environmental impact compared to EPS has been increasing its market share during the last decade, the majority of fresh fish products are still transported in EPS boxes. Thus, only using EPS should not be seen as a great limitation in the current study. The study was graphically limited to Iceland, UK and France since the studied supply chains only covered producers in Iceland to markets in the UK and France by air and sea freight transportation. This somewhat limits the ability to generalise about the logistic processes but should give a good view on both air and sea transport processes in Europe and areas with similar circumstances.

2. METHODOLOGY

The methodology used in this paper is divided into three different parts. First, a literature study was carried out to identify the most relevant contributions found in the major journals within the field of logistics, food science and refrigeration of fresh food. This was done using the following keywords: fresh/chilled/perishable food, fresh/chilled/fish, logistics, supply chain, cold chain, transport, transportation, shipping, air freight/freighting/transport/transportation, product temperature, temperature history, temperature abuse/fluctuation, temperature distribution, food quality, food safety, shelf life. Secondly, an activity and temperature mapping was done to find out the temperature fluctuations during the transportation process and the associated activities, and finally, an analysis of the associated processes was conducted to find out the major reasons for the temperature augmentation during the different logistics operations.

The temperature mappings were performed for two air freight transportation trips and two sea freight transportation trips of fresh fish supply chains from the processors in Iceland (IS) to the markets (distributors, retailers, or secondary processors) in the UK and France (FRA) during several time periods in September 2007, and June, July, and September 2008.

The studied products were in all instances fresh cod loins from a processing company in North of Iceland. The cod was caught east of Iceland. Onboard it was bled, gutted, washed and iced in insulated tubs. The fish was put in alternating ice layers with a fish to ice ratio of about 3:1. The raw material was hold in tubs in a ship refrigerator until landing approximately 2-4 days post catch. Onshore it was transported by un-refrigerated trucks to the processing plant which was a few hundred meters away from the harbour. The fish was processed the following day after a chilled storage overnight.

Fish for air shipment was headed, filleted, skinned, and cut into portions (approximate size: 26 x 5 x 2.3 cm, approximate weight: 0.32 kg). The cod loins were then immediately packed in EPS boxes (outer dimensions: 400 x 264 x 118 mm) containing about 3 kg of fish with 2 frozen gel mats (September 2007) or 1 gel mat (June 2008) of 125 g lying on top of the loins, and with a plastic film in between. The EPS boxes were stacked on Euro-pallets (120 x 80 cm) with 8 - 9 boxes in each row and 12 - 13 rows high, and then wrapped in a thin plastic sheet for protection.

For the products prepared for sea freight, the processing steps included heading, filleting, liquid cooling, Combined Blast and Contact (CBC) cooling, skinning and trimming. After processing, the cod loins of the same size as for air transport were immediately packed in EPS boxes (400 x 264 x 135 mm) which contained 5 kg of fish. The boxes were equipped with drainage holes at the bottom for draining the melting ice (about 0.3-0.5 kg) which was put on top of a thin plastic sheet above the loins. The boxes were palletized on Euro pallets with 9 boxes in each row and 12 rows on each pallet. A few layers of thin plastic film were wrapped around the palletized boxes before the containerization.

Each mapped box was equipped with 3 loggers inside (one at the bottom, one in the middle height of product, and another on top of product) and a logger on the box surface (top or side). This gave the actual temperature history of product at different position inside a box, as well as the actual temperature changes on the box surface.

DS1922L temperature loggers iButton® were used for recording the product temperature, with resolution: 0.0625 °C; accuracy: ± 0.5 °C and ± 1 min/wk; recording intervals 2-10 min. TBI32-20+50 Temp Data Loggers were used for measuring the box outside surface temperature, with resolution: 0.3 °C; accuracy: ± 0.4 °C and ± 1 min/wk; recording intervals 1-5 min. All loggers were calibrated in thick mixture of freshly crushed ice and water before use.

The final step of the research was then to look at the involved logistics activities and try to recognize what activities contribute to most increase in temperature and thereby affect the quality of the fish most.

3. RELEVANT LITERATURE

A literature study was carried out to identify the issues that are relevant to the field that is in focus in this work. The identified issues deal with fresh and chilled food, fresh food logistics, cold chain transportation, traceability and more.

Supply chains of fresh food do differ somewhat from traditional supply chains of ordinary goods to some extent. The requirement of monitoring the processes and tracing the activities is higher as stable, low temperature is necessary and lead times often need to be short, not allowing any delays. A traditional fish supply chain is shown in Figure 3.1, integrated from farm to fork with flows of materials, information and cash.

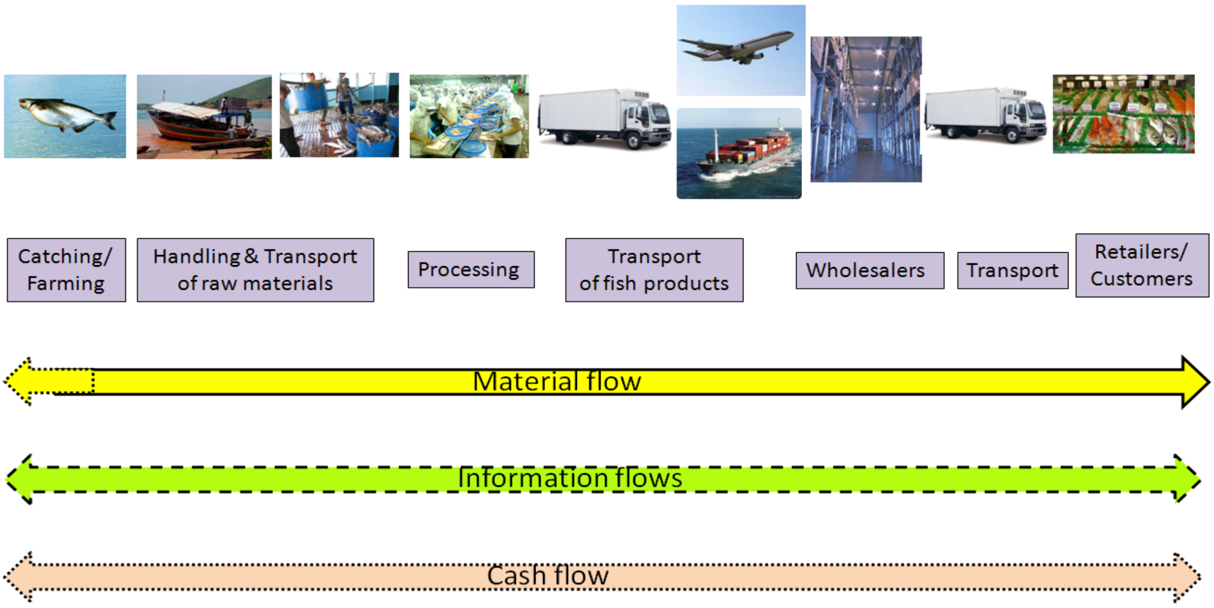

Figure 3.1. Integrated fish supply chain, (Adopted and modified from Coyle et al. 2003; EAN, 2002)

Material flows are in focus in logistics (Coyle et al. 2003), where quality of products delivered to the immediate and/or final customers is emphasized. Once a product does not meet the market requirements, standards or regulation, it can be rejected (Nunes et al. 2003), returned (Coyle et al. 2003) or even recalled in case of a food safety problem (Buhr 2003).

Information flow is considered vital in supply chain management (Coyle et al. 2003). It is a fundamental factor to enable product traceability, tracking and tracing the material flow and history. Logistics is a collection of functional activities that are repeated many times throughout the channel through which raw materials are converted into finished products (Ballou, 1999). The most dominant definition of logistics is given by the Council of Supply Chain Management Professionals (CSCMP) in 2010 as follows:

> *"Logistics management is that part of the supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services, and related information between the point-of-origin to the point-of-consumption in order to meet customers' requirements…."*

This definition explicitly states that logistics management is a part of SCM and contains a variety of activities and related processes in different operations. Warehouse operation is an important part of logistics where products are stored at and between point of origin and point of consumption (Lambert et al., 1998). In addition to storage, there are two other major operations associated with warehousing: movement and information transfer (ibid.). Distribution Centers have a narrower role, including receive and ship as the main activities – while receive, store, ship, and pick are part of the warehouse activities. Terminals are facilities where load units are shifted between links in a transportation network. Examples of terminals are seaports, airports, crossing points of transport modes (e.g. between road and rail), and facilities specialized in fast throughput of load units which makes cross-docking possible. Examples of terminal activities are transshipments, coordination and cross-docking (Lumsden, 2006).

Different transportation modes have diverse characteristics such as length of transit time, cost, reliability and environmental impacts (Coyle et al. 2003). Air transportation takes shortest time and is most expensive. Operations related to air transportation can include steps that affect the products due to the fact that the products are often not containerized, especially in smaller passenger airline operation. Similar situation is with chilled products, the operations prior to air transit, such as warehouse or terminal operations, can include serious temperature abuses. Pre-cooling the product before packing shows to be necessary to minimize the negative effect of abusive temperature, especially during passenger flights where boxes are more exposed to the environment due to the splitting up of pallets. Sea transportation is less expensive but slower. However, products are often well protected as majority of consumer products are containerized in sea transportation (Lumsden, 2006).

Traceability is defined as "the ability to trace the history, application or location of that which is under consideration" (ISO 9000:2000 - Part 3.4.2); or ''the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution" (EU regulation No 178/2002, Article 3 (EC, 2002)).

Improving traceability can potentially reduce the costs to downstream actors (e.g. retailers or processors) of monitoring the activities of upstream steps (e.g. raw material supply) (Hobbs 2003). Good traceability in food supply chains has the potential to reduce risks and costs associated with food borne disease outbreak (ibid.), e.g. reduce their magnitude and possible health impact; reduce or avoid medical costs; reduce labour productivity losses; reduce safety costs arising from a widespread food borne illness (Can-Trace 2007). Reduction of costs associated with product recalls, e.g. reduced recall scope and time, is considered as another main economic incentive for implementing traceability (Can-Trace 2007; Golan *et al.* 2004).

In a recommended guide to good traceability practices (GTP) in the food industry (SINTEF 2007) traceable units can be trade units (TUs); logistic units (LUs); or production batches (raw materials' or ingredients' batches; and product batches). The production batches are considered an internal matter and do not need to have globally unique identifiers; while TUs and LUs are recommended to be assigned with GS1 (Global Solution) numbers (GS1 2009). Information related to history (e.g. temperature record, information related to production process), application (information related to property: weight, species, fat content, etc.) and location (distribution route) should be recorded and linked to a traceable unit. From the chain traceability perspective, it is required to record identifications (IDs) of supplier and transporter of received TUs (raw materials and/or ingredients) and ID's of buyer and transporter of dispatched TUs.

There are several studies about the effect of different factors in the cold chains on the temperature distribution and/or quality of food products such as fresh cut endive (Rediers et al. 2009), strawberry (Nunes et al. 2003), asparagus (Laurin 2001), chilled chicken breast (Raab et al. 2008), frozen fish (Moureh and Derens 2000), chilled gilt-head seabream (Giannakourou et al. 2005), to mention some. However, scientific publication on the temperature mapping and comparison for a real supply chain of fresh food from processing to market by air and sea transportation are scarce.

4. TEMPERATURE MEASURES AND LOGISTICS ACTIVITIES DISCUSSION

In this section, the results from the studies will be shown and discussed. The activities carried out during the two different transportations modes will be shown and different temperature mapping discussed and the major results analysed.

4.1. Air freight transportation

The first air freight transportation study was carried out in September 2007 and the second one in June 2008. The transportation studies will be discussed separately below.

4.1.1. Air freight transportation study in September 2007

The first air transportation study in September 2007 was done on cod loins caught east of Iceland and processed on board as described in the Methodology section above. The transportation was carried out in a dedicated freight airplane operation. Table 4.1 shows the logistics activities carried out during the air transportation study and the temperature measurements done. Two pallets were used for temperature measurements and the average temperature is shown.

Table 4.1 presents the outside surface temperature of the boxes at different positions on the two studied pallets. High fluctuation and several abuses of temperature were observed during loading/unloading processes (steps 4 and 10), interim storage at the airports and the wholesaler (steps 6, 9, and 10), and the flight (step 8). The pallets were exposed to un-chilled conditions (up to 15 °C) for more than 16.5 hours, accounting for about 17.4% of the total logistics time from processor to retailers. These led to a temperature increase of the product inside the boxes in steps 6-8 and high-end temperature of the product at the retailers as shown in Figure 4.1.

Table 4.1 List of logistics activities and temperature measures during the air freight transportation study in September 2007 (Source: adopted from Mai et al. 2010).

Step	Description	Duration	Ambient temperature of pallet 1 Mean ± STDEV (°C)	Ambient temperature of pallet 2 Mean ± STDEV (°C)
1	Frozen storage at producer after packing	6 h	-22.5 ± 3.3	-13.0 ± 9.6
2	Chilled storage at producer	2 h	2.3 ± 0.3	2.5 ± 0.5
3	Transportation from producer to Reykjavik (RVK, IS) in a refrigerated truck	8 h 20 min	-8.1 ± 3.5	-14.4 ± 5.9
4	Unloading and loading in a chilled truck in RVK	2 h	8.4 ± 1.1	8.7 ± 1.3
5	Transportation from RVK to Keflavik airport (KEF, IS) in a chilled truck	1 h 20 min	2.2 ± 0.7	1.3 ± 1.1
6	Un-chilled storage at KEF airport	5 h 20 min	13.3 ± 2.0	10.3 ± 3.0
7	Chilled storage at KEF airport	6 h	8.1 ± 5.3	0.5 ± 1.6
8	Flight from KEF to Humberside airport (HUY, UK) and un-chilled storage at HUY	6 h 15min	6.4 ± 4.8	11.7 ± 3.1
9	Storage at HUY and transportation to Carlisle (UK)	7 h 15 min	1.0 ± 0.4	-0.2 ± 0.6
10	Unloading/un-chilled storage at wholesaler in Carlisle	3 h	4.7 ± 2.7	3.6 ± 1.7
11	Storage in Carlisle	45 h 45 min	1.3 ± 1.0	1.7 ± 1.1
12	Distribution to retailers	2 h 12 min	3.0 ± 1.2	4.0 ± 1.2
Total	3.9 d at distributor; or 4 d at retailers		0.7 ± 8.0	0.5 ± 7.6

The initial product temperature inside boxes was considerably high (up to about 5 °C) (beginning of step 1, Fig. 4.1) and the time to chill the product to the average temperature below 2 °C was up to above 8 hours, despite the fact that the pallets were mostly facing ambient temperature around -20 °C. This is because the product is well insulated by the EPS boxes and their stack on pallet. This shows the possibility for the producer to improve the production, for instance, using pre-cooling (e.g. liquid cooling or other chilling method) to lower the product temperature before packaging.

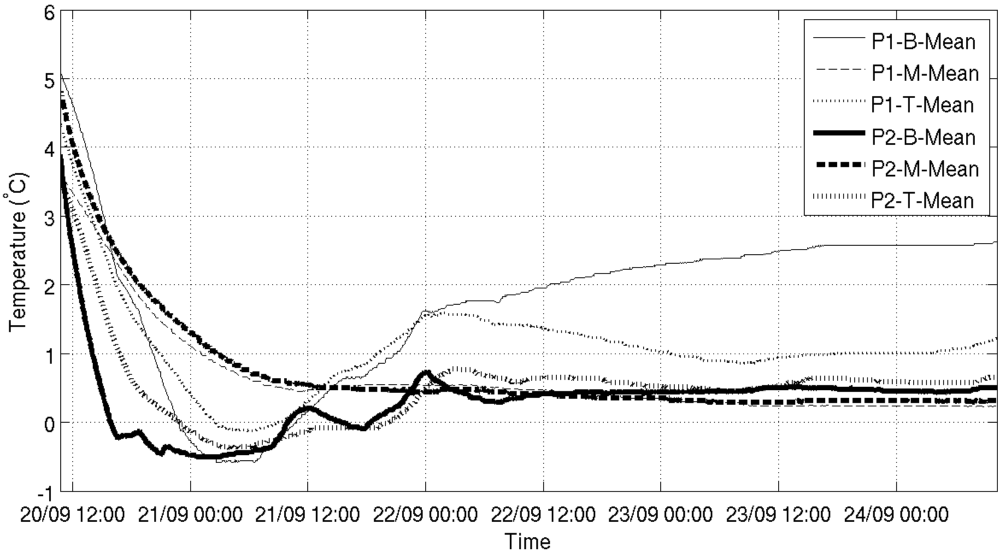

Figure 4.1 Average product temperatures during the air cargo study in September 2007. P stands for pallet; T indicates top corner box; B is bottom corner box; and M is middle row box on the side of a pallet.

The box locations on a pallet have influenced the temperature evolution inside the packaging. It took considerably longer time to cool down the middle boxes (P1_M_ and P2_M_) than those boxes with more free sides, e.g. the top (P1_T_, P2_T_) and bottom (P1_B and P2_B) corner boxes. Furthermore, boxes with more exposed surfaces such as the top and bottom corner boxes have experienced more temperature fluctuations compared to the middle ones.

4.1.2. Air freight transportation study in June 2008

The second air freight transportation study in June 2008 was done as well on cod loins caught east of Iceland. The logistics setup differs from the previous study as more handling was necessary in the first study due to time constrains and airplane schedule. The transportation was as before carried out in a dedicated freight airplane operation. Table 4.2 shows the logistics activities carried out during the second air transportation study and the temperature measures done. Two pallets were used as before for temperature measures and the average temperature is shown. Total time of operation was 1.7 days.

Table 4.2 shows some hazardous parts of the supply chain concerning the temperature abuse on the pallets. The two most noticeable steps were the holding storage in step 3 and the loading followed by the flight in step 6. The short time increase of the ambient temperature at the top corner of pallet 2 (P2_A_T) at the beginning of loading the airplane (step 6) might be attributed to the effect of sunlight on that part of the pallet. Total abusing (ambient temperature > 5 °C) time is about 14.5 hours, amounting to 36.1% of the total time from producer to final destination. This shows that a considerable time in air transportation is under non-refrigerated conditions as stated elsewhere (e.g. James *et al.* 2006).

Table 4.2 Descriptions of logistics activities during the air freight transportation study in June 2008 (Source: adopted from Mai et al. 2010)

Step	Description	Duration	Ambient temperature of pallet 1 Mean ± STDEV (°C)	Ambient temperature of pallet 2 Mean ± STDEV (°C)
1	Cold storage after packing at producer	2h	-11.5 ± 6.0	-2.2 ± 7.4
2	Loading truck and transportation to RVK	9 h 35 min	-2.4 ± 2.8	1.7 ± 1.1
3	Un-chilled storage over night in RVK	10 h 10 min	10.5 ± 1.7	7.1 ± 2.0
4	Transportation in refrigerated truck to KEF	2 h 15 min	4.5 ± 2.5	2.2 ± 2.7
5	Chilled storage at KEF airport	2 h 45 min	1.9 ± 0.7	0.5 ± 0.6
6	Loading at KEF and flight from KEF to Nottingham (UK)	5 h 30 min	3.6 ± 2.6	5.6 ± 3.2
7	Transportation from processors storage	7 h 55 min	1.0 ± 2.6	2.3 ± 1.8
Total		1.7 d	2.6 ± 6.3	3.5 ± 3.7

Exposure of the pallets to un-chilled conditions for over 10 hours in step 3 caused a sharp increase of product temperature in the top and bottom corner boxes of pallet 1 and in the bottom corner box of pallet 2 as shown in Figure 4.2. Again the effect of box locations on a pallet on the product temperature distribution could be clearly observed in this case study, for example, the product temperature in the top corner box of pallet 1 (P1_T_Mean) was more affected than that in the bottom one (P1_B_Mean). The temperature in the middle box of pallet 1 (P1_M_Mean) was more resistant to change compared to those in the top and bottom boxes.

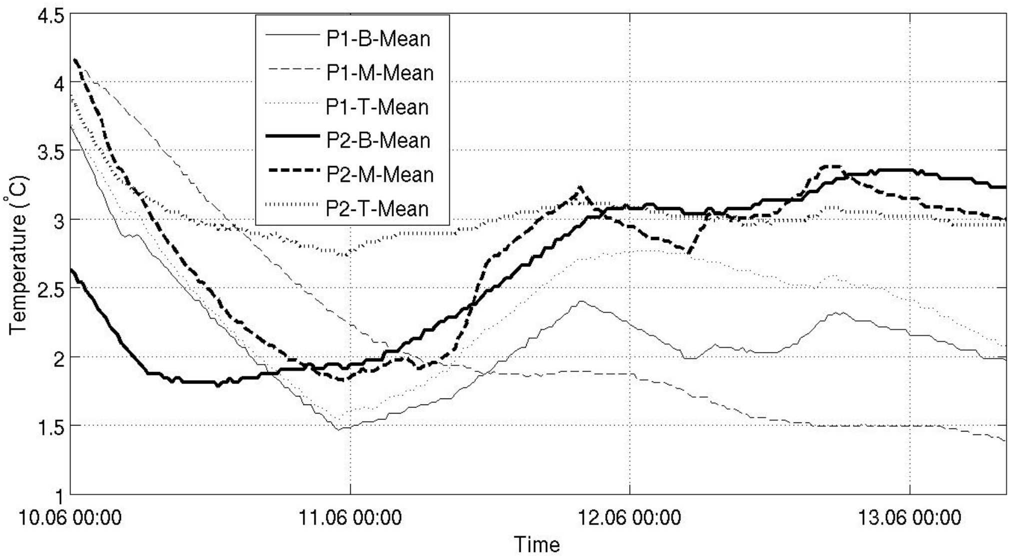

Figure 4.2 Average product temperatures during the air cargo study in June 2008: P stands for pallet; T indicates top corner box; B is bottom corner box; and M is middle row box on the side of a pallet.

This result from this study is in good correlation with the findings for the case study in September 2007 and the results of Moureh et al. (2002). Since the middle boxes were better insulated, ambient temperature change affected them to a smaller degree than the other boxes.

4.2. Sea transportation

The two sea freight transportation studies were carried out during a short period in September to October 2008. Both studies included a supply chain including the catching process, handling and storage processes, and transportation processes. The sea freight transportation studies will be discussed separately below.

4.2.1. Sea transportation September 23rd – 29th 2008

The first sea transportation study in September 2008 was done on cod loins caught east of Iceland as described in the Methodology section above. The transportation was carried out in temperature controlled sea containers. Table 4.3 shows the logistics activities carried out during the sea transportation study and the temperature measures registered. The measures are not anymore limited to two pallets as the temperature inside the whole container is measured.

Table 4.3 Descriptions of logistics activities during the Sea transportation study in September 23rd – 29th 2008 (Source: adopted from Mai et al. 2010)

Step	Description	Duration	Ambient temperature Mean ± STDEV (°C)
1	Cold storage at the producer	3 h 35 min	-11.6 ± 5.5
2	Loading into container and transportation to RVK	8 h 30 min	-2.8 ± 2.1
3	Partly-chilled hold in RVK	4 h 50	3.5 ± 4.3
4	Transportation and handling in refrigerated container: trucked from producer to RVK; shipping to Immingham (UK); and land transportation till final destination (Grimsby, UK)	5 d 3 h 30 min	-0.4 ± 1.5
Total		5.9 d	-0.7 ± 2.8

As can be seen from Table 4.3, the temperature during logistics processes after leaving the producer were very stable and the long duration processes such as transportation (steps 2 and 4) were carried out in a low and stable temperature conditions. During step 3 the surface temperature of the boxes increased due to the turning off of the cooling equipment. In step 4 when the cooling equipment inside the container was functioning, the temperatures of all boxes became stable, maintaining below 0 °C most of the time until the destination. Figure 4.3 shows the surface temperatures during the logistics operations described above.

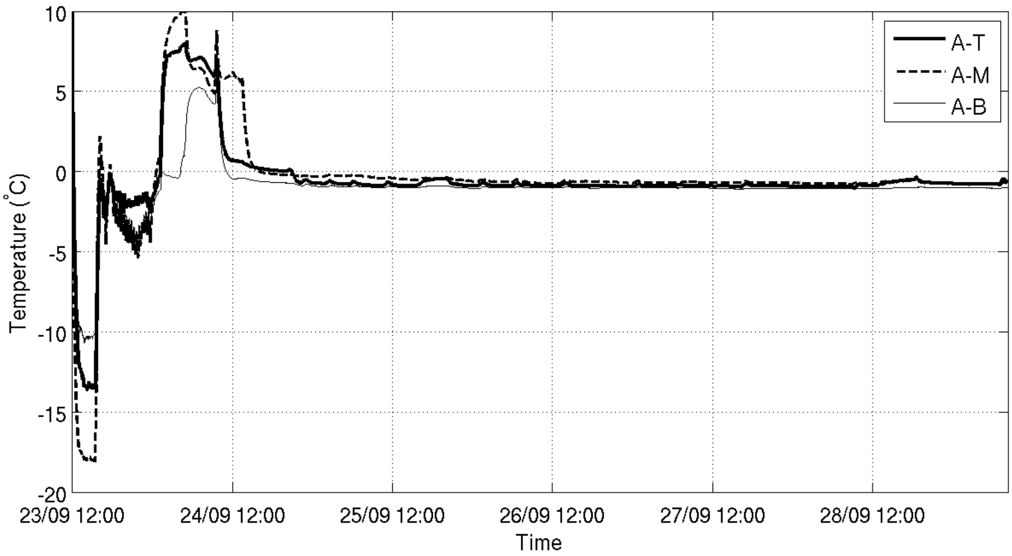

Figure 4.3 Surface temperature (A) of the top corner (T), bottom corner (B), and middle side boxes on a pallet during the sea transportation study on September 23rd-29th 2008.

As can be seen, the major temperature fluctuations occurred during the processing at the processor site but after the container loading and during transportation, a very stable situation was reached where a temperature measures around 0 °C were registered.

4.2.2. Sea transportation September 24th – October 1st 2008

The final study included containerized fresh fish transportation as before but the details of the activities were not logged as before, only single activity of handling and transportation was reported as show in Table 4.4 below.

Table 4.4 Descriptions of logistics activities during the Sea transportation study in September 2008 (Source: adopted from Mai et al. 2010)

Step	Description	Duration	Ambient temperature Mean ± STDEV (°C)
1	Handling and transportation in refrigerated container: trucked from producer to RVK; shipping to Immingham (UK); and land transportation till final destination (Grimsby, UK)	6 d 16 h 35 min (6.7 d)	-0.7 ± 0.2

Table 4.4 shows a very stable temperature with a low deviation in the ambient temperature. Further, Figure 4.4 below shows the product temperature, which was very stable since in the sea freight chain the boxes were kept in a refrigerated container for the whole trip from the processor to the final destination. The product temperature difference between the locations inside a box is small (≤ 0.2 °C most of the time) thanked to the pre -cooling (by liquid and CBC cooling) before skinning and adding of ice on top of the fillets when packing into the EPS boxes.

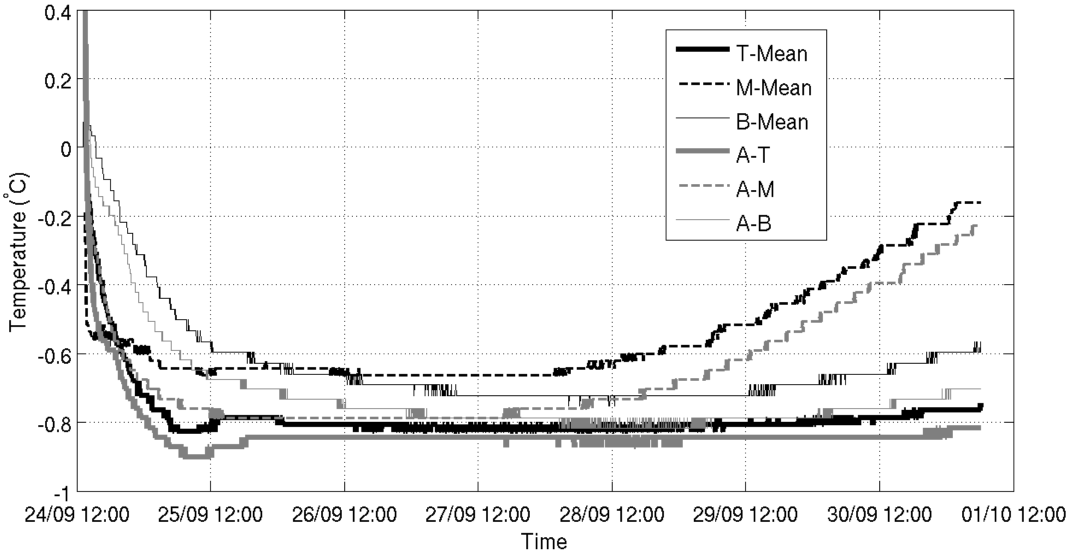

Figure 4.4 Surface temperature (A) and average product temperature (Mean) of the top corner (T), bottom corner (B), and middle side boxes (M) on a pallet during the sea transportation study September 24th - October 1st 2008.

The temperature results show a very stable situation where temperature is kept close to 0 °C as contracts state.

5. ANALYSIS OF THE TRANSPORTATION AND LOGISTICS PROCESSES

The logistics processes described above can be divided into three different areas including *handling, storage,* and *transportation*. Table 5.1 summarizes the highest ambient temperature registration during the different processes and the time period (in hours:minutes) the exposure lasted.

Table 5.1 Mean ambient temperature registrations during the four studies

Study	Storage	Handling	Transportation
Air freight (September 2007)	11.3 °C / 5h:20m	8.6 °C / 2h	9.9 °C / 6h
Air freight (June 2008)	8.8 °C / 10h:10m	4.6 °C / 5h:30m	3.4 °C / 2h:15m
Sea freight (Sept. 23rd – 29th 2008)	3.5 °C / 4h:50m	-0.4 °C / 123h: 30m	
Sea freight (Sept. 24th – Oct 1st 2008)	-0.7 °C / 160h: 35m		

As can be clearly seen from Table 5.1 above, the air freight transportation study results in the highest temperature fluctuations compared to the sea transportation. Of the activities, carried out in the air freight transportation solutions, the storage function had the highest ambient temperature and the longest duration as well. This is not a good combination for fresh food as it puts a lot of temperature load on the products that will easily affect the shelf life in a negative way. The reported storage times included waiting times between mode changes such as road transportation and air transportation, which often is carried out in uncontrolled temperature situations. The situation can involve the product standing on the ramp waiting for loading to take place to the airplane or similar. This is the single largest contributor to temperature augmentation in both of the air freight studies. This situation is, however, not coherent when it comes to the product temperature increase. Due to the fact that the producers prepare the products for these severe externals temperature exposures by installing cooling enablers such as gel mats or similar into the well thermally insulated packaging (EPS boxes), the ambient temperature does not affects the product temperature to such extent as one might suggest. This has clearly surfaced in the figures shown in earlier sections and shown in Figures 4.1 and 4.2. Despite this costly preparation, the temperature augmentation is much higher for the air freight transportation compared to sea transportation. It should still be noted that the freshly crushed ice provides thermal protection for the sea transported fish in a similar way as the more expensive cooling mats do for the air transported fish.

In addition, another result from the study showed that the product temperatures turned out to be non homogeneous depending on the different locations of the boxes on the pallet. As shown in Figure 5.1, steps 1 – 10 show considerable change in temperature measured but becoming more uniform in later stages (11 and 12). On the other hand, the temperature differs based on the location of the box. As shown during steps 11 and 12 in Figure 5.1, the most temperature augmentation takes place in the bottom corner of the pallet and the least in the middle of the pallet, top corner being in-between. Similar results are found in the literature (e.g. Moureh and Derens 2000; Moureh et al. 2002).

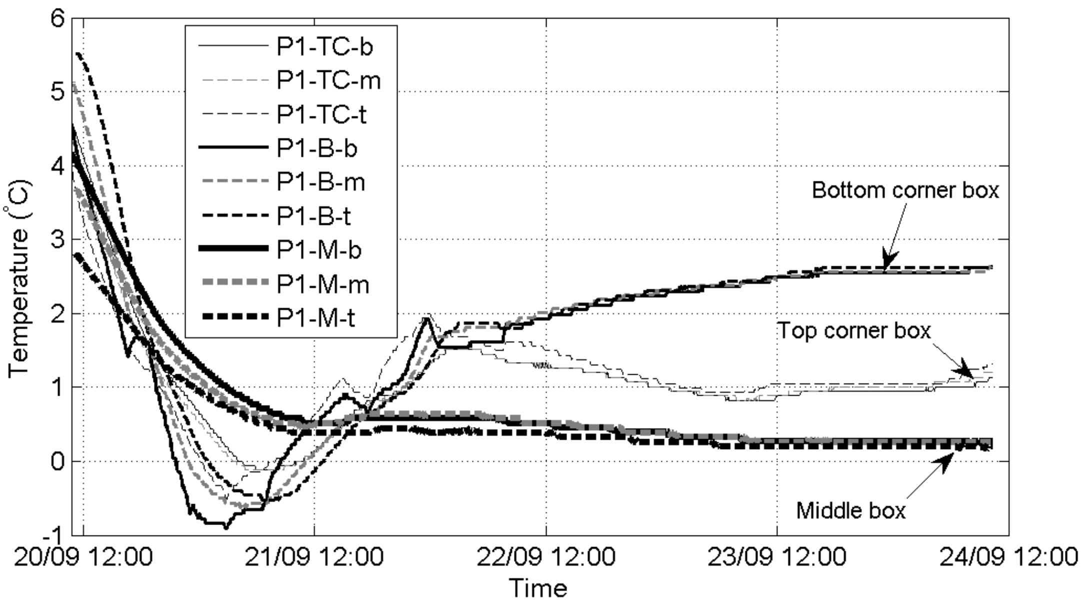

Figure 5.1 Product temperature at different locations inside the boxes during the air cargo study in September 2007: P stands for pallet; T indicates top corner box; B is bottom corner box; and M is middle row box on the side of a pallet; t is top; m is middle height; and b is bottom product inside a box.

These results indicate that it is possible to group the boxes according to their positions on pallets and collect boxes with similar temperature evolution during the pallet unloading. This would improve the quality management of the product and have potential increase in the market duration and possible shelf life of the products which have been exposed to lower ambient temperature. Jedermann et al. (2009) have also mentioned the possibility of grouping products with equal temperature in batches.

6. CONCLUSIONS

Temperature abuse during the logistics processes of air freight transportation causes fluctuation and/or augmentation of product temperature inside boxes, particularly in those with more free sides such as at bottom corner boxes of a pallet. The higher fluctuation in the ambient temperature around the boxes and the longer the thermal load duration, the larger temperature range of the product becomes. Grouping products according to their positions during transportation is therefore useful for downstream management of the products and can influence the shelf life depending on pallet location. Temperature on top and bottom of product inside an EPS box is more sensitive to environment changes than the products found deeper in the box.

The results from the air freight transportation study turned out to include several critical steps, including pre and post transportation and the flight itself (transportation), loading/unloading operations (handling), and holding storage at un-chilled conditions (storage). The single process contributing to the highest rise in product temperature turned out to be the storage process in the air freight transportation study. This indicated that most potential for improvements is during this process, which would in most cases require access to a cool storage within the airport area, where products can then be moved fast to the airplanes for loading and further transportation to distributors or retailers.

Compared to air freight transportation, temperature during sea transportation in refrigerated containers is well controlled, keeping a very stable temperature during the whole transportation process.

The trade-off in selecting transportation mode needs to be based on different aspects including the product quality and remaining shelf time as the sea transportation takes approximately 3 - 4 days longer than air freight transportation in total, available time to reach the market, costs of transportation, in addition to the environmental impact of the transportation process.

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