

# A Field Test Study on a Dynamic Shelf Life Service for Perishables

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## ABSTRACT

### Purpose

To investigate the possibilities, risks and requirements of a dynamic shelf life service – a technological innovation focusing on minimizing food waste in supply chains (SC).

### Design/methodology/approach

Semi-structured, open-ended interviews with SC actors have been used to identify the requirements, possibilities and risks with a dynamic shelf life service. Field tests have been conducted to investigate practical implications and effects of small temperature variations on shelf life. The field tests involved sensors based on Bluetooth Low Energy (BLE) and Radio Frequency Identification (RFID).

### Findings

The results show that a DSLP service holds great potentials. The field tests revealed that shelf life predictions are sensitive to small temperature differences along the cold chain. Results from the interviews confirm the importance of accuracy. The interviews also emphasize the importance of sharing costs among the involved actors.

### Research limitations/implications (if applicable)

Key aspects from 11 SC actors concerning dynamic shelf life prediction in cold chains are provided. The field tests involve a SC from production to household.

### Practical implications (if applicable)

Implementation of a dynamic shelf life service can increase visibility and information flow within SCs. The system can also be integrated with companies' business systems creating new business opportunities and reducing manual work by automatically alerting quality fluctuations of food products.

### Original/value

Quantitative and qualitative data from 11 SC actors are provided. This information, together with the experiences reported from the field tests, have the potential to help replacing dysfunctional date labelling systems and reduce food waste.

*Keywords: dynamic shelf life, best before date, food supply chain, cold chain, temperature monitoring*

# 1 INTRODUCTION

The total food loss worldwide was estimated in 2011 to be 1.3 billion tons (Gustafsson *et al.*, 2011). In Europe the food loss was estimated to over 90 million ton per year (European Commission, 2014) which corresponds to one third of the yearly food production (Gustafsson *et al.*, 2011). In Europe and other developed regions food loss occurs throughout the whole SC, from production to table, but the largest amount is wasted at retail and consumer levels (European Commission, 2014). There are many factors that directly or indirectly cause food waste like political and economic activities and incentives, as well as market demands and consumer behavior (Institution of Mechanical Engineers, 2013).

The quality of perishable food products, such as vegetables, fruit, meat or fish, is often extremely time- and temperature-dependent, thus placing high demands on a well-functioning SC. Insufficient SCs can lead to food disposal, product returns, and decreased food quality, which all contribute to food waste. Consumers may not find their purchased product adequate for consumption throughout the stated shelf life<sup>1</sup> of the product and can easily be unsure of, or lose trust in, the date-labeling system (WRAP, 2011). However, perishable food products that are distributed through a well-functioning SC which always keeps the storage temperature on or below the recommended temperature limits, have in most cases a longer shelf life than the printed best-before<sup>2</sup> date (Göransson and Nilsson, 2013). This causes many consumers who strictly follow the printed best-before date, to throw away perfectly good food (WRAP, 2007). Wholesalers and retailers also contribute to food waste by rejecting food of good quality that has not been delivered on time.

Many food producers do not fully trust the other actors further down the SC to treat their perishable food products correctly. Consequently, many producers reduce the shelf life of food products, to ensure high quality until the best-before date has passed (Göransson and Nilsson, 2013). In Sweden and other Nordic countries with cold climates, and in countries with well-functioning SCs, an increased shelf life could have huge financial effects for both consumers and SC actors. It would also contribute to decreased food waste.

This paper has been written as a part of the work within an innovation project called “DynahMat, Minimized food waste with dynamic shelf life” (Lund University, Malmö University and SIK). The project tackles problems caused, directly and indirectly, by the static best-before date, by adding a dynamic shelf life prediction (DSLIP) service. The final aim of the project is to create new DSLIPs based on the real-time quality of chilled food products and their storage conditions in terms of, for instance, temperature or bacterial growth (DynahMat, 2013). Such a system is not available on the market today. This paper provides insights from the initial field tests and interviews conducted within the DynahMat project. The aim of this paper is to:

- Investigate the possibilities, risks, and requirements of a DSLIP service, through interviews
- Explore the practical requirements for providing data to a DSLIP service, based on the initial field tests performed within the DynahMat project

The findings are analyzed and discussed, providing an insight into the potential of a DSLIP service and how such a service can be designed.

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<sup>1</sup> In this paper we define shelf life as the length of time for which a product remains usable, fit for consumption.

<sup>2</sup> In this paper we define the best-before date as the date until which the producer guarantees good quality (if certain conditions have been respected).

## 2 RELATED WORK

A common goal of all SC actors is to cut costs and increase customer value as well as market share (Mentzer *et al.*, 2001). In a well-functioning SC, actors share mutual activities and objectives, i.e., they have a strategy for how the SC should be managed (Mentzer *et al.*, 2001; Miemczyk and Howard, 2008). The core of SC management is to integrate and optimize material, information, and financial flow within a SC (Lee and Whang, 2000). This paper focuses on information flow and material flow within perishable food SCs.

### 2.1 Supply Chain Information Sharing

SC information sharing is essential for coordinating, monitoring and planning processes and activities within the SC (Lambert *et al.*, 1998; Mentzer *et al.*, 2001). Moreover, information-sharing facilitates the matching of supply and demand and thereby the possibility to reduce amplified variability and inventories (Bourland *et al.*, 1996).

Terms strongly connected with SC information sharing are: visibility, trust, integration, and collaboration (Gigure and Householder, 2012; Moberg *et al.*, 2002). Gigure and Householder (2012) argue that the level of visibility is purely related to the nature of relationships and the level of trust shared between the actors in the SC. Furthermore, they argue that increased visibility does not go hand in hand with an increased quantity of shared data. Instead, visibility requires an understanding of the characteristics of the shared data and should be used as a tool to convert data into useful information and knowledge.

The quality level of the information shared is highly dependent on the collaboration between SC actors (Lui and Kumar, 2011). Timing and quality of the shared information require high level of SC integration (Gigure and Householder, 2012). Näslund & Hulten (2012) defines SC management integration as “the co-ordination and management of the upstream and downstream product, service, financial and information flows of the core business processes between a focal company and its key supplier (and potentially the supplier’s key supplier) and its key customer (and potentially the customer’s key customer)”. Simultaneously, Näslund & Hulten (2012) emphasize the difficulties related to SC integration, especially beyond a dyadic level, and asks for more empirical research within the area of SC integration. Further challenges arise when implementation of cross-functional innovations is initiated (Power, 2005). Cross-functional technology implementations are always accompanied by intra-organizational as well as inter-organizational changes. It is thereby vital to understand the implications of the implementation for all the involved SC actors. Cross-functional implementation is many times very complex in nature and an incremental implementation strategy may hence be more preferable (Power, 2005).

Food supply is more complex and difficult to manage than other product supplies. Perishables have short shelf lives, demanding temperature requirements and specific storing conditions. In order to safely provide consumers with high quality food products, information sharing within the SC is a necessity (Aung and Chang, 2014).

### 2.2 Cold Chain Monitoring

The temperature surrounding perishable food along the cold chain is, together with the micro-flora initially present in food at the time of packaging, the most influential factors affecting the shelf life of a product (Jol *et al.*, 2006). Perishables are shipped in refrigerated vehicles and since different types of products, with different ideal temperatures, are often transported in the same vehicle, the inside temperature has to be a compromise between the different temperature requirements (Bijwaard *et al.*, 2011). Furthermore, depending on the distance from the cooling unit, the distance from the walls, the characteristics of the other products

transported within the same vehicle etc., the temperature within a vehicle varies (Grunow and Piramuthu, 2013). Different activities may also affect the product temperature, e.g., temporary opening of the vehicle doors, temporary interruptions of the refrigeration function (for instance during a boat trip), loading and unloading of the products, etc. (Carullo *et al.*, 2009). The factors affecting the temperature variations during transport may also naturally affect temperature variations during storage (for instance, inside a terminal or warehouse). Temperature monitoring inside a vehicle or a warehouse is common, although monitoring on pallet level is less common (Grunow and Piramuthu, 2013). In the absence of monitoring more close to the individual consumer packages, an entire truck load may be falsely rejected, or accepted, based on temperatures affecting only a part of the load.

Several studies can be found on the subject of cold chain monitoring and some of those also focus on dynamic shelf life. Many of the applications reported execute cold chain monitoring by means of RFID (Ruiz-Garcia and Lunadei, 2011). One of the major advantages with RFID is that hundreds of RFID tags can be scanned at the same time, and that more information than just an ID often can be stored on them. Some studies claim that there is a market push toward item-level RFID tags to capture more fine-grained information on items through the SCs (Grunow and Piramuthu, 2013). However, cost is often seen as a major obstacle to a widespread use of RFID, especially for low-value products (Ruiz-Garcia and Lunadei, 2011). Some types of RFID tags integrate a temperature sensor and may therefore be used for cold chain monitoring. It has been shown that using RFID temperature tags can be analogous with conventional methods as regards accuracy, but superior in performance in terms of fast instrumentation as well as accessibility of sensor data without line of sight, amongst others (Amador *et al.*, 2009). The relatively high water content of food causes signal attenuation and problems in wireless communication, and wireless communication in combination with metals usually involves penetration problems (Jedermann *et al.*, 2011; Ruiz-Garcia and Lunadei, 2011). Jedermann *et al.*, (2009) have studied the most suitable implementation for RFID-monitoring of perishables, as well as the minimum number of sensors necessary for reliable temperature control.

A few of the cold chain monitoring studies apply a Wireless Sensor Network (WSN) for local sensor monitoring, in some cases in combination with RFID. Carullo *et al.* (2009) highlight measurement problems and constraints that have to be handled in a WSN designed to monitor temperature-sensitive products. They furthermore propose and test an architecture, including a number of sensor nodes inserted into bottle caps that takes these problems into account. Ruiz-Garcia *et al.* (2009) present a review of the technical and scientific state of the art of wireless sensor technologies and standards for wireless communications within the agriculture and food industry. They state that RFID loggers are roughly 10 times cheaper than wireless sensor nodes. Jedermann *et al.* (2006) combine technologies from the fields of RFID, WSN and software agents, by proposing a system in which RFID tags are scanned during freight loading and agents follow the goods along the SC, pre-processing the sensor data from WSN. Finally, Becker *et al.* (2010) have deployed a WSN in a cargo container, travelling on a vessel as well as on a truck. The WSN monitors the environmental conditions inside the container and data is communicated through gateways using the satellite system on the vessel or using WLAN/UMTS respectively. The authors suggest using the telematics unit already present in many freight vehicles, for data transmission.

### **2.3 Remaining Shelf Life Prediction**

Automated sensor data processing, in this case the calculation of remaining shelf life, can be implemented either centrally on a server (e.g. in a corporate IT system) or locally; directly on the sensor nodes or on a local processing platform (Jedermann *et al.*, 2011). Local implementation reduces the amount of data that has to be transmitted from the local level to

the central, and thereby also the dependency of unreliable wireless network links. However, the power required for calculation increases the total energy consumption. Jedermann *et al.* (2011) measure and compare the energy consumption and calculation times with the energy required for communication, and their results show that it is feasible to run algorithms, such as shelf life calculations, on low-power embedded systems. Bijwaard *et al.* (2011) describe a solution using a WSN for measuring the environmental conditions. In their approach, a shelf life prediction algorithm travels with the products during the whole transport chain, from production to destination. The algorithm is executed on sensor nodes attached to returnable transport items (e.g. containers, pallets or carrier boxes). Wang *et al.* (2010) have developed a real-time monitoring and decision support system, designed to be combined with existing technologies such as RFID, WSN and GPS. Based on mathematical models, the quality of the products can be predicted. Pang *et al.* (2012) have investigated how different stakeholders assess (influence factor, interest factor etc.) different added-values, such as shelf life prediction. The results show that shelf life prediction receives relatively high scores by the wholesalers and the retailers.

Dynamic shelf life prediction may enable dynamic logistics re-planning, which in turn may affect the sales price. For instance, transport routes can dynamically be adjusted and some discount can be given to new recipients, instead of throwing the products away. Dynamic shelf life prediction may also help retailers sell products with the shortest remaining shelf life first, as well as increase safety for consumers and ensuring the product quality. The real-time monitoring may also allow identifying interruptions along the cold chain, improve traceability, enable early decisions etc. (Bijwaard *et al.*, 2011). Grunow and Piramuthu (2013) present mathematical models for how to evaluate the relative advantage, from an economical perspective, of remaining shelf life information. Tromp *et al.* (2012) predict that a dynamic expiry date can decrease opportunity losses by almost 80%. Other studies address dynamic pricing based on the real-time quality of the products (Liu *et al.*, 2008)(Wang, 2010).

The research presented in this paper differs from the work above since it describes the requirements on, as well as the perceived advantages and risks with dynamic shelf life prediction, based on interviews with SCM actors. Furthermore, the effects of small temperature variations on the remaining shelf life are presented based on field tests. A project similar to ours is the Catrene Pasteur project, which aimed to develop the concept of smart sensor tags. RFID tags were developed together with environmental condition sensors to monitor the dynamic quality of fruit and meat (Guillory and Strandhardt, 2012). The Pasteur project has been an inspiration to develop an integrated DSLP system together with the industry.

### **3 METHODOLOGY**

In order to understand the possibilities and limitations of a DSLP system and the user/customer wishes, a mixed method design was used. The data collection of this study is divided into two parts: semi-structured, open-ended interviews and field tests including observations as well as time and temperature tracking.

This paper is an outcome of an industry innovation project, “DynahMat, Minimized food waste with dynamic shelf life”. Due to the fundamental structure of the innovation project, such as the implementation and industry usability focus, the conducted research has had a pragmatic approach (Zikmund *et al.*, 2009). The data collection from the interviews and the field tests has been performed with companies and organizations, part of the DynahMat innovation project.

### 3.1 Interviews

The interviews were conducted with one or several employees, at 11 companies. The interview target groups were selected to cover viewpoints from the whole SC including different company positions, such as management, production, logistics, sales and R&D. Table 3.1 shows the selected target groups.

*Table 3.1 Target groups for the interviews*

Type of actor	Discipline	Number of participants
SC actors	Food packaging	1
	Food production	4
	Logistics	2
	Retail	2
	Sensor technology	1
Consumer organizations	Consumer insight	1

The interviews aimed to get to know the companies and their willingness for innovation, as well as to investigate their views of on possibilities, risks and requirements of a DSLP system. The interviews were based on a number of predefined questions, focused on the current and future aims of the companies concerning quality control, temperature monitoring, information sharing and co-operations within the SC.

### 3.2 Field Tests

The field tests were performed to obtain the temperatures, with corresponding time stamps, of food products travelling along the cold chain from production to consumption. The monitored cold chain included 3 actors: a producer, a transporter and a retailer. Additionally an end consumer was involved. The monitored cold chain did not include many intermediates, in order to assure a close contact between the observer and the observed goods.

Temperature sensor tags were placed close to consumer-packed food products in order obtain measured data as close to the actual product temperature as possible. The sensor tags logged time and temperature from the time of packaging at the production site, to the time of consumption in the household. Handling activities and other environmental conditions were observed by a researcher throughout the whole cold chain. These observations enabled mapping the activities to different temperature changes.

The monitored food product was in this study cod, packed in a modified atmosphere. Three RFID tags and one BLE tags were placed in a cardboard box together with 8 primary packages of cod. The temperature tags were places on top, under or beside the cod packages, all in close contact with the packages. When the cardboard box was opened at the retailer the sensors were placed together with the cod in a refrigerated display before transportation and subsequent storage in a household refrigerator. The tags were collected for analysis. The time and temperature data were used in microbial growth algorithms (inoculation was pre-defined as of 0.04 cfu *Photobacterium phosphoreum* bacteria /gram cod) in order to calculate, compare and analyze new shelf lives for the cod products.

The calibrations of the tags were controlled in a thermal incubator (type KB 5260, Termaks, Norway) before usage in field test. The control test was performed to test both the accuracy of the calibrations as well as any variations in calibration between the different tags.

As stated above, two different wireless short-range communication technologies were included in the field tests: BLE and RFID. Today there is a widespread use of Bluetooth

technology (e.g. in mobile phones and laptops), and since BLE has been designed as a low-power and low-cost alternative to previous Bluetooth flavors, the adoption of BLE is expected to escalate in the near future (Gomez et al., 2012). Since BLE have high deployment expectations in devices such as smartphones, especially in comparison to other low-power wireless technologies, temperature data from BLE tags can very well be read by consumers in the near future (Gomez et al., 2012). Therefore, BLE temperature sensor tags were included in the field tests. The model used is nRF51822 from Nordic Semiconductor, operating at 2.4 GHz.

Semi-passive RFID temperature sensor tags were also included in the field tests. RFID was selected since it is generally considered as a possible candidate for complementing or replacing the traditional bar code technology, and since it has been the subject of a lot of attention from the research community within cold chain monitoring (see section 2.2). The model used was RT0005 from CAEN RFID, operating in 860 – 928 MHz , i.e. Ultra High Frequency (UHF). Both BLE tags and semi-passive tags require a battery. An associated battery enables the tags to perform temperature logging without being inductively powered by a nearby reader. On the other hand, it limits the life time of a tag and induces a higher cost. Therefore, future studies within the Dynahmat project will test passive RFID tags as well.

### **3.3 Data Analysis**

The interviews were recorded and partially transcribed to extract relevant information to this study. The interviews were conducted and transcribed by two researchers in order to validate that the correct answers and interpretations were documented. Based on the information collected from the interviews, and the interview questions, themes were identified. The conducted information was summarized in order to reflect the vital extractions of the interviews. The result is presented in Table 4.1 and reveals the possibilities, risks and requirements of a DSLP system.

The field tests were also conducted by two researchers, in order to observe the surrounding environment, for instance, registering when the sensor tags were started and placed close to the food products, or registering information from the people handling the food packages. More in depth observations were performed each time the environment changed, in order to explain changes in the collected data sample from the tags. The reliability of the collected data was validated by the results from thermal incubator tests. Time versus temperature was plotted in order to evaluate individual temperature differences along the cold chain as well as how these differences affect the DSLPs.

From the results analysis of the interviews and field tests, a triangulation was conducted (Venkatesh *et al.*, 2013). The results from the qualitative and quantitative data collection methods were compared in order to find common outcomes.

## **4 RESULTS AND ANALYSIS**

### **4.1 Interviews**

This section presents the results and analysis of the set of interviews conducted in order to get a clear picture of the possibilities and risks with, as well as the requirements on, a DSLP service. Table 4.1 shows the summaries of the interviews, grouped according to the identified themes.

*Table 4.1 Results of the interviews on the possibilities, risks and requirements with a DSLP service*

<b>Theme</b>	<b>Findings</b>	<b>Illustrative quotes</b>
Advantages and risks	<p>The DSLP must reach the consumers in order to be useful, since the consumer behavior determine the final revenues.</p> <p>There are great advantages for the consumers. It may be hard to make them trust a DSLP, though.</p> <p>DSLP will probably reduce the food waste. However, that might also lead to fewer sold products.</p> <p>The first actors to implement DSLP might get a strategic advantage over competitors.</p> <p>DSLP could be used for prioritizing the products in retail, and be combined with a dynamic pricing strategy.</p> <p>The temperature data must not be possible to alter. Inaccurate dates increase the risks of food waste or consumption of decayed food.</p>	<p>“Today, people have no knowledge of how to find out whether a product is still ok.”</p>
Costs	<p>The solution must not be too expensive.</p> <p>Many actors, including retail, have to cooperate, since it is expensive for one actor to bear all costs.</p> <p>The consumers will probably not be willing to pay more for a product associated with a DSLP</p> <p>A DSLP service has the potential to reduce costs in the long run.</p> <p>The distribution of responsibilities must be clear in different situations, e.g. who will bear the costs of shorter shelf lives due to temporarily raised temperatures.</p>	<p>”We need help from other actors - we cannot afford this service on our own.”</p>
impact on daily work	<p>The solution must not add too much extra work, and preferable be integrated with the systems used today.</p> <p>Quality assurance of arriving raw material, e.g. by using biosensors as part of the DSLP, would eliminate the current need for specialist knowledge.</p> <p>Some documentation can be reduced if the information generated is reported directly into the Enterprise Resource Planning (ERP) system.</p> <p>The random temperature samplings taken today can be removed if temperature data can be provided.</p>	<p>“When delivering sensitive products, such as shrimps, almost every box is manually checked.”</p>
Sensitivity of DSLP service related information	<p>There are no problems in sharing information with the actors involved in a DSLP system. The information must not, however, reach the competitors.</p>	<p>“Sharing information is not a delicate matter as long as all involved have ‘signed’”</p>
Other services/ information to integrate with a DSLP service	<p>Pure temperature data as part of the DSLP service, in particular from the transportations, is very interesting since it is hard to get information about who was responsible at elevated temperatures today. The data would serve as a quality control and it would reveal the weak points of the cold chain.</p> <p>Today, traceability is integrated in the SC but a DSLP system might increase visibility.</p> <p>Information about the actual arrival times of the products is interesting, in order to control the commitments.</p>	<p>“A lot of money might be involved if violations of the cold chain are found.”</p>



Food waste	<p>Food is discarded due to expired static best before dates, wrong products shipped, inaccurate product weights, waste by the production taken when a cold machinery etc. One of the producers has a total waste of nearly 20%, chain has been broken including returns from the retailers. A large part can be derived from since it costs too expired static best before dates as well as inadequate cooling units. much effort.”</p> <p>One producer reported a food waste related to problems with keeping the products cold, of about 1.5% (excluding food waste further down the cold chain).</p> <p>A retailer reported a food waste of pre-packed meat products of 2%, and perishables of 6-7%.</p>
Sources of cold chain errors	<p>Long distance transports during summertime sometimes cause problems. “Products are sometimes placed outside the cold room of a terminal if the cold room is already full. The product may thereby arrive to the final destination fully refrigerated, but nevertheless unsuitable for human consumption.”</p> <p>At arrival, the products are sometimes left at the loading bay for too long (e.g. during lunch break).</p> <p>In smaller vehicles, the cooling units are switched off when the engine is switched off. This causes problems, e.g. at ferry crossings.</p> <p>Local actors sometimes transport perishables in vehicles without cooling units.</p> <p>In perishable transports, temperature is usually only measured close to the cooling unit.</p> <p>Products are sometimes transported to the wrong address (e.g. by summer stand-ins).</p> <p>At rare occasions, the wrong static best before dates are printed on the packages. This causes severe problems; in particular, the further down the cold chain the problem is discovered.</p>

The results from the interviews show that the SC actors believe in the overall concept of a DSLP service, and its ultimate goal to reduce food waste. They respondents seem positive towards sharing information with other actors in the SC. This is critical for the success of a DSLP service, and calls for increased integration within the SC. Apart from the DSLP, the actors are also very interested in additional services, such as getting real-time temperature data along the cold chain. In particular, the availability of real-time temperature data has the potential to improve logistical activities as well as self-monitoring documentation. It’s also emphasized that the accuracy of the data, both in terms of avoiding tampering and the precision of the temperature measurements, is vital for the success of the DSLP service. However, The DSLP service has the possibility to initiate new innovative business opportunities such as dynamic pricing strategy and rerouted logistic flows. The interviews also emphasize the importance of sharing costs during, and after, implementation in order to justify the business case. SC collaboration and visibility is hence extremely important for the implementation process.

## 4.2 Field Tests

Figure 4.1 shows the temperature measurements from the RFID tags along the cold chain investigated. The initially elevated temperatures, for 15 minutes, derive from the production. Thereafter the products were placed in a cooler storage for 20 hours. The transport took only 3 hours, during which the temperature was kept at low temperatures despite several door openings at intermediate stops, as well as a temporary switch off of the cooling unit during a short boat trip. The temperature dip after one day derives from the transportation. These low temperatures can be explained by the outside temperatures at the time of the transport, which was 1-3°C. After arrival at the retailer, the products were placed in a cooling storage for 30 minutes. Thereafter the products were placed in a refrigerated display (deep in order to avoid theft), available to the consumers. The temperature variations between day 1 and day 4 derive

from the refrigerated display. Thereafter we removed the tags from the products in order to simulate a product being bought. The tags were moved around in the store for a short while, after which they were placed in the trunk of a car, open to the passenger compartment. During the home transportation, which took an hour, the temperature rose to above 20°C. Thereafter, the products were immediately put in a consumer refrigerator, from which the final temperature variations derive from.

The accuracy of the RFID sensor tags was verified by a thermal incubator. The results showed an error of approximately 0.5°C, but the individual differences between the tags were negligible.

Figure 4.1 shows that the most significant individual temperature differences between the different tags occur during transport, at the retail and during the home transport. These differences arise from temperature variations inside the cardboard box, as well as between different places in the refrigerated display and in the trunk. In all these three situations, the tags were placed at most a few decimeters from each other. Thus, even at relatively small distances, the temperature varies. These results confirm previous studies on temperature variations inside boxes of fish, during transport (Abad *et al.*, 2009), between bottles inserted into a crate (Carullo *et al.*, 2009), and inside compartmented trucks (Jedermann *et al.*, 2009).

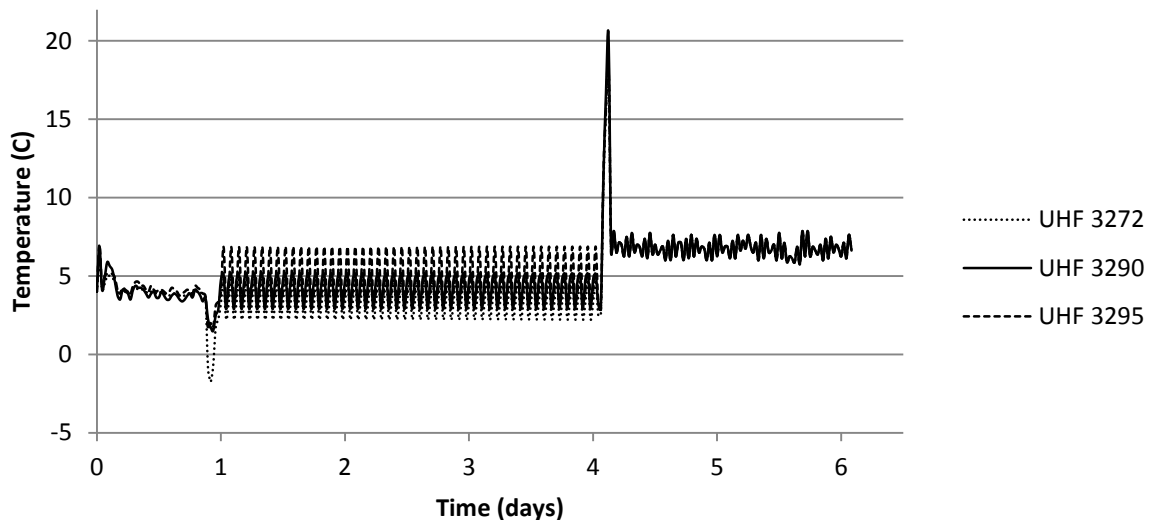


Figure 4.1 Temperature measured by the RFID tags

Figure 4.2 shows the DSLPs calculated from the temperature measurements. Since the initial microbial levels in the products were not determined, absolute values of the remaining shelf lives were not generated. Instead, the differences in temperature between the tags have been used to determine the differences in remaining shelf life of the products being distributed. In the absence of initial microbial information, a pre-defined inoculation value is used to calculate the remaining shelf lives, in order to be able to investigate the shelf life differences. As can be seen, the small differences in position of the tags result in a difference of the remaining shelf life of as much as one day, at the end of the 6 days period. Thus, even small differences in temperature affect the remaining shelf life. Table 4.2 shows theoretical calculations on how different temperatures affect the remaining shelf life, if the temperature is kept constant. As can be seen, a raised temperature of 1°C, from 3.5°C to 4.5°C which represents 0.5°C on each side of the recommended temperature for cod, reduces the shelf life with 1.4 days. The results from the field tests demonstrate the need for a DSLP service in order to get more correct shelf lives, as well as the importance of using reliable sensors.

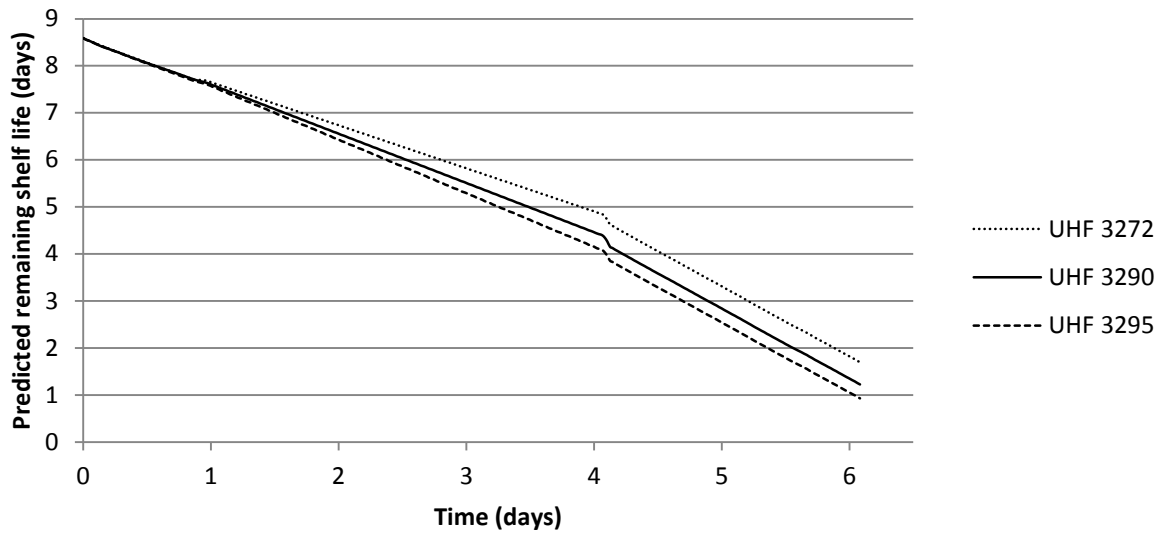


Figure 4.2 Predicted remaining shelf life of the RFID tags, at a future temperature of 4°C

Table 4.2 Predicted shelf life at different temperatures of cod, stored in a modified atmosphere (50% CO<sub>2</sub> and 50% N<sub>2</sub>), with a starting value of the *Photobacterium phosphoreum* bacteria of 0.04 cfu/gram cod (Dalgaard et al., 1997)

Cod temperature	Predicted shelf life
2°C	12.2 days
3.5°C	9.3 days
4°C	8.6 days
4.5°C	7.9 days
6°C	6.4 days

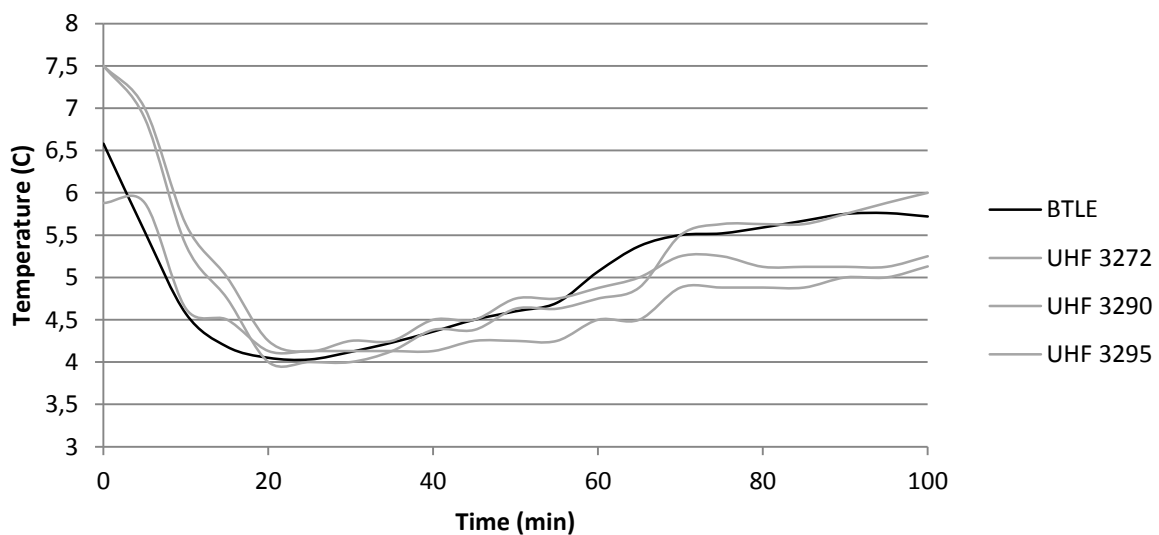


Figure 4.3 Temperature measurements from Bluetooth versus RFID tags

Figure 4.3 shows the individual differences between the selected RFID tags and the BLE tag during the first 100 minutes of the cold chain investigated. As can be seen, the measurements follow the same main curve. The initial temperature drop can be explained by the environments the tags were stored in, prior to the field tests. The studied time period elucidate

that the RFID tags respond quicker to temperature changes. This indicates that these particular RFID tags exhibit a more sensitive behaviour than the BLE tag. The RFID tags seem to respond quicker to temperature changes which indicate a better accuracy of the RFID tag than of the BTLE tag. However, more research is needed in order to confirm these indications.

### 4.3 Discussion

The triangulation primarily shows that a DSLP service holds great potentials, both since the actual quality of the products differs along the cold chain, and since the SC actors are positive towards, and believe in, the service. It also shows that the accuracy of the temperature measurements is critical for the success of a DSLP service. The temperature should thereby preferably be measured as close to the individual food products as possible. Based on the findings from the field tests and the interviews, a number of design principles for a DSLP service can be identified.

From a technical perspective, the sensors should be placed close to the products, to attain high accuracy of the DSLP, for instance on each primary package. Placing sensors on each primary package would require relatively cheap sensors in order to justify the business case. Placing the sensors on a higher package level instead (e.g. outer box, pallet or container), would demand fewer sensors and thereby lower costs, but also a lower level of accuracy. By using components commercially available today, the time to market as well as the development costs can be reduced. Consequently, placing commercially available sensors inside each secondary package might be preferred as a first implementation and evaluation step, in accordance with the incremental implementation described by Power (2005).

Placing the sensor on, for instance, the secondary package means that the IDs of products carried by the package must be linked with the correct sensor. A solution that may be integrated with the systems used today can be achieved by adding a reader to the packaging process, scanning a unique ID of each primary package as well as the ID of the corresponding sensor. The primary package ID will enable consumers to scan a product using e.g. a smart phone. The smart phone may in turn retrieve the corresponding DSLP from a central server. This solution means that the consumers, as well as the SC actors, would have access to a DSLP until retail. Thereafter more sophisticated predictions are needed, or the primary packages must incorporate sensors.

The field tests explored temperature sensors in semi-passive RFID tags and BLE tags. Of the two particular models selected, the RFID tag proved to be more sensitive than the BLE tag. However, the BLE tag might be preferred anyway due to the widespread use of Bluetooth technology. The lowest costs are provided by passive RFID tags, since they have no incorporated batteries. Passive temperature sensor tags must continuously be activated by a reader, though, each time the temperature is measured, and this might be impossible among products with relatively high water content, due to signal attenuation (Jedermann et al., 2011).

As shown by the interviews, pure temperature measurements and context information together with time would be interesting to reach as part of the DSLP service. Real-time information would furthermore enable immediate actions, for instance the ordering of new products or collecting products transported to the wrong address. The sensor data generated along the cold chain can be retrieved in real-time, either through a tag reader mounted on the vehicles, inside warehouses etc., or by using sensor tags able to communicate directly to a central server. The transmitted information might include context information, for instance in terms of GPS information or simply the ID of a reader. It may also be programmed to transmit sensor data only when it has changed, in order to reduce communication costs.

Integrating the information related to the DSLP service into the ERP system has several advantages. For instance, dynamic pricing strategies, prioritization of products in retail, and

documentation are facilitated. Furthermore, appropriate actions should be taken to prevent the information to reach competitors and it must not be possible to alter. For instance, if only the ID of the product is stored on the product itself and the rest of the data is stored centrally, the information can be more easily protected.

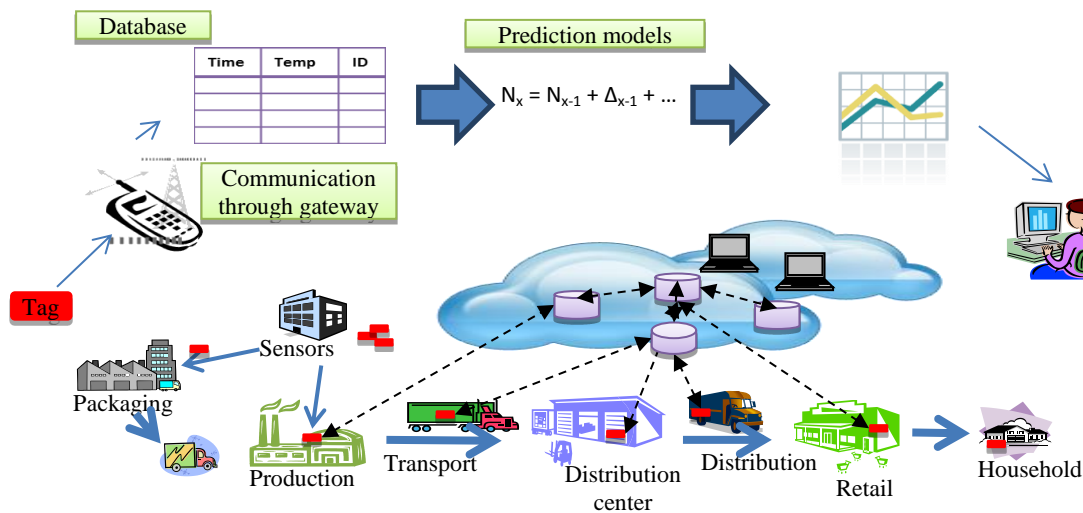


Figure 4.4 Illustration of how DSLP implementation in SC. The gateway reads sensor data and transmits it to a central server. It is then used in prediction models to estimate the remaining shelf lives, which may be accessed from, e.g. web pages or smart phones.

The DSLP service has a great potential to increase the level of information shared within a SC. The comprehensive amount of data, collected and stored at central servers, enables business opportunities both at intra- and inter-organizational levels. Actors are able to customize inbound information given to operational, SC and financial management. Customization enables a higher level of shared information quality. Outbound information from the servers is also reduced, eliminating unnecessary data transfer. An integration of the DSLP service into ERP systems adds further value for managers and employees. The increased information quality enabled by the DSLP service facilitates an increased level of integration and collaboration within the SC. Well-functioning SC collaborations are essential in order to cut cost and streamline the operational processes. However, SC collaborations are not able without long term commitments and trust.

The DSLP service puts high demands on the information technology and its architecture. Implementation cost might be high and business models that clearly define cost and revenue sharing may be one of the most vital factors of success. Another key factor of success is the involvement of the end consumer in the DSLP service. Actors are not willing to take on any costs if the value adding service does not reach the end consumer. Moreover, reaching the consumer is also an essential part of increasing consumer trust in the involved supply chain actors. By providing consumers with DSLPs, behaviors causing food waste can be changed.

## 5 CONCLUSIONS

In this paper we have shown the results from interviews as well as field tests investigating the possibilities, risks and requirements of a dynamic shelf life service for perishable food products. The triangulation primarily shows that a DSLP service holds great potentials, and that the accuracy of the temperature measurements is critical for the success of a DSLP

service. In order to provide a service with high accuracy of the DSLP, the temperature measurements must be precise and data tampering must be avoided.

The field tests revealed how sensitive the shelf life is to small temperature differences along the cold chain. Only 0.5°C may decrease the shelf life with a whole day. The field tests furthermore showed that temperature variations significant enough to affect the shelf life take place even within small areas. One of the main practical requirements on a DSLP service is thereby that the sensors should be placed as closely to the food products as possible.

The interviews show that the SC actors strongly believe that a DSLP service can reduce food waste. They respondents seem positive towards sharing information with other actors involved in the SC. This is critical for the success of a DSLP service, and calls for increased integration within the SC. Furthermore, the actors are very interested in getting real-time temperature data along the cold chain, as part of the DSLP service.

The service enables pro-activeness and new business opportunities. Moreover it facilitates an increased level of integration and collaboration within the SC due to enhanced trust and information visibility. An integration of the DSLP service into ERP systems adds value for managers and employees, in terms of increased information quality.

The research presented in this paper differs from previous studies since it investigates the potentials, as well as highlighting some essential requirements, of a DSLP service. Future work involves studying different implemented service solutions, based on the suggested design principles. This will provide information about supply chain implementation issues related to a DSLP service, beyond the dyadic SC level.

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