How New Technologies Can Improve Cold Chain Management?

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Abstract. There is a growing attention towards technological solutions that can improve cold chain management. This paper analyzes pros and cons of four alternative solutions (Data Loggers, Time Temperature Indicators, semi-passive RFId and Wireless Sensor Networks), paying particular attention to the overall balance of costs and benefits. Thanks to this preliminary study, a solution based on Wireless Sensor Networks has been designed to monitor more efficiently the ice-cream supply chain of a prominent company (Nestlé Italy) and its impacts on overall cold chain performance have been evaluated.

1 Introduction

Cold chain management is gaining increasing attention both in the academic and generalist press. There are several industries (e.g. pharmaceutical, healthcare, fresh and frozen foods) in which an unbroken cold chain must be guaranteed, i.e. an uninterrupted series of storage and distribution activities to be performed at a given temperature range.

From a technological perspective, there are several solutions available that can help monitor and control the temperature. In addition to the most traditional, there are some innovative systems based on Radio Frequency Identification (RFId) technology that enable new functionalities and opportunities. In the last few years the potentialities of RFId technology have started to be explored [1], but today much of the attention is still paid to applications that improve the efficiency (e.g. reducing the identification time) and the accuracy (e.g. reducing the percentage of errors) in the Consumer Packaged Goods supply chain (e.g. [2], [3]).

This study aims at analyzing how innovative technologies can be used to manage a cold chain in a more efficient (e.g. by reducing the costs of temperature controls) and effective (e.g. by assuring a better product quality) way. Among the above mentioned industries, this paper focuses on the food industry, and in particular on the ice-cream industry, even though almost every issue discussed is common to other fresh (and frozen) cold chains whose products suffer frequent temperature abuses and shocks [4]. In this regard, the purpose of this paper is twofold: first, it presents an analysis of the pros and cons of four temperature monitoring technologies, from the most traditional (e.g. Time Temperature Indicators and Data Loggers) to the most

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innovative ones (e.g. semi-passive RFId and Wireless Sensor Networks, WSN). Second, it seeks to analyze in depth how a solution based on Wireless Sensor Networks can improve the ice-cream cold chain management of a prominent company – i.e. Nestlé Italy.

In this regard, the paper is structured as follows: Section 2 describes the research context while section 3 introduces the four technological solutions available, pointing out their advantages and disadvantages as well as their requirements in terms of costs and organizational complexity; Section 4 analyzes the most innovative WSN solution whose application to the Nestlé Ice-Cream supply chain in Italy is then discussed in Section 5. Eventually Section 6 is devoted to draw some concluding remarks and outline future research paths.

2 Context and Problem Setting

Figure 1 reports the reference supply chain, which reflects the structure of the most common ice-cream cold chain.

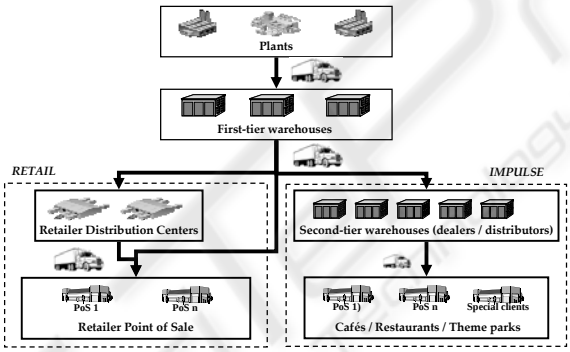

Fig. 1. The reference supply chain.

After the ice-creams have been produced and palletized, they have to spend a certain amount of time – depending on the type of product – in the plant warehouse for the hurdling phase, to ensure that the required (-18°C) is reached. After the hurdling, the products are shipped to the first-tier warehouses which have two main functions: to collect the products manufactured in different plants and to stock them for seasonality reasons (more than 60% of produced ice-creams are sold between May and August).

There are two main distribution channels: the *retail* and *impulse*. Through the retail channel the products are delivered to supermarkets and hypermarkets. Even if direct-to-store deliveries are possible, the products are usually delivered to a retailer distribution center and then shipped to the points of sale. The impulse channel is used to serve restaurants, cafés and special clients, e.g. theme parks. The ice-creams are shipped to local distributors that can either buy the products (dealers) or simply provide logistic services (distributors). Both channels end up refilling the freezers located in the points of sale. In this paper, we will focus on the impulse channel,

which is considerably more complex than the retail one, from a temperature control point of view.

3 Technological Solutions for the Cold Supply Chain

The most interesting technological solutions available to monitor the cold supply chain are the Time Temperature Indicators (TTI), the Data Loggers, the semi-passive RFId (Radio Frequency Identification) tags and the Wireless Sensor Networks (WSN).

TTIs are smart labels that help verify whether perishable goods have been exposed to harmful temperatures during their transit or storage. Placed directly on the packaging of each single product, they provide an easy-to-read visual indication of the accumulated time and temperature history of a product. [5]. In order to assure an acceptable level of reliability, TTIs require a preliminary study on how the product deteriorates and on how the TTI responds to a temperature change. Although applied directly on product and so enabling continuous control of the cold chain, real-time management is not possible, since actions can be taken only after the problem has occurred. Moreover, the intensity of the problem is not measured, and a small break of the cold chain will be reported in the same way as a severe one.

Data Loggers are probably the most widespread tool for temperature monitoring. They are medium-sized electronic devices, with a separate power source (e.g. vehicle battery) that collect and record data over time. Unlike the TTIs, the Data Loggers support real-time response, and alarms can be generated. The main disadvantage is that they monitor the temperature of air and not that of product, being positioned on the containers. Moreover, they do not provide any information on what happens when and where the Data Loggers are not present (e.g. loading/unloading activities).

Radio Frequency Identification (RFId) is an automatic identification technology with which data can be stored and remotely retrieved data using small devices called RFId smart tags. For temperature monitoring, semi-passive tags have to be used, with a small battery on board to power the sensor, while the communication ability still relies on passive RF data exchange. Their working principle is similar to that of a Data Loggers but, being much smaller and power independent, they can be physically put onto products: cost reasons make it impossible to tag each single product, but with a careful selection of tag positioning a continuous monitoring capability can be achieved. Moreover, they can use RF communication for a quick data download, even if a specific hardware and software infrastructure has to be put in place to interrogate the tags (with a reading distance of about 5-7 meters for UHF semi-passive tags); in this regard, they do not allow for real time control, since they have to be interrogated to communicate that a temperature shock has occurred [6].

Wireless Sensor Networks are mesh networks consisting of spatially-distributed autonomous tags (nodes) endowed with sensors to monitor any physical parameters of their environment cooperatively. Sensor nodes are very small computers consisting of a processing unit with limited computational power and memory, one or more sensors, a wireless communication device and a power source (e.g. a battery) [6]. As for the RFId semi-passive tags, the nodes are very small, and can be put within the shipped batch, even though not on each single product, and data can be automatically

recorded and downloaded. In this case the reading distance is much greater than before (up to hundreds of meters) and the nodes can work as a mesh communication network (so one node can act as a bridge for another node's communication). Therefore a much simple reading infrastructure is needed (usually, a final node with gateway capabilities is used to link the mesh sensor network to an internet connection). Moreover, being active, they can be used for real time control (alarm issuing).

The short comparison in Table 1 allows to point out the most important technological performance dimensions which characterize these solutions.

Table 1. Comparison of the four technological solutions in terms of performance.

	TTI	**Data Loggers**	**Semi-passive RFId**	**WSN**
Realtime	No	Yes	No	Yes
Resolution	Single Item	Air	Air / Selected items in the shipping lot	
Precision	Bad	Good	Good	Good
Data download	None	Cable	RF	RF
Reading process / infrastructure	Manual	Manual	Portals or handheld readers, 5-7 meters reading distance	Wi-Fi access points, hundreds meters reading distance

The technological solutions presented might yield different performances, but they are also characterized by different costs and organizational complexity (cfr. Figure 2).

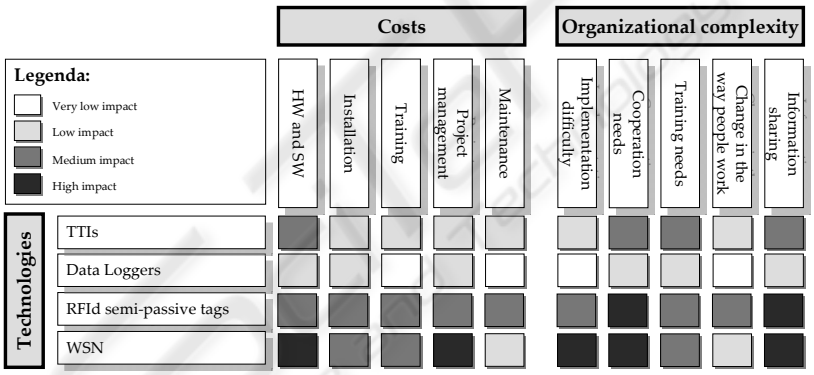

Fig. 2. Comparison of the four technological solutions in terms of cost and complexity.

TTIs do not require a dedicated infrastructure, and they are quite cheap if they are applied at pallet or case level, while the cost dramatically increases if they are applied to all items. This solution is quite easy to manage. The main difficulty concerns the interpretation of the color in intermediate situations, which requires specific training. Data Loggers require a slightly higher initial investment, depending on their exact number. However, they can be used for a long time without requiring any expensive maintenance, so the overall life-cycle costs are quite low. Furthermore, project management and technology roll-out is quite easy.

The use of RFId semi-passive tags implies higher costs (for tags, readers, antennas, middleware): such a solution means much greater organizational complexity,

especially when the tags are applied to the products. On the other hand the system is very precise in monitoring the goods' temperature.

The WSN is the most expensive solution, because of the high cost of the wireless sensors, the bridges and the gateways used to download the data. The installation phase may be complex and requires the collaboration of various actors but, once in place, the operational activities are not affected; sensors are very versatile and the quality and visibility (real-time internet browsing) of the collected data are excellent.

4 The Application of Wireless Sensor Networks in the Nestlé Ice-Cream Division Italy

In this section, we focus on how WSN can improve the cold chain management in Nestlé Ice-Cream Division Italy, with respect to the impulse channel (cfr. Section 2).

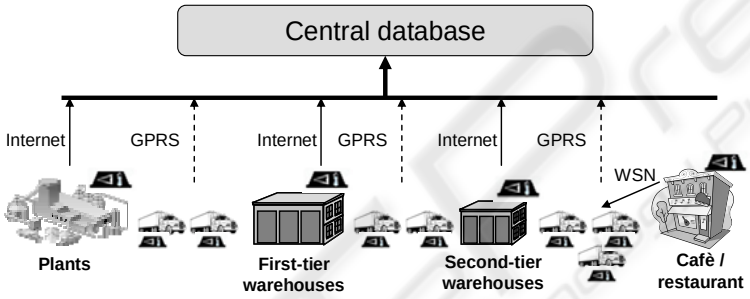

Fig. 3. The WSN solution to monitor Nestlé Italy ice-cream supply chain.

Sensors are installed in the cold rooms of the warehouses (plant, first-tier and second-tier warehouses) and the sensed data is sent to the central database via the Internet (cfr. Figure 3). During transport, measurement data is locally recorded and is sent to the central database on arrival to a warehouse. Alternatively, the data might be transferred in real-time using a GSM/GPRS connection. At the point of sale, the sensors are installed in the freezers. Since cafés and restaurants usually do not have an Internet connection, data is collected by the access boxes installed in the trucks. It is in monitoring and automatically gathering the temperature data from the points of sale that WSN reveal their potential in comparison to traditional solutions which offer only local control. All information is globally accessible on the Web, once the trucks have ended their route.

The system provides full traceability of the temperatures, of the alarms and of the actions relating to the refrigeration assets.

5 Benefits for the Supply Chain

The WSN solution described above can offer various benefits in four main areas: product quality, supply chain visibility, asset management and brand image.

5.1 Product Quality

The WSN helps maintain the right conservation and transportation conditions, thus assuring better product quality. Should a problem occur, the system helps the company to identify where and when the cold chain was broken. Every year, Nestlé Ice-Cream Division Italy has to destroy a certain amount of products because of breaks in its "internal" cold chain, i.e. before shipping from the first-tier warehouses to the distributors. The continuous monitoring of the temperature across the whole supply chain (both in fixed and mobile environments) will help identify out-of-control situations, thus preventing breaks in the cold chain. The current costs might be reduced by 30%.

However, most of the problems do not occur within the boundaries of the company, but after the products have been shipped to the local distributors, since the complexity is higher (e.g. higher number of stops per truck). Complaints from customers (i.e. restaurants, the cafés) about poor product quality making products difficult to sell are very frequent. As the company is currently unable to identify responsibility of quality problems, Nestlé offers a block discount to all dealers.

Considering both the reduction in the number of cold chain breaks and the objective assessment of the responsibilities, the WSN solution can yield a 50% reduction in the cost of poor quality (about € 250,000/year).

5.2 Supply Chain Visibility

As described in the previous sections, the ice-cream supply chain is made up of various actors organized in multiple tiers. Since supply chain performance significantly depends on the behaviour of all the actors, it is important to monitor effectively the whole supply chain. The WSN solution helps identify critical situations: currently, people working in the quality function operate in two ways: they react to a problem that has already occurred (e.g. a distributor affirms he has received unsellable goods) or they carry out statistical quality controls. Thanks to the on-line visibility of the thermal conditions in the whole supply chain it is possible to optimize these activities, so deciding to carry out controls when and where problems are more likely to occur. It is therefore possible to increase the productivity and even to reduce the number of people needed to carry out the quality controls.

5.3 Asset Management

Since the freezers located in the cafés and restaurants are usually owned by the producer, e.g. Nestlé Italy, one of the most critical issues in the ice-cream supply chain is freezer management. Currently, visibility is very low which leads to an increase in freezers turnover and to high maintenance and energy costs.

However, data on the temperature cycles inside the freezers would yield many benefits. First, it would be possible to identify more easily the freezers that need to be serviced. The maintenance costs are usually incurred by the local distributors, but since the producer indirectly pays for this service they can both benefit from the WSN solution. A prudent estimate of the reduction in the annual freezer maintenance costs

would be 10%, corresponding to €1.5-2/freezer. If we consider that a large ice-cream manufacturer usually owns thousands of freezers, the order of magnitude of these benefits becomes clear. For illustrative purposes, consider a manufacturer owning 100,000 freezers managed by 40 local distributors: thanks to the WSN solution, each distributor can save about €4,000-4,500/year, leading to overall benefits of €150,000-200,000/year.

Second, the point of sale could reduce its energy costs. A preliminary analysis of the temperatures inside the freezers showed that they are often lower than necessary. A more careful control of the temperature would facilitate the identification of these cases. Assuming a 6% reduction in overall energy consumption (about €20/year for each freezer), a substantial monetary benefit could be achieved (€2 million in the previous example), in addition to the positive effect on the environment.

Third, it has been estimated that a better maintenance policy could increase the freezer lifecycle by two years. Taking the figures of the previous example, the cost saving might reach €700,000/year.

Finally, the proposed solution enhances freezer traceability. It would be easy to know where they are and if they are used in the proper way. For instance, the monitoring of the internal temperature prevents unwanted use of the freezers (e.g. to store cakes, vegetables, ham, etc.).

5.4 Brand Image

Better control on the distribution process – both inside and outside the manufacturer boundaries – could lead to a better brand image.What is, however, the consumers' perception of this issue? In order to understand more fully consumer awareness and the value they assigned to temperature monitoring, a descriptive survey has been carried out, involving about 200 consumers selected among the people buying frozen foods in five retail stores located in the north of Italy. To provide general relevance the focus is not only on ice-creams, but on all products that have to be stored and transported at controlled temperature, with a special attention to frozen goods.

The questionnaire was divided into four main sections. First, some data on the interviewee (e.g. sex, age) and his/her shopping behaviour were collected. In the second and third sections, the consumers' knowledge of the cold chain was investigated as well as their reaction to a break in the chain. Finally, the value assigned by the consumers to temperature monitoring was explored.

The main results can be summarized as follows. About 50% of the interviewees have a good knowledge of what the cold chain is and usually look at the conservation temperature given on the product packaging. It is interesting to note that this percentage is similar (48%) to that of the number of people experiencing a break in the cold chain. Moreover, about 65% of the interviewees know that there is a thermometer inside the freezers located in the point of sale. About 35% of the interviewees think that if a break in the cold chain occurs, it is possible or even likely that the product is sold anyway. In order to prevent such phenomena, more than 30% of the interviewees declare they would accept an increase in price of 5% or even more in order to reduce the likelihood of temperature breaks.

6 Conclusions and Managerial Implications

Careful study of the state-of-the-art technologies highlights the existence of innovative solutions to improve cold chain management. In particular, the paper investigates the benefits offered by Wireless Sensor Networks in terms of improved quality, increased supply chain visibility, asset management and brand image. An application to the Nestlé Ice-Cream Division Italy supply chain has been provided. Future developments of the research must also investigate other technological solutions providing a quantitative assessment of the costs and the benefits and therefore a useful tool to support investment evaluation.

Even if the presented study deals mainly with the ice-cream supply chain, the key principles and conclusions can be extended to other food cold chains.

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