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Temperature management for the quality assurance of a perishable food supply chain

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ABSTRACT

Compared to most product supply chains, food supply chains are often more complex and more difficult to manage because the food product is perishable and has a short shelf life. A cold chain or temperature-controlled supply chain provides the essential facilities and methods required to maintain the quality and quantity of foods. Since foods can be time and temperature sensitive in nature, they need to be properly taken care of in terms of harvesting, preparation, packaging, transportation and handling – in other words, throughout the entire chain. Temperature is the most important factor in prolonging or maintaining the shelf life of perishables. Refrigeration is one of most widely used methods to date to slow the bacteria growth that leads to food deterioration. The proper control and management of temperature is crucial in delivering perishables to consumers and ensuring that those perishables are in good condition and safe to eat. This paper addresses the methods used to improve the ability to define an optimal target temperature for multi-commodity refrigerated storage. Simulation results support the fact that the presented methods provide more accurate results compared to the conventional method. In addition, an experiment with a Wireless Sensor Network (WSN) was conducted. As a result, the sensor-based methods for real time quality monitoring and assessment that consider product metabolism and Euclidean distance cost depending on temperature changes are found to be superior to the traditional visual assessment method.

1. Introduction

In the global market place, getting the right goods at the right time and place is as important as reducing costs. Visibility is especially important in a supply chain where temperature control in transportation or storage is needed to keep the quality and quantity of products at the end of the supply chain at the required level (Bogataj, Bogataj, & Vodopivec, 2005). The supply chain can be quite complex when dealing with food products. The limited lifetime and the deteriorating quality of perishable foods over time contribute substantially to the complexity of their management (Bowman, Ng, Harrison, Lopez, & Illic, 2009). Perishable foods need proper temperature-controlled environments during the production, storage, transportation and sales processes to ensure food quality and reduce food losses. This is generally referred to as "cold chain logistics" (Ma & Guan, 2009).

Among all of the particular factors that have an impact on the storage life of perishable food products after being harvested, temperature is the most important. The reduction of post-harvest losses is very important as it accounts for about 25% of food production worldwide. Post-harvest losses of horticultural crops are estimated to result in the waste of more than 50% of total production due to poor post-harvest handling techniques, including bad temperature management (Miles, Sarma, & Williams, 2008). Refrigeration is an important means of preserving the quality of foodstuffs and thus has a vital role to play in reducing post-harvest losses. However, proper refrigeration requires accurate control of the cold chain (IIR, 2009). Refrigerated and frozen food accounts for the majority of the products being stored in cold storage facilities – the global frozen foods market alone is expected to grow from an estimated $165.4 billion in 2009 to $199.5 billion by 2014. However, cold storage is also important to other industries, including pharmaceuticals, petro-chemicals and even some high-tech electronics (Rojers, 2012).

The shelf life of food is determined in part by microbial activities, and the impact of these activities is heavily influenced by storage temperature. In fact, freshness is almost exclusively a function of time and temperature. Accordingly, temperature management is becoming a very important criterion for frozen and chilled food (Zhang, Liu, Mu, Moga, & Zhang, 2009). It is crucial to

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not only control temperature but also to manage the facilities and processes that are assisted by technology and protocols under the information systems framework. In this paper, we address the challenge of keeping perishable foods that have diverse temperature requirements for storage and distribution environments, and we endeavour to determine how to define the optimal temperature setting for such environments. The methods to categorise products for refrigerated storage are discussed, and appropriate solutions are suggested. The deviation of optimal temperature settings from the absolute value in a real time environment causes product quality to deviate, and therefore, methods of quality monitoring and assessment are also discussed.

2. Food cold chain

A food supply chain is complex, time-critical and dynamic (Bourlakis & Weighman, 2001; Olsson, 2004; Trienekens, Wognum, Beulens, & van der Vorst, 2012). The food industry is facing challenges due to increasing operational complexity, dynamic changes of customer needs, new regulations and short product life cycles. It requires a very smart and agile supply chain to manage the needs of the customers. Most food products are perishable and their shelf life can be greatly affected by temperature conditions in the supply chain. Temperature control and timely management of goods are critical tasks for fresh food logistics (Montanari, 2008).

In a cold chain, the shelf life, quality and safety of perishable foods throughout the supply chain is greatly impacted by environmental factors, especially temperature. If the temperature of some chilly foods exceeds specific limits, the rise in temperature of just a few degrees can cause microbial growth leading to the great decrease of quality, spoilage of foods and the increase of the risk of food poisoning (Carullo, Corbellini, Parvis, Reyneri, & Vallan, 2009). Loss and damage of perishable goods during storage and transportation is a substantial global issue (Ruiz-Garcia & Lunadei, 2010). Therefore, perishable food products must be continuously monitored for safety and quality concerns throughout the whole supply chain. A breakdown in temperature control at any stage will impact on the final quality of the product (SARDI, 2006).

Temperature control in a food supply chain is the most important factor to prolong the practical shelf life of produce. Maintaining the desired or ideal holding temperature is a major factor in protecting perishable foods against quality loss and wastage. Temperature control in a cold chain preserves both sensory and nutritional qualities, e.g. vitamin C losses in vegetables can be up to 10% per day when stored at a temperature of 2 °C; however, vitamin C loss can increase to over 50% per day when stored at temperatures of +20 °C. Most of the mechanisms of quality loss are determined by storage temperature and are accelerated with time spent above the recommended value. They are also promoted by temperature fluctuations (Martin & Ronan, 2000).

3. Temperature management in a cold chain

Since a cold chain refers to a temperature controlled supply chain, temperature monitoring and management are vital to maintain a sustainable and unbroken cold chain (Abad et al., 2009). In food industries, deterioration occurs mainly with fresh products because of their short shelf life and perishability. Fresh food in particular demands proper temperature control during the entire logistics process. Therefore, to control food quality and safety efficiently in the cold chain process, and to improve the quality monitoring and management system of the cold chain logistics process, the issue has become a concern of government and enterprises, and it is also an important topic for research (Xiaohong, Lan & Wang, 2010). Unlike other products, fresh products have stringent temperature requirements during the logistics processes. Temperature requirements vary among food items, whether frozen or chilled, and they even differ across types of foods. Even a short period of exposure such as a few hours of extreme hot or cold temperatures can cause a marked decrease in shelf life and loss of quality. Correct and careful temperature management throughout harvest and marketing chain is essential if quality of the product is to be assured (Jobling, 2000).

To achieve visibility and controllability of every link in a cold chain, real time data should be communicated between customers and suppliers. Technologies such as sensors, Radio Frequency Identification (RFID) and wireless networks are key components to ensure visibility of each product throughout its lifecycle. Intelligent cold chains are those with advanced analytics and modelling based on food science and safety guidelines, which will assist managers with complex decisions in practical and efficient ways (Terreri, 2009).

Good temperature management is, in fact, the most important and simplest procedure for delaying the deterioration of food products. In addition, storage at the optimum temperature retards the aging of fruit and vegetables, softening and changes in texture and colour. It also slows undesirable metabolic changes, moisture loss and loss of edibility due to invasion by pathogens. Temperature is also a factor that can be easily and promptly controlled. Preservation of perishables quality and safety can be only achieved when the product is maintained under its optimum temperature as soon as possible after harvest or production (Jedermann, Edmond, & Lang, 2007; Zhang et al., 2009). Chilled foods are easily temperature-abused and for such foods, temperature control and monitoring is an important factor in the control of safety and quality. There is also the need to maintain awareness for the potential growth of microorganisms such as Listeria, Yersinia and Aeromonas at chill temperatures (Martin & Ronan, 2000).

Obviously, temperature control is essential and is an effective way of slowing bacterial growth, maintaining quality and minimising spoilage. Conversely, high temperatures will cause an increase in the rate of bacterial growth, enzyme activity and also other chemical reactions. To overcome these time-related problems, reliable temperature management is essential to guarantee that the product arrives at its final destination in the best possible condition (Bowman et al., 2009). Parties involved need better quality assurance methods to satisfy customer demands and to create a competitive point of difference. Successful cold chain logistics calls for automated and efficient monitoring and control of all operations (Ruiz-Garcia & Lunadei, 2010).

4. Multi-commodity cold storage management

It is important to make sure that all kinds of perishable products with different temperature requirements can be maintained in the best condition, from the point of supply to the point of consumption, throughout the processes of storage and distribution. The freshness and safety of food have to be ensured in each stage in logistics service so as to maintain the value and quality to satisfy customers. All cold chain products are not the same in terms of lifespan and storage conditions. The variety of the products and the diversified requirements in temperature or humidity contribute to the complexity of cold chain management. Before setting up a cold chain system, it is necessary for logistics managers to know the product characteristics in the cold chain (Zhang, 2007). At extreme temperatures, products are damaged. Some suffer chilling injury, some suffer damage at very high temperatures and all products are damaged if they freeze at extreme low temperature (Jobling, 2000). The more distant the real storage temperature of a product is of its ideal temperature, the greater the costs with the loss of quality of