Quality Monitoring and Dynamic Pricing in Cold Chain Management

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***Abstract*—**This paper presents a cold chain monitoring system which focuses on assessment of quality and dynamic pricing information about food in cold chain. Cold chain is composed of many actors and stages; however it can be seen as a single entity since a breakdown in temperature control at any stage can impact the final quality of the product. In a cold chain, the shelf life, quality, and safety of perishable food throughout the supply chain is greatly impacted by environmental factors especially temperature. In this paper, a prototype application is implemented to retrieve time-temperature history, the current quality and the dynamic price setting according to changing quality impacted by temperature fluctuations in real-time.

***Keywords*—**cold chain; monitoring; quality; temperature; traceabiltiy

I. Introduction

COLD chain is typically a temperature-controlled supply chain which relates to perishable goods. From the primary production to the final consumption stage, the goods are maintained in a safe, wholesome and good quality state. Perishable goods which are time and temperature sensitive in nature are of higher value and more vulnerable to temperature disturbances.Cold chains are common in the food and pharmaceutical industries and also some chemical shipments. For storage and distribution of perishable food, the proper temperature condition is needed in order to retain high quality and good nutritional value.

Quality control and monitoring of goods during the cold chain is an increasing concern for producers, suppliers, transportdecision makers and consumers. Commercial systems are presently available for monitoring containers, refrigerated chambers and trucks, but they do not give complete information about the cargo, because they typically measure only a single or very limited number of points. Since quality can degrade depending on time and environmental conditions, it is beneficial to know and act appropriate planning when the quality and safety problems arise. As soon as the current quality status is known, the shelf life and price is adjusted dynamically and decision support to management and competitive advantages could be achieved.In food industries, deterioration arises mainly on fresh products, because of its short shelf life and perishability. Fresh food highly demands proper temperature control in the whole logistics process. Therefore, to control food safety efficiently in the cold chain process, and to improve the quality monitoring and management system of cold chain logistics process, become concerns of government and enterprises, also an important topic for research [1].

The development of telecommunication, information technology and information system, especially the rise of wireless sensing technologies such as Radio Frequency Identification (RFID) and wireless sensors, provides a feasible way to enhance the safety and quality of food cold chain. Integrating RFID systems with condition-monitoring systems will enhance existing track and trace applications, not only the location and movement history, but also the condition of perishable products. Moreover, the availability of product trace history data in combination with historical condition monitoring data can facilitate numerous decision-making processes [2].

II. Cold Chain Management

Cold chain management refers to maintaining the proper temperature of the products through all the handoffs in the cold chain until it reaches the consumer [3]. The aim is to preserve quality of perishables and deliver them to market in safe and good condition.

A. Quality and Safety

Food and Agriculture Organisation (FAO) stated managing food safety and quality as shared responsibility of all actors in the food chain including governments, industry and consumers [4]. Quality is defined by ISO as “the totality of features and characteristics of a product that bear on its ability to satisfy stated or implied need” [5].Also, quality can bedefined as “conformance to requirement”, “fitness for use” or, more appropriately for foodstuffs, “fitness for consumption”.Thus, quality can be described as the requirements necessary to satisfy the needs and expectations of the consumer [6] [7]. However, food quality is very general, implying many expectations which can be different from consumer to consumer. Quality includes attributes that influence a product’s value to the consumer. Quality does not refer solely to the properties of the food itself, but also to the ways in which those properties have been achieved [8]. The classes of quality attributes are listed in Table I [9].

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TABLE I
CLASSES OF FOOD QUALITY ATTRIBUTES

External	Internal	Hidden
Appearance (Sight)	Odor	Wholesomeness
Feel (touch)	Taste	Nutritive Value
Defects	Texture	Safety

Evaluation for quality of food is not an easy task. Some of the quality attributes are experienced attributes. In cold chain, there is a problem to know the quality of the product inside containers or refrigerated rooms without visual inspection. Therefore quality evaluation can be considered based on the environmental factors which have direct impact on the quality of the products during their storage and distribution. The role of wireless sensors plays a very important role in this kind of sensory evaluation. Sensors can either be simply associated directly with the items or produce of interest or attached to a Returnable Transport Item (RTI) that is being used to transport the goods [10].

The internal biological and chemical processes of fresh produce continue after harvesting. Produce is a living, breathing commodity, which emits heat and carbon dioxide. The risk of a failure in the cold chain could cause excessive ripening, weight loss, softening, color and texture changes, physical degradation and bruising, and attack by rot and molds. These factors affect freshness, desirability, and marketability. Strict temperature control throughout the supply chain can minimize the risk of food-borne illnesses because low temperatures drastically reduce the growth rate of most human pathogens [11].

Storage at the optimum temperature reduces respiration rates, extends the shelf life of the product and is also an important tool for controlling postharvest rots. Even short breaks in the cool chain will compromise product quality and safety. Product-tracing systems are found essential for food safety and quality control [12].

B. Temperature Monitoring

Throughout the food chain, many kinds of products have to be handled under controlled environmental quantities, such as temperature, humidity, vibrations and light exposure. Among all these parameters, the temperature is usually one of the major concerns due to its huge variety of effects. 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 and the increase of the risk of food poisoning [13]. 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 [14]. The International Institute of Refrigeration (IIR) indicates that about 300 million tonnes of produce are wasted annually through deficient refrigeration worldwide [15]. Therefore, the key to managing the cold chain is to monitor and maintain the product temperature in each stage of the supply chain.

Temperature control in 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 [16].

C. Visibility through Traceability

Consumer perceptions show an increasing concern about food safety and properties of the food they buy and eat. The information available from labeling conventions does not always translate into more confidence. It has been recognised that there is an increasing need for transparent information on the quality of the entire food chain, supported by modern tracking and tracing methods. Essentially, food quality is associated with a proactive policy and the creation of requirements to maintain safe food supply [17].

Traceability is the ability to trace and follow a food, feed, food producing animal or ingredients, through all stages of production and distribution [18]. It may relate materials, their origin, processing history, and their distribution and location after delivery. In particular product identification is fundamental, with physical characteristics such as volume, weight, dimensions, and packaging etc. The bill of material (BOM) structure is very useful for the tracing system to trace the parts which make the product [19].

Traceability systems help firms isolate the source and extent of safety or quality control problems. This helps to reduce the production and distribution of unsafe or poor-quality products, which in turn reduces the potential for bad publicity, liability, and recalls. The better and more precise the tracing system, the faster a producer can identify and resolve food safety or quality problems. If we have specific information about product, the processor can trace faulty product to the minute of production and determine whether other products from the same batch are also defective [12].

The main fact that differentiates food supply chains from other chains is that there is a continuous change in the quality from the time the raw materials leave the grower to the time the product reaches the consumer [20]. Perishables shipments such as meat, fish, milk and more maypass throughseveral hands before arriving to the consumer. Keeping food in safe and good quality is a significant challenge as it moves through the supply chain. The quality of food is dependent on how food products are handled at every touch point throughout the food chain.

The efficiency of a traceability system depends on the ability to track and trace each individual product and distribution (logistics) unit, in a way that enables continuous monitoring from primary production (e.g. harvesting, catch, and retirement) until final disposal to consumer. Traceability schemes can be distinguished in two types: logistics traceability which follows only the physical movement of the product and treats food as commodity and qualitative traceability that associates additional information relating to product quality and consumers safety, such as pre-harvest and post-harvest techniques, storage and distribution conditions, etc [21].

Many businesses follow this practice to protect themselves against liability. Shelf life or lot expiration tracking systems also require supporting inventory record subsystems. Typically, they track lot creation dates and expiration dates and provide for First-In, First-Out (FIFO) use of material as well as periodic aging reports used to predict material that is potentially expiring [22]. But in cold supply chain, a retailer who knew which of the products had the shorter shelf life could put it out before the one with the longer shelf life - a process known as FEFO “First Expire, First Out” [23]. Using a FEFO strategy based on cold chain RFID data, a food distributor can direct shipments to the specific store, or store group, in the most advantageous location [24].

The food chain which demands for both logistics and qualitative traceability is found to be cold supply chain in which foods are perishable items and very sensitive to environmental conditions such as temperature, humidity and light etc. The ability to collect this information, and use it to ensure product quality in “real time” provides tangible benefits to the food industry. It provides a greater assurance of product quality, and enables quick identification of problems. It also provides the mechanism for communicating to the consumer the diligence with which a business operates [25].

III. TEMPERATURE MONITORING TOOLS

Since a cold chain refers to a temperature controlled supply chain, temperature monitoring methods are vital to maintain a sustainable and unbroken cold chain. Chart recorder is an electromechanical piece of equipment that documents/records a mechanical or electrical input signal or trend onto a chart, paper or a rolled piece of paper. Temperature Indicator (TI) and Time Temperature Integrator (TTI) typically refer to temperature sensitive colour changing labels. TI can provide a permanent record of temperature abuse and indicate simply by colours if the temperature is above or below the specified interval. TTIs base on chemical, physical, or microbiological reactions and indicate quality problems with a colour code based on the accumulated time and temperature history of a product. A data logger device calculates the product’s quality based on time and temperature and visualizes the result with an LED. In contrast to the TTI, it can be used multiple times, allows the temperature history to be read out through a serial interface.

Currently, food, dairy and pharmaceutical companies are already monitoring and tracking their environmentally sensitive products using temperature data loggers placed in their transportation vehicle, containers or even pallets. But these are usually expensive and not automated, thus require manual inspection. In order to read the temperature information recorded, it is necessary to open the container or package containing the food, and therefore, they can only be read at the final destination. For these reasons, their use is limited only to some parts of the cold chain or to a few type of products, while for other products and important parts of the chain, continuous product temperature monitoring is not completed [26] [27].

Semi-passive RFID tags or active RFID tags equipped with a temperature sensor allow the temperature history to be read out through a radio frequency (RF) interface [28]. Unlike TI, TTI labels, data loggers and chart recorders, RFID offers the possibility of hands-free operation and comparatively allows for real-time data integration in supply chains [24]. Wireless Sensor Network (WSN) is an idealsolution for physical and environmental monitoring. The main difference between a WSN and a RFID system is that RFID devices have no cooperative capabilities, while WSN allow different network topologies and multi-hop communication [29].

To achieve the monitoring and control of every link in a cold chain, real time data should be communicated via data retrieval devices. The improved cold chain need to be instrumented, interconnected and intelligent. Cold chains need to be interconnected to customers, suppliers and IT systems, as well as to products, trailers and other smart objects that monitor the cold chain. Technologies such as sensors, RFID, wireless and wired networks are potential components of a model to ensure an ongoing portable record of each product or its surroundings 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 [30].

RFID can help improve the efficiency and safety of the food supply chain by enabling the collection of the vast amount of data required to ensure the safety of food as it moves through either the national or international food supply chain. Passive RFID tags provide cost-effective tracking and traceability as food moves through the supply chain, while temperature-sensing and data logging RFID tags capture information about the conditions the food is subjected to on the journey from field to fork [31].

IV. QUALITY MONITORING AND DYNAMIC PRICING

Quality monitoring and dynamic pricing module is implemented as a part of Smart Cold Chain Management (SCCM) project. All the food items are attached by passive RFID tags and sensor tags are used to monitor the condition of food. For quality monitoring system, the relationship between temperature and quality of the products is very fundamental.

The temperature of refrigeration unit for storage of the product should be set optimal value because the temperature fluctuations from optimal value can deteriorate the quality of the product. Typically a mean value of the temperature range or specific temperature value is specified as an optimal value.

A. Quality evaluation in term of Freshness

Quality is considered alternatively as freshness of the product. Initially, the Freshness Gauge (FG) of a new product item is assumed to be 100 %. FG value can be changed whenever the temperature fluctuations happen. FG is calculated based on product shelf life and current temperature value received from temperature sensor. The value of FG can be calculated as follows:

1) Calculation of FG(Freshness Gauge)

$$FG = FG - \frac{(CLT-PLT)}{((ST-MT)*WS)} * 100 \quad (1)$$

Where,

FG = Freshness Gauge

CLT= Current Log Time

PLT = Previous Log Time

ST = Sell-By Date time

MT = Manufacturing Date time

WS = Weight of Shelf Life

Typically the original shelf life (ST-MT) will decrease as the time passed by. The shelf life of an item can be reduced more if temperature goes up or down from optimal range of specific product. The period how long the temperature abuse happened is considered in our formula. As time goes on with temperature fluctuations up and down, the FGwill go down with respect to the values of weight. The values of WS are different for each 1ºCup or down outside optimal temperature range.

2) Weight of Shelf Life

CEN 12380 (1999) legislation demands class one temperature measurement for refrigerated food transport. Measurement has to be feasible in the range between -25 ºC up to +15 ºC with an accuracy ± 1 ºC and resolution ≤ 0.5ºC[32]. In [33], Tanner and Amos studied thermal variations during long distance transportation of fruits from New Zealand to Europe. The results showed that the products were out of the set-point more than 30% of the time, with a significant variability both spatially across the width of the container as well as temporally along the trip.

Considering feasible temperature variations mentioned above, the tolerance value for optimal temperature is assumed to be ±1ºC. The following Fig.1 shows that the classification of temperature range and their assigned sample weigh of shelf life.

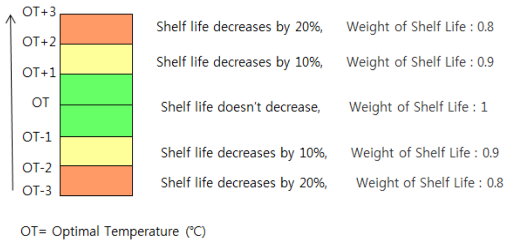

Fig. 1 Shelf life weight definition

To calculate WS for FG and dynamic price, we use Q_{10} temperature coefficient which refer to the rate of change of a biological or chemical system as a consequence of increasing the temperature by 10 °C. Based on temperature fluctuations, WS will make changesin both FG and price accordingly.

$$Q_{10} = \left[\frac{R2}{R1}\right]^{\left[\frac{10}{T2-T1}\right]} \tag{2}$$

R1= rate at temperatureTT11,, RR22== rate at temperature T2

For harvested commodities, the increased temperatures cause an exponential rise in respiration. The higher rates of respiration tend to have shorter storage-life than those with low rates of respiration. We use CO_2 sensors to monitor the respiration rates at different temperatures. The storage life of products especially varies inversely with the rate of respiration. Q_{10} show that different temperatures have impacts on the rates of respiration or deterioration and relative shelf life of a typical perishable commodity. For example, if a commodity has a mean shelf-life of 100 days at 0 °C, then Q_{10}=2.0 at 10 °C simply imply that it can be stored no more than 50 days. Using this concept, the value for each WS is calculated [34].

B. Cold Chain Monitoring User Interface

Cold chain monitoring user interface is implemented to show product information along with FG value and dynamic price in real time (Fig.2). The graphical user interface allows to see up-to-date information of the product not only name and location but also the price assigned regarding with the quality changes due to temperature fluctuations. Search function is available for product information by either item ID or item name. Therefore it is easy to check time-temperature history of the product.

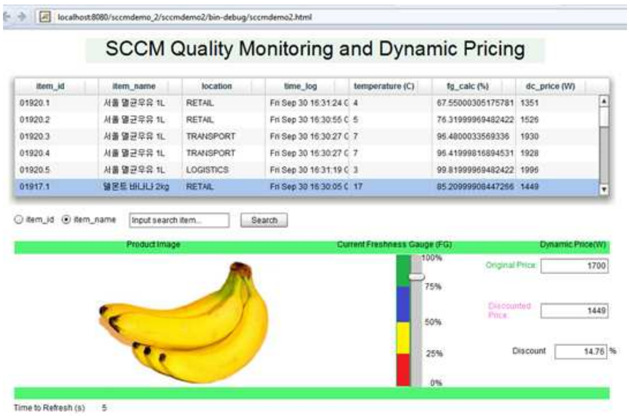

Fig. 2 Cold Chain Monitoring user Interface

V. Conclusion

Quality monitoring and dynamic pricing system which based on temperature measurement is presented in this paper.We consider temperature and its related respiration rates in order to know the quality status of the product in real time. Respiration rate is found to work only for harvested commodities. Actually, food quality is difficult to define precisely but the knowledge on the degree of excellence of foodsis invaluable for all actors involved in food cold chain.

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