MONITORING THE "COOL CHAIN"

Maximizing Shelf Life for Safer Food

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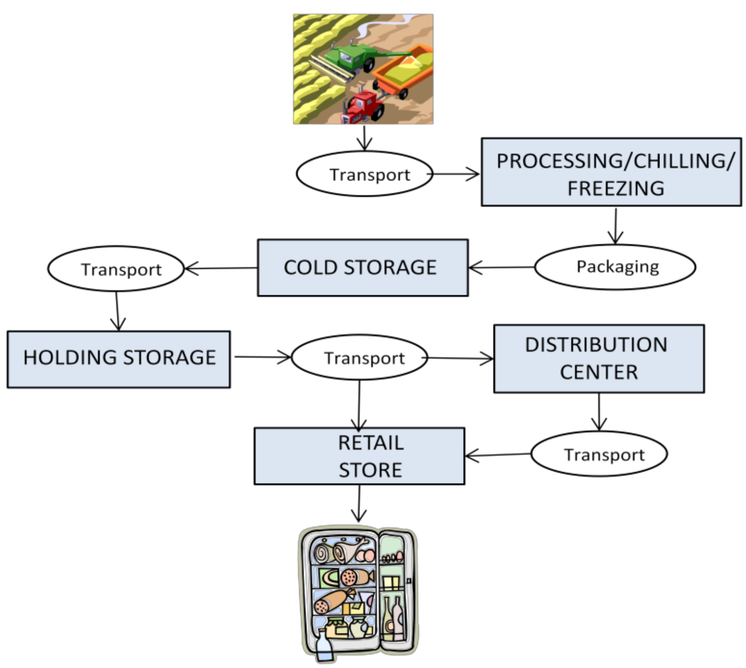
SYNOPSIS

The safety of our global food supply depends on a properly maintained and monitored cold chain. Cold chain failures contribute to the increased perishability of food and drug products, as well as the increased risk of food contamination and foodborne disease. The lack of an adequate cold chain also contributes to increased food waste—an especially critical problem in many developing countries. New technologies are being developed that help to assure that proper temperatures are maintained as products move through the food chain. These technologies allow logisticians to monitor the temperature of products in transit. Some technologies issue alerts when the temperatures exceed target temperatures. In this case, we explore the cold chain requirements of perishable food and drug products, as well as strategies for monitoring their temperatures as they move across the cold chain.

THE COLD CHAIN

The cold chain includes those organizations and companies that are involved in the production, distribution and sale of food products that must be maintained within a specified temperature range. The cold chain extends from the raw material supplier (e.g. dairy farm, cattle ranch, etc.) all the way to the consumers' refrigerator/freezer, and all the steps in between. A typical food chain is provided in **Figure 1**. An effective cold chain must maintain temperature control across all the links in the chain—especially while in transport.

FIGURE 1: TYPICAL COLD CHAIN

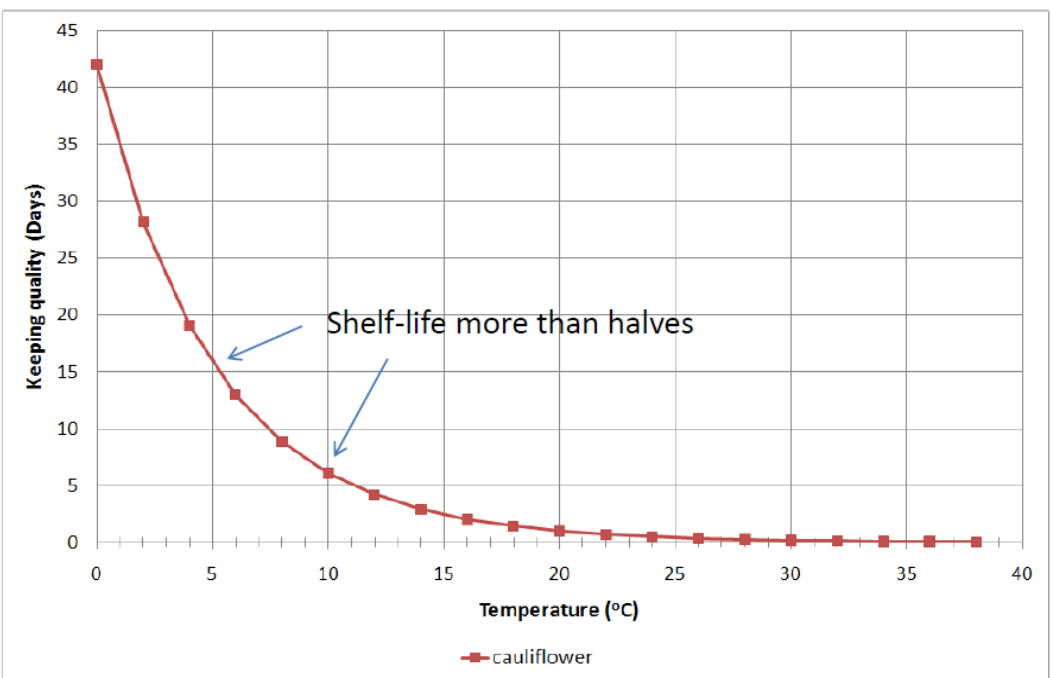


As noted by the World Food Logistics Organization, the cold chain can be as simple as moving one product by truck from a manufacturer to a nearby customer. It can also be a very complicated process involving the coordinated movement of a number of products from many suppliers around the world. Increasingly, our cold chains are more and more complicated due to the increased sourcing of foods from emerging market countries halfway around the world.

PRODUCT SHELF LIFE

Shelf life is defined as the length of time a product may be stored without becoming unsuitable for use or consumption. While a number of factors determine the perishability of cold chain products, temperature is the most important since is directly related to the rate of product deterioration. A properly maintained cold chain maximizes the shelf life of both food and drug products. As shown in **Figure 2**, below, the shelf life for cauliflower is approximately halved for every 5 degree drop in ambient storage temperature. The shelf life curve varies considerably across different products. Even short and small deviations from the optimal storage temperature can have a significant impact on shelf life.

FIGURE 2: SHELF-LIFE AS A FUNCTION OF TEMPERATURE



Source: Food Chain Intelligence, UNISA School of Management

COLD CHAIN REQUIREMENTS

Typically, products moving through the cold chain are either chilled or frozen. Chilling involves reducing food temperatures to below ambient temperatures, but above -1^{o}C. Chilling between 0^{o}C and $+5^{o}$C is an effective tool for short-term preservation of food because it retards many of the microbial, physical, chemical and biochemical reactions associated with food spoilage and deterioration. However, even chilled foods are perishable and continue to deteriorate when chilled, although more slowly.

The use of chilling to slow down the rate of growth of microorganisms reduces food spoilage and improves food safety and quality. Fresh meat and poultry, as well as most dairy, vegetables and some fruit, are typically chilled to between 0^{o}C and 2^{o}C. Pastry-based products, butters, fats and cheeses are typically chilled to between 2^{o}C and 4^{o}C, while potatoes, eggs, bananas, and some exotic fruit require between 8^{o}C and 15^{o}C. A common temperature range for pharmaceutical cold chain products is between 2°C and 8 °C.

Freezing further preserves the storage life of foods by making them more inert and by further slowing down the biological and chemical reactions that promote food spoilage and limit quality shelf life. A typical temperature range for frozen products is between -25^{o}C and -18^{o}C. Although few microorganisms grow below -10^{o}C, freezing and frozen storage are not a fail-safe methods of assuring safety. A number of physical and biochemical reactions that compromise quality and safety can still occur after freezing. While a lot of attention is given to making sure food products and pharmaceuticals do not get too warm during transport, sometimes food products can become too cold during transport. Also, many fresh or raw food products should not be re-frozen after thawing without incurring additional safety risk.

Meat products present special challenges. Because meat contains a large amount of unfrozen water, chilled meat can only be considered for short transport operations. Relative humidity must also be maintained at optimal conditions. When there is too little moisture in the air, meat tends to dry out. On the other hand, too much moisture increases the activity of bacteria and other microorganisms. The optimum storage and transport temperature for chilled meat is the lowest possible temperature at which no freezing occurs. A well executed cold chain for chilled meat can expand the shelf life by about 25 days (from 30-35 days to 55-60 days) from conventional methods.

THE "REEFER"

The primary technology for maintaining the temperature of a shipment of temperature-sensitive products in transit is the refrigerated container or reefer. Reefer is a generic name for a temperature controlled container, which can be a van, small truck, a semi or a standard ISO container. Thus, a reefer can be a large 40 foot-cube container on the ocean, smaller containers such as unit load devices or ULDs that travel by air, or other insulated and refrigerated containers of various sizes that travel by truck.

The typical ocean-going reefer is cooled by (re)circulating chilled air through the internal space where the cargo has been positioned. Chilled air is typically blown through grating located in the container floor under the cargo. The air then flows through and around the cargo and, finally, to the top of the container where it is extracted and returned to the refrigeration unit (return air) where it is re-chilled and then and blown back into the container.

The supply and return air temperatures are measured and recorded in the refrigeration unit. Under normal operating conditions the return air temperature is between 0.5 °C and 3 °C higher than the entering temperature because the return air is carrying the heat from the products in the container. Maintaining a constant temperature inside the container can be difficult due to a number of factors including the escape of chilled air when the doors are opened for delivery, differential warming of the circulating air due to product placement, and possible maintenance problems.

The temperature of the ambient air outside the container will also affect the interior container temperature. Most reefers are painted white to increase the reflection of the incident solar rays. For example, a container that does not reflect a large portion of the incidence rays can have its internal temperature increase to 50 °C when the external temperature reaches 25 °C on a sunny day. In contrast, a container that reflects a large fraction of the incident rays will experience an internal temperature rise of only 38 °C under the same conditions.

In addition to heat contributed by ambient external conditions, the deterioration of fruits and vegetables generates heat within the container and contributes to the difficulties of maintaining temperature control. The rate of deterioration of the product is largely determined by the rate of respiration of the product. Even after being harvested these products continue the process of respiration which produces carbon dioxide, water and heat. Another concern with the transport of fruit and vegetable products is the production of ethylene which triggers ripening which, in turn, leads to increasing rates of respiration and deterioration as the produce continues to warm. Keeping products cool reduces the production of ethylene.

If the airflow through the cargo is good, the return air temperature will be very close to the temperature of the cargo. The return air temperature will also depend on the way in which the cargo has been stowed in the container. Placement that impedes circulation of the refrigerated air will affect its ability to chill the cargo and can trap pockets of warm air that contribute to product deterioration. Consideration needs to be given to the variability in temperatures throughout the container when loading and unloading.

TEMPERATURE MONITORING OF CONTAINER SHIPMENTS

Increasingly, logistics companies are implementing technologies for in-transit temperature monitoring and control. Attaching monitoring devices to the shipment insures the recipient that the temperature integrity of the product has been maintained during transport, and also alerts whenever a temperature breach occurs. It also helps to identify the product's location along the supply chain when a temperature breach does takes place. Some technologies even provide the capability to adjust the temperature of the shipment in transit.

A range of technologies are available to monitor temperature and humidity levels of the container. Data loggers are electronic devices that record data over time, or in relation to location. Data loggers, comprised of sensors and other measuring instruments, can be placed in the container along with the shipment.   One of the primary benefits of using data loggers is the ability to automatically collect data on a 24-hour basis. Upon activation, data loggers are typically deployed and left unattended in the container to measure and record information for the duration of the monitoring period. A data logger such as shown in **Figure 3** is able to download a detailed time/temperature history to a PC for analysis.

FIGURE 3: DATA LOGGER RECORDS CONTAINER TEMPERATURE HISTORY

Source: www.sensitech.com

Another technology, referred to as a timestrip, monitors excursions above or below the target temperature ranges and shows the duration of the excursion. Timestrips can be calibrated to monitor temperatures of shipments for the duration of a shipment or for the lifetime of the product—anywhere from 2 minutes to 18 months. Timestrips can be peel-and-stick labels or embedded into the product. Unlike most data loggers, these products do not provide a trace of the temperature at every point in time during shipment. The timestrip in **Figure 4** shows has been activated, and indicates that the temperature has exceeded target temperatures for two hours.

FIGURE 4: TIMESTRIP SHOPWING TEMPERATURE BREACH

Source: www.sts-smartlabels.com

Current temperature monitoring systems like timestrip recorders or data loggers are usually not automated. As a result, they require manual and visual inspection, usually after the shipment has reached its destination. Thus, they cannot be used for real-time monitoring of temperatures. New technologies such as sensor-enhanced radio frequency-identification (RFID) are being used by some shippers for real-time monitoring of cold chains in transit.

RFID is an automatic identification method that is able to store data about location and temperature that is recorded on tags, and transmit that data to another location by transponder. This data is read by an RFID reader. RFID tags can be affixed to a pallet or to a particular product and can be used to identify products down to the item level. Unlike bar codes, they can be read at a distance and you do not have to have line-of-sight reading.

Most RFID tags contain at least two parts. The first is an integrated circuit for storing and processing information. The second is an antenna for receiving and transmitting the signal to remote locations. For example, information about location, temperature and humidity could be sent directly from the truck to a dispatcher's office in another state. RFID can help track temperatures in a real-time data stream so that decisions about the handling and delivery of the product can be made in sufficient time to maximize the shelf life of the product.

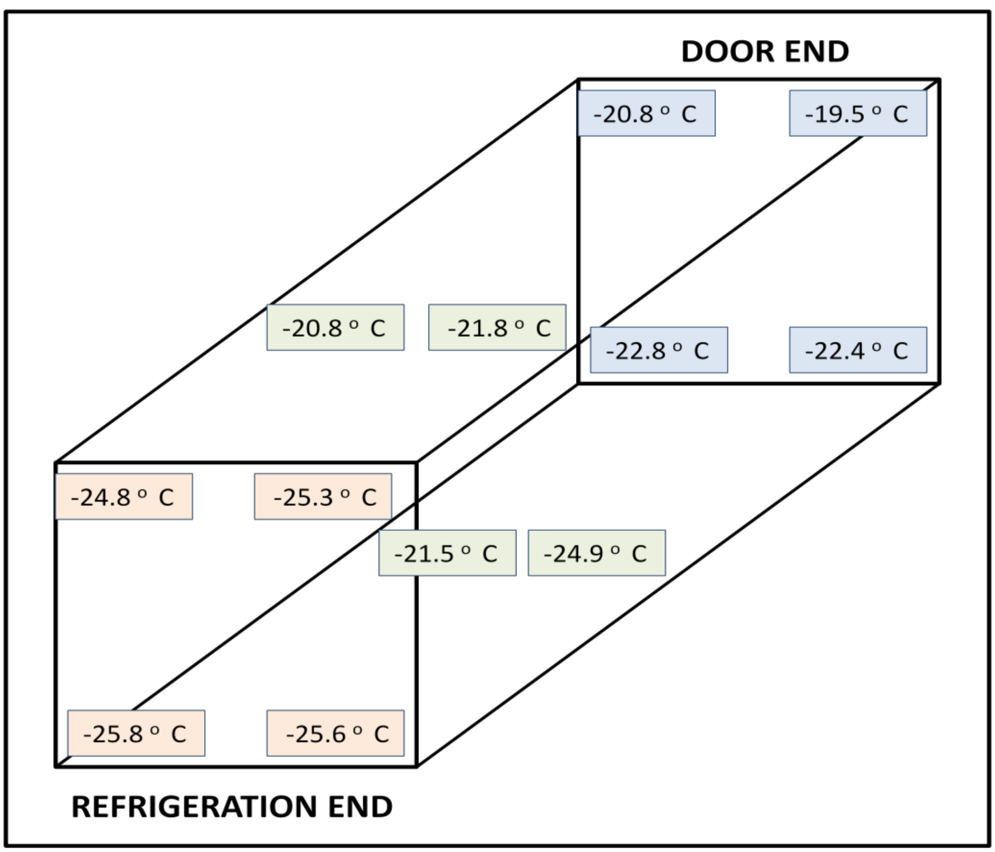
For example, a supplier of produce could attach a tag to a pallet of fruit. The tags will repeatedly transmit temperature readings to a telematics unit installed on the refrigerated trailer (or railcar or container). The telematics unit would then forward the temperature data to a server at the shipper headquarters or at the logistics provider, along with GPS location data. These systems could also be used as a predictive maintenance tool to warn of equipment failure, to improve energy management, or to provide automatic record-keeping for regulatory compliance.

The availability of new temperature sensing and tracking technologies like radio frequency identification (RFID), supported by communications and information technologies, are making it possible to better monitor products as they move through the food chain. RFID and sensor technology is evolving rapidly and is enabling greater capabilities at lower costs. The value of this technology can be best realized when integrated with decision support systems.

EXERCISE

Figure 5 provides a temperature map for a reefer—in this case a delivery truck for ice cream and other frozen desserts that is responsible for (re)stocking the inventory of a chain of grocery stores in the greater Chicago area. Temperature readings at 12 locations in the truck are shown in the figure.

FIGURE 5: TEMPERATURE PROFILE FOR REFRIGERATED CONTAINER



Considering the container temperature profile above:

1. Explain the variability in temperatures across the container.
2. What recommendations would you make to the driver about improving the temperature profile of the truck?
3. As a logistician, how could you use this information to sequence the delivery of the ice cream to the stores?

Considering new RFID and sensor technologies for real-time monitoring of the cold chain:

1. How could new sensor-enhanced RFID technology improve the effectiveness of supply chain operations?
2. What are some of the issues that could prevent this new technology from being implemented in cold chains?
3. Design and describe the concept for one such application.