The Cold Chain and its Logistics

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1. The Cold Chain

While globalization has made the relative distance between regions of the world much smaller, the physical separation of these same regions is still a very important reality. The greater the physical separation, the more likely freight can be damaged in one of the complex transport operations involved. Some goods can be damaged by shocks while others can be damaged by undue temperature variations. For a range of goods labeled as perishables, particularly food (produces), their quality degrades with time since they maintain chemical reactions which rate can be mostly mitigated with lower temperatures. It takes time and coordination to efficiently move a shipment and every delay can have negative consequences, notably if this cargo is perishable. To ensure that cargo does not become damaged or compromised throughout this process, businesses in the pharmaceutical, medical and food industries are increasingly relying on the cold chain.

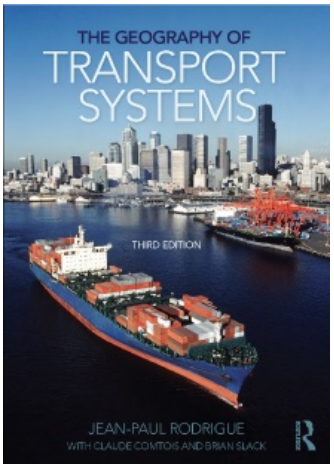
> The **cold chain** involves the transportation of temperature sensitive products along a supply chain through thermal and refrigerated packaging methods and the logistical planning to protect the integrity of these shipments. There are several means in which cold chain products can be transported, including refrigerated trucks and railcars, refrigerated cargo ships as well as by air cargo.

The cold chain is thus a science, a technology and a process. It is a **science** since it requires the understanding of the chemical and biological processes linked with perishability. It is a **technology** since it relies on physical means to insure appropriate temperature conditions along the supply chain. It is a **process** since a series of tasks must be performed to prepare, store, transport and monitor temperature sensitive products.

From an economic development perspective, the cold chain enables many developing countries to take part in the global perishable products market either as producers or as consumers. The growth in income is associated with a higher propensity to consume fruits, vegetables, fish and meat products. Increasing income levels create a change in diet with amongst others a growing demand for fresh fruit and higher value foodstuffs such as meat and fish. Persons with higher socioeconomic status are more likely to consume vegetables and fruit, particularly fresh, not only in higher quantities but also in greater variety. Consumers with increasing purchase power have become preoccupied with healthy eating, therefore producers and retailers have responded with an array of exotic fresh fruits originating from around the world.

From a geographical perspective, the cold chain has the following impacts:

- **Global**. Specialization of agricultural functions permitting the transport of temperature sensitive food products to distant markets. Enables the distribution of vaccines and other pharmaceutical or biological products from single large facilities.
- **Regional**. Can support the specialization of production and economies of scale in distribution. This could involve large cold storage facilities servicing regional grocery markets or specialized laboratories exchanging temperature sensitive components.
- **Local**. Timely distribution to the final consumer of perishables, namely grocery stores and



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Related Topics

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The Containerization of Commodities

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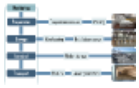
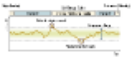
The Cold Chain


Operational Conditions of Cold Chain Logistics


The Cold Chain Technology


Maintaining Temperature Integrity along a Cold Chain


Temperature Standards for the Cold Chain

restaurants.

Some domestic or transnational supply chains may only require one transportation mode, but many times ground shipments are only one link in a combination of transport modes. This makes intermodal transfers critical for the cold chain. Intermodal shipments typically use either 20 or 40 foot refrigerated containers that are capable of holding up to 26 tons of food. The container makes loading and unloading periods shorter and less susceptible to damage both on the container and its cargo. The environments in these containers are controlled electronically by either plugging into a generator or power source on the ship or truck. The efficiency of cold chain logistics permitted the consolidation of cold storage facilities.

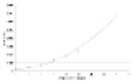
2. Emergence of Cold Chain Logistics

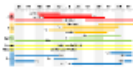
While global commodity chains are fairly modern expansions in the transportation industry, the refrigerated movement of temperature sensitive goods is a practice that dates back to 1797 when British fishermen used natural ice to preserve their fish stock piles while at sea. This process was also seen in the late 1800s for the movement of food from rural areas to urban consumption markets, namely dairy products. Cold storage was also a key component of food trade between colonial powers and their colonies. For example, in the late 1870s and early 1880s, France was starting to receive large shipments of frozen meat and mutton carcasses from South America, while Great Britain imported frozen beef from Australia and pork and other meat from New Zealand. This process was incited by a shortage of meat production in Europe and substantial surpluses in developing countries. By 1910, 600,000 tons of frozen meat was being brought into Great Britain alone. The first reefer ship for the **banana trade** was introduced in 1902 by the United Food Company. This enabled the banana to move from an exotic fruit that had a small market because it arrived in markets too ripe, to one of the world's most consumed fruit. Its impacts on the reefer industry were monumental.

The temperature controlled movement of pharmaceuticals and medical supplies is a much more recent activity than the shipping of refrigerated or frozen food. Since the 1950s, logistical third party companies began to emerge and institute new methods for successfully transporting these global commodities. Before their emergence, cold chain processes were mostly managed in house by the manufacturer. In the United States, Food and Drug Administration restrictions and accountability measures over the stability of the cold chain incited many of these companies to rely on specialty couriers rather than completely overhauling their supply chain facilities. Specialization has led many companies to not only rely on major shipping service providers such as the United Parcel Service (UPS) and Fedex, but also more focused industry that have developed a niche logistical expertise around the shipping of temperature sensitive products. The potential to understand local rules, customs and environmental conditions as well as an estimation of the length and time of a distribution route make them an important factor in global trade. As a result, the logistics industry is experiencing a growing level of specialization and segmentation of cold chain shipping in several potential niche markets within global commodity chains. Whole new segments of the distribution industry have been very active in taking advantage of the dual development of the spatial extension of supply chains supported by globalization and the significant variety of goods in circulation.

The reliance on the cold chain continues to gain importance. Within the pharmaceutical industry for instance, the testing, production and movement of drugs relies heavily on controlled and uncompromised transfer of shipments. A large portion of the pharmaceutical products that move along the cold chain are in the experiment or developmental phase. Clinical research and trials is a major part of the industry that costs millions of dollars, but one that also experiences a failure rate of around 80%. According to the Healthcare Distribution Management Association about 10% of drugs are temperature sensitive. If these shipments should experience any unanticipated exposure to variant temperature levels, they run the risk of becoming ineffective or even harmful to patients.

In all the supply chains it is concerned with, cold chain logistics favor higher levels of integration since maintaining temperature integrity requires a higher **level of control of all the processes involved**. It may even incite third party logistics providers to acquire elements of the supply chain where time and other performance factors are the most important, even farming. This may involve the acquisition of produce farms (e.g. orange groves) to insure supply reliability. Temperature control in the shipment of foodstuffs is a component of the industry that has continued to rise in relation with international trade. As a growing number of countries focus their export economy


Income per Capita and Perishable Share of Food Imports

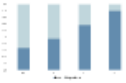

Availability of Fresh Produce by Season and Region


Shelf Life of Selected Perishable Food Products


Meat Cold Chain


Source Loading of Chilled Meat in a Reefer


Preponderance of Fresh and Frozen Cargo by Transport Mode


Share of Refrigerated Transport Capacity in Maritime Shipping


Seaborne Reefer Trade


Reefer Slots Available at North American Ports


Main American Banana Import Ports


Unloading a Banana Ship, New Orleans, 1903

around food and produce production, the need to keep these products fresh for extended periods of time has gained in importance for commercial and health reasons. The cold chain is also a **public health issue** since the proper transport of food products will reduce the likeliness of bacterial, microbial and fungal contamination of the shipment. Also, the ability to transport medical goods over long distances enables more effective responses to healthcare issues (e.g. distribution of vaccines).

3. Providing Temperature Controlled Environments

The success of industries that rely on the cold chain comes down to knowing how to ship a product with temperature control adapted to the shipping circumstances. Cold chain operations have substantially improved in recent decades and the industry is able to answer the requirement of a wide range of products. Different products require the maintenance of different temperature levels to ensure their integrity throughout the transport chain. The industry has responded with the setting of temperature standards that accommodate the majority of products. The most common temperature standards are "banana" (13 °C), "chill" (2 °C), "frozen" (-18 °C) and "deep frozen" (-29 °C), each related to specific product groups. Staying within this temperature range is vital to the integrity of a shipment along the supply chain and for perishables it enables to insure an optimal shelf life. Any divergence can result in irrevocable and expensive damage; a product can simply lose any market value or utility.

Being able to ensure that a shipment will remain within a temperature range for an extended period of time comes down largely to the type of container that is used and the refrigeration method. Factors such as duration of transit, the size of the shipment and the ambient or outside temperatures experienced are important in deciding what type of packaging is required. They can range from small insulated boxes that require dry ice or gel packs, rolling containers, to a 53 footer reefer which has its own powered refrigeration unit. The major cold chain technologies in providing a temperature controlled environment during transport involve:

- **Dry ice**. Solid carbon dioxide, is about -80°C and is capable of keeping a shipment frozen for an extended period of time. It is particularly used for the shipping of pharmaceuticals, dangerous goods and foodstuffs and in refrigerated unit load devices for air cargo. Dry ice does not melt, instead it sublimates when it comes in contact with air.
- **Gel packs**. Large shares of pharmaceutical and medicinal shipments are classified as chilled products, which means they must be stored in a temperature range between 2 and 8°C. The common method to provide this temperature is to use gel packs, or packages that contain phase changing substances that can go from solid to liquid and vice versa to control an environment. Depending on the shipping requirements, these packs can either start off in a frozen or refrigerated state. Along the transit process they melt to liquids, while at the same time capturing escaping energy and maintaining an internal temperature.
- **Eutectic plates**. Also known as "cold plates". The principle is similar to gel packs. Instead, plates are filled with a liquid and can be reused many times. Eutectic plates have a wide range of applications, such as maintaining cold temperature for rolling refrigerated units. They can also be used in delivery vehicles to keep temperature constant for short periods of time, a process that can be suitable for deliveries in noise sensitive areas or for night deliveries.
- **Liquid nitrogen**. An especially cold substance, of about -196°C, used to keep packages frozen over a long period of time. Mainly used to transport biological cargo such as tissues and organs. It is considered as an hazardous substance for the purpose of transportation.
- **Quilts**. Insulated pieces that are placed over or around freight to act as buffer in temperature variations and to maintain the temperature relatively constant. Thus, frozen freight will remain frozen for a longer time period, often long enough not to justify the usage of more expensive refrigeration devices. Quilts can also be used to keep temperature sensitive freight at room temperature while outside conditions can substantially vary (e.g. during the summer or the winter).
- **Reefers**. Generic name for a temperature controlled transport unit, which can be a van, small truck, a semi trailer or a standard ISO container. These units, which are insulated, are specially designed to allow temperature controlled air circulation maintained by an attached and independent refrigeration plant. A reefer is therefore able to keep the cargo temperature cool and even warm. The term reefer increasingly apply to refrigerated forty foot ISO containers with the dominant size being 40 high-cube footers (45R1 being the size and type code).

4. Refrigerated Containers

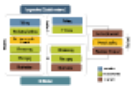
Reefer Containership entering the Zeebrugge Harbor

Reefer Stacking Area, Maher Terminal, Newark

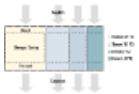
Reefer Stacking Area, Porte Oceane Terminal, Le Havre

The Limon Moin Container Port Project

Subtropolis Underground Warehousing Facility, Kansas City



Containerization, Cold Chains and the Flexibility of Supply Chains



Large Scale Grocery Cold Chain Distribution Center

Grocery Chain Cold Storage Facility, Regina

Grocery Section of a Large Food Distribution Center

Banana Ripening Room

Reefers and Source Loading in the Chilled Meat Cold Chain

Fresh Flowers Cold Chain, Ecuador-United States

Refrigerated containers, **reefers**, account for a growing share of the refrigerated cargo being transported around the world. While in 1980 33% of the refrigerated transport capacity in maritime shipping was containerized, this share rapidly climbed to 72% in 2013. The structure of global maritime shipping is thus adapting to service the reefer trade implying a shift away from specialized ports, or specialized terminals within ports, to standard container terminals. The reefer has become a common temperature-controlled transport unit used to insure load integrity since it can accommodate a wide range of temperature settings and accordingly a wide range of temperature sensitive products. Also, it is a versatile unit able to carry around 20 to 25 tons of refrigerated cargo and is fully compatible with the global intermodal transport system, which implies a high level of accessibility to markets around the world.

About 2.02 million TEUs of reefers were being used by 2011, which represents about 5% of the global ISO container capacity. While a regular 40 foot container costs around $5,000, a reefer of the same size is in the range of $30,000. The cost difference is attributed to insulation and the refrigeration unit that keeps the temperature constant. This implies that a reefer has less volume than a regular container of the same size. While a regular 40 foot high cube container can accommodate a volume of 76 cubic meters, a reefer of the same size handles 67 cubic meters (12% less). This shortcoming is compensated by the heavier loads that are usually carried in reefers. From a manufacturing standpoint, all the world's reefers are made in China. In 2015, MCI, a subdiary of Maersk will begin operations of a new reefer manufacturing plant in San Antonio, Chile. This will convey the advantage of manufacturing reefers next to major export areas of refrigerated cargoes (fruits such as oranges and grapes).

Proper air circulation must also be insured, implying that reefers have gratings on the floor and that at clearance of about 15 cm must be kept between the cargo and the ceiling. Cold air coming out of the refrigeration unit flows through the bottom part of the reefer and as it warms up it climbs towards the ceiling to flow back to the refrigeration unit, usually 0.5 °C to 3 °C warmer. The heat is the outcome of ambient temperature permeating into the reefer (this is particularly the case when ambient temperature is high) as well as the cooling of the cargo if it was loaded in at a warmer temperature than the one maintained in the reefer. All reefers are painted white to increase the albedo (share of the incident light being reflected; high albedo implies less solar energy absorbed by the surface). For instance a low albedo container can have its internal temperature increase to 50 °C when the external temperature reaches 25 °C on a sunny day while a high albedo container sees its internal temperature increase to only 38 °C under the same conditions.

The refrigeration unit of a reefer requires an **electric power source** during transportation and at a container yard. For the road transport of a reefer, either a clip-on generator (called genset; it attaches to the upper front end of a reefer) or an underslung generator (it attaches under a container chassis) are used. For modes such are maritime and rail that can carry multiple containers, the capacity of the power system determines the number of reefers that can be carried. Regular containerships have 10 to 20% of their slots adapted to carry reefers, with some ships having up to 25% of their slots being dedicated when servicing routes with a higher intensity of refrigerated cargo (e.g. Latin American exports). The power is directly provided by the ship's generator. For rail movements, diesel generators are used to provide power to about 8 reefer containers. These genset units have the same dimensions than a 40 foot container and can thus use the same intermodal equipment than intermodal containers. A common loadout for unit trains is to have two stacked genset units about to power a group of 16 reefers. For smaller reefer loads, or for shorter distances, clip-on generators are commonly used.

It is important to underline that the refrigeration units are designed to **maintain the temperature** within a prefixed range, not to cool it down. This implies that the shipment must be brought to the required temperature before being loaded into a reefer, which requires specialized warehousing and loading / unloading facilities. A new generation of reefers is coming online, which are equipped with an array of sensors monitoring effectively the temperature and shutting the cooling plant when unnecessary. This enables to improve the reliability of temperature control and well as extend the autonomy of the reefer.

The growth of the intermodal transportation of reefers has increasingly required transport terminals, namely ports, to dedicate a part of their storage yards to reefers. This accounts between **1% to 5% of the total terminal capacity**, but can be higher for transshipment hubs or terminals in areas with an important reefer trade. The stacking requirements simply involve having an adjacent power outlet, but the task is more labor intensive as each container must be plugged and unplugged manually and the temperature to be monitored regularly as it is the responsibility of the terminal operator to insure that the reefers keep their temperature within preset ranges.

This may also forbid the usage of an overhead gantry crane implying that the reefer stacking area can be serviced by different yard equipment. Even if reefers involve higher terminal costs, they are very profitable due to the high value commodities they transport. Depending on the intensity of reefer use, reefer activities can account for up to 20% of a container terminal energy consumption.

The higher costs of the reefer and the additional equipment and monitoring required involve higher shipping rates. To be profitable, a reefer must be used 4 to 6 times per year as a revenue generating movement. Due to the specific trades they service, reefers are often repositioned empty or used as regular containers with their power supply turned off. As such they are labeled as non-operating reefers. The reefer trade is a full container load (FCL) and point-to-point only. Unlike the regular container trade, there is no consolidation or deconsolidation function performed in reefer transportation, since they would increase the risk of damaging what is being carried. Deconsolidation usually takes place either when the contents of reefers are transloaded into domestic refeers or at the distribution center when orders are assembled for customers (particularly for grocery).

5. Cold Chains Operations

Moving a shipment across the supply chain without suffering any setbacks or temperature anomalies requires the establishment of a comprehensive logistical process to maintain the **shipment integrity**. This process concerns several phases ranging from the preparation of the shipments to final verification of the integrity of the shipment at the delivery point:

- **Shipment preparation**. When a temperature sensitive product is being moved, it is vital to first assess its characteristics. A key issue concerns the temperature conditioning of the shipment, which should already be at the desired temperature. Cold chain devices are commonly designed to keep a temperature constant, but not to bring a shipment to this temperature, so they would be unable to perform adequately if a shipment is not prepared and conditioned. Other concerns include the destination of the shipment and the weather conditions for those regions, such as if the shipment will be exposed to extreme cold or heat along the transport route. Using a reefer with its own power unit usually mitigates such concerns.
- **Modal choice**. Several key factors play into how the shipment will be moved. Distance between the origin and the final destination (which often includes a set of intermediary locations), the size and weight of the shipment, the required exterior temperature environment and any time restrictions (perishability) of the product all effect the available transportation options. Short distances can be handled with a van or a truck, while a longer trip may require an airplane or a container ship. In this case, the cost / perishability ratio becomes a factor in modal choice.
- **Custom procedures**. If the freight crosses boundaries, custom procedures can become very important, since cold chain products tend to be time sensitive and more subject to inspection than regular freight (e.g. produce, pharmaceuticals and biological samples). The difficulty of this task differs depending on the nation (or economic bloc) and the gateway since there are variations in procedures and delays. Customs issues are commonly identified as the most crucial in establishing reliable international cold chains.
- **The "Last Mile"**. The last stage is the actual delivery of the shipment to its destination, which in logistics is often known as the "last mile". Key considerations when arranging a final delivery concern not only the destination, but the timing of the delivery so the critical labor and warehousing space is available. Trucks and vans, the primary modes of transportation for this stage, must meet the specifications necessary to transfer the cold chain shipment. Since many deliveries of cold chain products, particularly groceries, are taking place in an urban setting congestion and parking difficulties Also important is the final transfer of the shipment into the cold storage facilities as there is potential for a breach of integrity.
- **Integrity and quality assurance**. After the shipment has been delivered, any temperature recording devices or known temperature anomalies must be recorded and made known. This is the step of the logistical process that creates trust and accountability, particularly if liability for a damaged shipment is incurred. If problems or anomalies that compromise a shipment do occur, an effort must be made to identify the source and find corrective actions.

Therefore, the setting and operation of cold chains is dependent on the concerned supply chains since each cargo unit to be carried has different requirements in terms of demand, load integrity and transport integrity. Because of the additional tasks involved as well as the energy required for the refrigeration unit transportation costs for cold chain products is much higher than regular

goods. The ongoing rise in standards of living and economic specialization will remain important drivers for years to come in the growing demand for perishable goods and the cold chain logistics supporting their transport.

6. Food Transportation

Any major grocery store around the world is likely to carry tangerines from South Africa, apples from New Zealand, bananas from Costa Rica and asparagus from Mexico. Thus, a cold chain industry has emerged to service these commodity chains. However, the level of application of cold chain technology varies substantially according to the level of development. About 70% of all the food consumed in the United States is handled by the cold chains. For China, less than 25% of the meat and about 5% of the fruits and vegetable is. Alone, the United States imports about 30% of its fruits and vegetables and 20% of its food exports can be considered perishables. The uncompromised quality and safety of this food is often taken for granted, despite being the main reason behind the ability to sell the food. The cold chain serves the function of keeping food fresh for extended periods and eliminating doubts over the quality of the food products. Still, about 25% of all food products transported in the cold chain are wasted each year due to breaches in integrity leading to fluctuations in temperature and product degradation.

There is a variety of methods for the transport of food products with the banana accounting for the world's most significant commodity transported in the food cold chain with 20% of all seaborne reefers trade. Land, sea and air modes all have different operations for keeping food fresh throughout the transport chain. Depending on their speed, different modes will service different cold chain markets. Innovations in packaging, fruit and vegetable coatings, bioengineering (controlled ripening), and other techniques reducing the deterioration of food products have helped shippers extend the reach of perishable products. For food products such as fruits and vegetables, time has a direct impact on their **shelf life** and therefore on the potential revenue a consignment may generate. Concomitantly, new transport technologies have permitted the shipment of perishable products over longer distances. For instance, improved roads and intermodal connections along the African coast reduced food transport time to European markets from 10 days to 4 days.

Moving away from ice refrigeration has allowed for much greater distances to be traveled and has greatly increased the size of the global food market, enabling many developing countries to capture new opportunities. Another efficient mode for transporting foodstuffs is air travel. While this is a preferred form of travel for highly perishable and valuable goods due to its ability to move much faster over longer distances, it does lack the environment control and transfer ease of the ground and sea transports. Also, during the flight the cargo is stored in a 15°C – 20°C environment, but close to 80% of the time the package is exposed to exterior weather while waiting to be loaded onto the plane or being moved to and from the airfield. This is troubling considering the value of the food and the importance placed behind quality and freshness. In order for this form of food transport to experience growth among market users, more uncompromising strategies and regulations will have to be embraced and enacted.

Food transportation is an industry that has fully adapted to the cold chain and can, despite the problems with air transport, be considered the most resilient, particularly since a large majority of food products have a better tolerance to temporary variations of transport temperatures. It is the cold chain distribution center that represents one of the most efficient link in cold chain logistics by providing facilities where vast amount of perishable food products can be received from a large amount of suppliers, stored, sorted and assembled into loads bound for respective grocery stores. These facilities usually have several storages areas with different temperature settings to handled regular grocery goods at ambient temperature, produces, dairy, meat and frozen products. As a result, small errors can be compounded without the concern of irreversible damage. For instance, for the transportation of produces, for every hour of delay in the pre-cooling of shipments, an equivalent one day loss of shelf life must be accounted.

The usage of refrigerated containers has particularly helped, since they account for more than 50% of all the refrigerated cargo transported in the world. **Source loading** can be an important factor extending the shelf life of a cold chain product since it is loaded in a reefer directly at the place of production without additional handling and risks for further breaches in the chain of integrity. For instance, source loading into a reefer can expand the shelf life of chilled meat by about 25 days (from 30-35 days to 55-60 days) from conventional methods and thus considerably expand the market potential of the product.

The efficiency and reliability of temperature controlled transportation has reached a point which

allows the food industry to take advantage of **global seasonable variations**, meaning that during the winter the southern hemisphere can export perishable goods to the northern hemisphere while an opposite trade, generally of smaller scale, takes place during the summer. Countries such as Chile have substantially benefited from this and have developed an active agricultural and food transformation industry mainly servicing the North American market during the winter, but also with several niche markets such as wine. A similar issue concerns some African countries such as Kenya that have developed a fresh produce and flower industries catering the European market. The fast food industry is also an active user of cold chain logistics as every outlet can be considered as a factory, with dozens of workers with schedules and shifts, inventory management and the supply chain of components (many of which are temperature sensitive), and which are assembly lines producing quality-controlled and high-volume products.