Advanced Logistic Systems – Theory and Practice, Vol. 16, No. 2 (2022), pp. 47-53.
https://doi.org/10.32971/als.2022.012

LOGISTICS AND COLD CHAIN RELATIONSHIP

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Abstract: The emergence of vaccines to contain and defeat the now-famous virus has been a huge step forward for mankind, but how and under what conditions these vaccines can get from the place of production to the place of use has been a major challenge. Whether in packaging or transport, there are stringent requirements to be met and COVID-19 vaccines have different cold chain requirements depending on the type of vaccine, its thermal stability, its current condition, and its shelf life at different storage temperatures. Currently, one vaccine must be stored and transported at ultra-low temperature (ULT - Ultra-Low Temperature) between -90°C and -60°C. Effective use of this requires good cold chain planning, efficient management of vaccine supply, logistics and distribution, and strategic deployment of ULT equipment. The pandemic has brought cold chain logistics to the forefront, and in this paper, we examine the relationship between logistics and the cold chain.

Keywords: logistics, warehousing, vaccine, virus, cold chain

1. INTRODUCTION

This paper deals with the Covid-19 vaccines and the cold chain that bring to the fore. The emergence of vaccines to contain and defeat the virus has been a huge step forward for mankind, but how and under what conditions these vaccines can get from the point of production to the point of use has been a major challenge. Whether in packaging or transport, there are stringent requirements to be met and COVID-19 vaccines have different cold chain requirements depending on the type of vaccine, its thermal stability, its current condition, and its shelf life at different storage temperatures. Currently, the Pfizer-BioNTech COVID-19 vaccine is the only COVID-19 vaccine that must be stored and transported at Ultra-Low Temperature (ULT) between -90°C and -60°C. Its efficient use requires good cold chain planning, efficient management of vaccine supply, logistics and distribution, and strategic deployment of ULT equipment. The pandemic has brought cold chain logistics to the forefront, and also became one of our research topics. In this paper, we examine the relationship between logistics and the cold chain. Further research has also covered how the cold chain evolved during the pandemic, what methods exist for packaging, storing, and transporting vaccines, and what logistical problems occurred during the processes, but these are not discussed within the scope of this paper.

2. THE RELATIONSHIP BETWEEN LOGISTICS AND COLD CHAIN

Thanks to globalization, we are now able to supply products to all parts of the world. However, the greater the physical distance to be covered in transit, the greater the chance of damage to the product. Because transport requires time and coordination to be efficient and

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any delay can have negative consequences. This is particularly true for food, pharmaceutical and medical products, so these businesses are increasingly relying on cold chain processes.

Cold chain refers to the transport of temperature-sensitive products in the supply chain, using thermal and refrigerated packaging methods, and logistics planning to protect the integrity of these shipments [1].

Thanks to the rise to prominence of cold chain processes, many companies no longer rely only on well-known suppliers such as FEDEX or United Parcel Service (UPS), but also on those specialized in the transport of temperature-sensitive products (Maersk, Patheon). These suppliers are familiar with customs duties, local regulations, environmental conditions, know which route is the most appropriate and have become very important factors in global trade. The cold chain allows many developing countries to participate in the global market for perishable goods, thus contributing to economic development. At global level, the cold chain has an impact on the specialization of agricultural functions that allow the transport of temperature-sensitive foods to distant markets, as well as the distribution of vaccines and other pharmaceutical or biological products [1].

In the world of logistics, cold chain technology has been around for decades and has evolved from the simpler days of packing food in ice during transport to the complex movement of life-saving vaccines at ultra-cold temperatures. Although advances in technology have facilitated the transport of temperature-controlled products worldwide, the basic concept remains the same: goods must be kept at the right temperature to ensure efficiency and safety for the end user. The transport of temperature-sensitive goods by refrigeration dates back to 1797, when British fishermen used ice to preserve their fish stores. This process was also used in the late 1800s to transport food, and more specifically dairy products, from rural areas to urban consumer markets. Cold storage was also a key element in the food trade between colonial powers and their colonies. France, for example, began receiving large shipments of frozen meat from South America in the late 1870s and early 1880s, and Britain imported frozen beef from Australia. By 1910, 600 000 tons of frozen meat had been imported into Britain alone. The United Food Company launched the first refrigerated vessel for the banana trade in 1903. This allowed bananas, an exotic fruit with a small market because it arrived too ripe, to become one of the most consumed fruits in the world. In 1930, Frederick Jones designed and patented a portable air-cooling unit for trucks carrying perishable food. By the late 1930s, refrigerated trucks and vans were transporting perishable food long distances. The rapid growth of the cold chain industry was made possible by the 1956 Interstate Highway Act [1, 2].

The cold chain and the cooling trucks (see Figure 1 [5]) have undergone many changes. Thanks to evolving technology, it is now possible to have a high level of control over every aspect of the cold chain. The cold chain industry contributed $56 billion to the US gross domestic product and supported 67,000 jobs in 49 states in 2012. As the United States is a world leader in the development of efficient cold chain technologies and management processes, cold chain now covers almost the entire world [2].

The temperature-controlled transport of pharmaceuticals and medical products is a much more modern idea than the transport of chilled or frozen food. From the 1950s onwards, third-party logistics (3PL) companies began to emerge, introducing new ways to successfully transport these global commodities. Before their emergence, cold chain processes were mostly managed in-house by the manufacturer. In the United States, restrictions imposed by the Food and Drug Administration on cold chain stability and other measures have encouraged many companies to rely on specialized courier services rather than completely transforming their supply chains. Thus this specialized industry was born.

Cold chain processes for the preservation of expensive vaccines and medical supplies only began to be recognized when these logistics providers emerged. As awareness began to grow, so did the need for effective cold chain management, especially during the Covid-19 pandemic [2].

Figure 1. Vaccine cold chain delivery vehicle [5]

Clinical research and trials are a major part of the industry, costing millions of dollars and with a failure rate of around 80%. According to the Healthcare Distribution Management Association, of the nearly $200 billion in drug distribution, about 10% is temperature sensitive. This means that the cold chain is responsible for delivering nearly $20 billion of investment. If the temperature changes for any reason during transport, there is a risk that shipments may become ineffective or even harmful to patients [1].

Temperature control of food transport is an element of the industry that is becoming increasingly necessary as international trade increases. With food and produce production at the heart of more and more countries' export economies, it has become increasingly important to keep these products fresh for longer. Demand for food has changed over the years, with more people preferring fresh fruit and higher value foods such as meat and fish, and demand for these has increased. Healthy eating is becoming increasingly important to consumers, and producers and retailers are responding with a wide range of exotic fresh fruit from around the world [1].

If you go shopping and stop at the fruit and vegetable section, you are likely to find produce that is out of season in our country, such as mandarins from South Africa, bananas from Costa Rica or apples from New Zealand. In 2002, an estimated $1,200 billion worth of food was shipped from 400,000 refrigerated containers (Reefers). Interestingly, the US imports about 30% of its fruit and vegetables and 20% of its food exports are considered perishable. Cold chain logistics favors a higher level of integration in all the supply chains it is involved in, as maintaining temperature requires a higher level of control of all the processes involved [1].

One of the most important things in cold chain processes is to ensure a temperature-controlled environment. Depending on what product is being shipped, different temperature levels need to be maintained to ensure a healthy arrival. The most common temperature standards include 'banana' (13°C), 'chill' (2°C), 'frozen' (-18°C) and 'deep-frozen' (-29°C). Staying within temperature limits is vital to the integrity of the shipment in the supply chain and any deviation can cause irreversible and costly damage; the product may simply lose its market or use value [1].

Keeping a consignment within a temperature range for a prolonged period is only possible with a suitable container. Since manual temperature recording is unreliable beyond a certain point, innovative solutions are needed. These began to gain momentum in the 1970s and 80s when Electrolux Luxembourg, working with a wooden refrigerated box from a laboratory in Sweden in 1974, developed an easily transportable vaccine storage container. The Luxembourg cold box was successfully tested in Ghana and became a widely used model for manufacturers. In 1976, the World Health Organization (WHO) developed a strategy to address critical problems in vaccine distribution, including temperature control systems during transport, lack of storage facilities and inadequate training of staff. In 1977, after the invention of the refrigerated box, a US-based portable container company collaborated with the Pan American Health Organization (PAHO) to create a vaccine container that is now used worldwide. In the late 1970s, PATH also began working with the WHO and various technology partners to better assess whether vaccines were exposed to heat. A big step forward was the development in the early 1980s by PATH and Temptime Corporation of temperature sensitive VVM (Vaccine Vial Monitor) stickers that change color when it gets too hot, meaning that the vaccine they are attached to has become ineffective. These VVMs have also been used for polio vaccines since 1996 and are now required by the WHO for all vaccines provided by the United Nations International Children's Emergency Fund (UNICEF). The cold chain monitor (CCM) was also created in the 1980s by companies in the United States and Switzerland. It was an innovation to reliably monitor vaccine warehouses from the manufacturer to delivery sites in different countries [4].

In order to know what kind of packaging is needed, it is important to know the size of the shipment, the duration of the transport and the ambient or external temperature. These can range from small, insulated boxes requiring dry ice or gel packs, to rolling containers, to refrigerated containers several meters long with their own motorized refrigeration unit. The main cold chain technologies include [1]:

- Gel packs. Most shipments of medicines and pharmaceuticals are refrigerated products, which means that they must be stored in a temperature range between +2°C and +8°C. This is achieved by using gel packs, which contain phase change materials that can change from solid to liquid and vice versa, thus controlling the environment. These packages start in a frozen or refrigerated state and become liquid during transport. During this process they absorb the energy released and maintain the internal temperature [1].
- Dry ice. This is solid carbon dioxide, at about -80°C, and can keep a shipment frozen for extended periods. It is used in particular for transporting dangerous goods, foodstuffs, and medicines. Importantly, when dry ice comes into contact with air, it sublimates rather than melts [1].
- Liquid nitrogen. This particularly cold substance, at about -196 °C, is used for long periods of freezing. It is mainly used for transporting biological cargoes such as tissues and organs. It is classified as a dangerous substance for transport [1].
- Reefers. A generic term for a temperature-controlled container, which may be a van, semi-trailer, van, or standard ISO container. In these containers, a connected and independent refrigeration unit maintains temperature-controlled airflow [1].

Different examples for these technologies are shown in the Figure 2 [6-9].

Grouping can also be based on vehicles. Of course, not all means of transport are suitable for the transport of perishable goods. The task of controlling the constant temperature, as defined by law, makes it possible to distinguish between the following types of carriers:

- Cold carrier. It has a cooling technology that allows the internal temperature to be reduced and always kept between +12°C and -20°C, depending on the type of vehicle [3].
- Isothermal substrate. It has a compartment with insulating walls, including the floor, doors, and roof. This significantly reduces the heat exchange between the interior and the exterior [3].
- Refrigerated substrate. A type of vehicle that helps to reduce the internal temperature of the passenger compartment and maintain the average external temperature between +30°C and -20°C [3].
- Heat carrier. It has equipment that generates heat and increases the temperature of the interior. This is maintained at a constant temperature for 12 hours and never falls below +12°C [3].

(a) Gel pack [6] (b) Dry Ice [7]

(c) Liquid nitrogen [8] (d) Reefers [9]

Figure 2. Different cold chain technologies [6-9]

For vehicles for refrigerated transport, capacity, weight and size constraints, the need to optimize fuel and safety must be taken into account. In addition, all vehicles must always comply with the requirements of the Agreement on the Carriage of Perishable Goods (ATP). The Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be used for such Carriage (ATP) was signed in Geneva in September 1970. The regulations define how perishable foodstuffs are to be transported, the requirements for special vehicles and the control procedures to ensure compliance. The aim is to guarantee to the final consumer that the food arrives in good conditions. As of 2016, it is in force in 50 countries, most of which are in Europe or Central Asia [3].

As mentioned above, temperature-sensitive (potentially perishable) goods are transported in reefers, which account for an increasing share of the refrigerated cargo transported worldwide. In 1980, 33% of reefer capacity in the maritime shipping industry was containerized, rising to 47% in 1990, 68% in 2000 and 90% in 2010. To minimize the amount of solar energy absorbed by containers, they are painted white. The internal temperature of a container with a low albedo (the ratio of incident light) can reach +50°C at an external temperature of +25°C, while the internal temperature of a container with a high albedo can only rise to +38°C under the same conditions [1].

The purpose of refrigeration units in refrigerated trucks is to keep the temperature within a predetermined range, not to cool it! In other words, before loading a consignment into the refrigerated compartment, it must be brought to the desired temperature. Of course, this requires special loading, unloading and storage solutions. Nowadays, refrigerated trucks are also increasingly modern, equipped with sensors that monitor the temperature and, if necessary, shut down the refrigeration system. This makes it possible to improve the reliability of temperature control and extend the autonomy of the refrigerated truck. Ports will also benefit from an important change, as they will have to dedicate between 1 and 5% of their total terminal capacity to refrigerated trucks. However, this is very labor-intensive and there is a lot of room for error, as only one socket may be needed, but all containers have to be manually connected and disconnected. Also, the temperature needs to be checked regularly and it is the responsibility of the port manager to ensure that the temperature of the refrigerators is kept within the pre-set ranges. Even if refrigerated trucks have higher port costs, they are very profitable because of the high value goods they carry [1].

Moving a consignment through the supply chain requires the development of a comprehensive logistics process. This process involves several phases, from the preparation of the consignments to the final check of the integrity of the consignment at the point of delivery:

- Preparing the shipment. When transporting a temperature-sensitive product, it is first vital to assess its characteristics. One of the most important issues is the conditioning of the temperature of the shipment, which should already be at the desired temperature. As mentioned in this paper, cold chain equipment is generally designed to maintain a constant temperature, so if the shipment is not properly conditioned (not at the shipping temperature), it cannot function properly. Problems can be caused by the destination of the shipment and the weather conditions of the regions, such as whether the shipment will be exposed to extreme cold or heat along the transport route [1].
- The choice of transport mode. Several factors need to be considered when choosing the mode of transport. For example, the distance between the origin and final destination, the size and weight of the shipment or time constraints on the product all affect the available transport options. Short distances can be covered by a van or truck, while a longer journey may require an aircraft or container ship [1].
- Specific procedures. Once the shipment crosses borders, customs procedures can become very important, as cold chain products are usually time-sensitive and more vulnerable to inspection than traditional shipments. The difficulty of this task varies from country to country as procedures and delays vary [1].
- The "last mile". The final stage is the actual delivery of the shipment, often referred to in logistics as the "last mile". When organizing the last shipment, timing must be a key consideration. At this stage, trucks and vans are used to make the deliveries. The final transfer of the consignment to the storage facilities is also important, as there is a risk of damage to the integrity [1].
- Integrity and quality assurance. After delivery of the consignment, temperature recording devices should be recorded and communicated. This is the step in the logistics process that creates confidence and accountability, especially if the

> shipment is damaged. In the event of problems that compromise a shipment, the source of these problems should be identified, and corrective action taken [1].

As it can be seen, the setup and operation of some cold chains depends on what you are transporting. After all, each unit load to be transported has different requirements in terms of stress, load, and transport integrity.

3. Summary

The paper presented the cold supply chain for vaccines that play a major role in containing the COVID-19 pandemic. The paper described how the cold chain has evolved and how it relates to logistics, covering companies, its history, and financial implications. It was also grouped cold chains by technologies and vehicles. It was also described the means used in cold chain transport. Finally, the transport process has been detailed, which involves several phases, from the preparation of the consignments to the final check of the integrity of the consignment at the point of delivery.

Acknowledgements

This paper has been produced with the technical support of the New National Excellence Programme of the Ministry of Culture and Innovation, code number ÚNKP-22-1, funded by the National Research, Development and Innovation Fund.

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