An Overview of Warehouse Operations for Cold Chain

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Abstract Warehouses play a significant role in cold chains as they do for regular supply chains. Although their goals are the same for both cold chains and regular supply chains, the operations of cold warehouses are more sophisticated since the cost of operation is considerably higher due to energy consumption and obsolesce of products in substandard conditions. Recently, there has been an enormous interest in the cold food supply chain to reduce food waste occurring along the chain. Hence, efficient management of cold warehouses becomes an important issue in this direction. Design and operation requirements in a cold warehouse may be different from a traditional non-cold warehouse. In this paper, we aim to provide an overview of cold chain operations, mostly by focusing on cold warehouse operations. We provide some statistics from a cold chain, design, and technology requirements for cold warehouses as well as warehouse operations shaped according to that warehouse features. It is observed that there are quite different design parameters in cold storage.

Keywords Warehouse operations · Cold supply chain · Cold warehouse · Technologies for cold chain

Introduction

Warehouses play a critical role in supply chains. The main purposes of warehouses are: (i) to store items in order to reduce demand variability for the upper echelon, and (ii) to decrease transportation lead times for customers. Storing and retrieving

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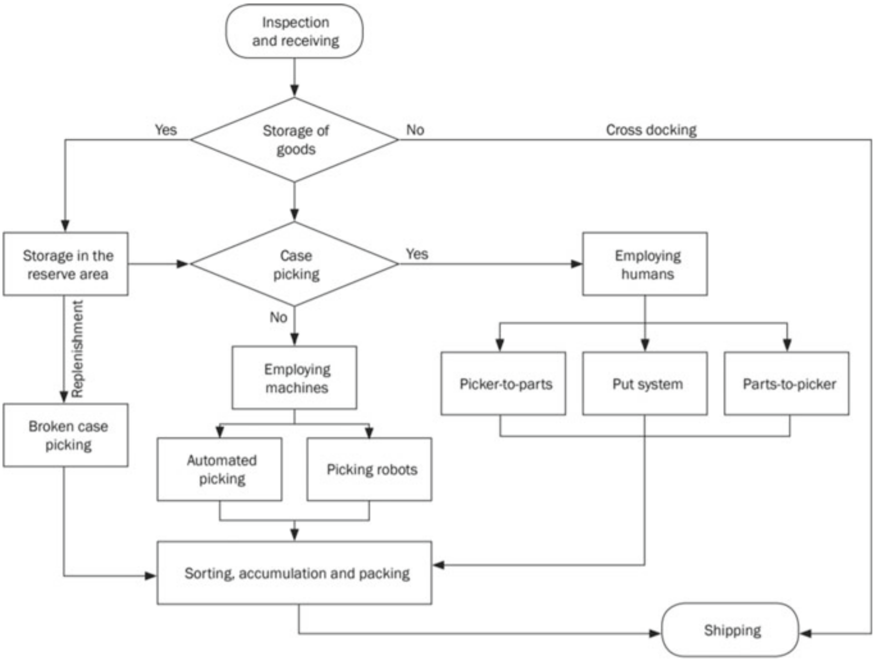


Fig. 1 Standard warehouse processes [15]

products promptly without any errors is desired to avoid any mistakes when satisfying customer demands. The main operations in warehouses such as shipment planning, order picking, assigning orders to vehicles with limited capacity, and routing of these vehicles are complex operations and have to be performed effectively. In the planning process, all of these operations should be considered simultaneously and optimized. Figure 1 shows a typical flow of operations/processes in a warehouse.

In warehouses, typically first, products arrive at the receiving docks, and they are unloaded from the trucks in that area. Second, products are sent to the storage area for their temporary storage. However, sometimes storage of products does not take place; in this case, products are sent directly from the receiving docks to the shipping docks that are called cross-docking. Those products stored in the reserve area wait until an order is received from a customer for their dispatch. The stocking policy of products may vary according to product type, size, and special requirements of those products. When a customer order arrives, interior vehicles or automated machines pick those products from their storage addresses and then send them to the shipment area where they will be loaded in the transporters.

Warehouses are designed based on the storage requirements of the products they will be used for. Storage requirements may change for raw materials, semi-products, or final products. Besides, based on the product types to store, the warehouse design requirements might vary. For instance, for frozen foods, pharmaceutical products, cold products, etc. refrigerated warehouses are required to keep the products in the right condition. It is challenging in cold warehouses to maintain the right cold storage temperature for the product inside while keeping personnel and equipment warm enough to perform at their optimal capacity.

The cold chain industry is growing and improving fast. As in recent trends in order to profile in the cold chain, customers value convenience, wholesome food, and just-in-time delivery. Moving away from highly processed packaged foods with a long shelf life to temperature-sensitive perishable food products requires an adjustment in the food supply chain. According to Lempert [17], the year 2017 goes down in history as the most important ever in grocery. He declares that the food world is changing at an incredible speed, and the industry must evolve to adapt to this change. He explains that for instance, groceries are now "cool," and they become industries attracting talents from the best schools and companies who would not even have thought about a career in grocery or food industry a few years ago [17].

Recently, it has been observed that the cold storage warehouse capacity has increased drastically. For instance, it has been reported that in 2018, India had the world's largest refrigerated warehouse capacity, weighing 150 million cubic meters following the United States with 131 million cubic meters. Refrigerated warehouses worldwide had a total capacity of 616 million cubic meters [23]. In an effort to attract readers on cold warehouses, in this paper, we aim to present a cold warehouse framework study by focusing on what operations, design metrics as well as critical issues to consider for operating them.

As mentioned, in this paper, we aim to shed light on cold chain operations, specifically by focusing on cold warehouses. We present an overview of operations in cold warehouses along with the points that should be focused on and improved in order to decrease the food loss.

Cold Chain

The cold chain includes the production of refrigerated products as well as the storage and distribution operations of those products throughout the chain. Cold chains are used in two main sectors: food and bio-pharmaceutical. Both sectors have considerably high revenues. More than $18 billion of the global third-party logistics revenue was received from the food and grocery market in 2017, whereas the healthcare market produced more than $17 billion in revenue [22].

Food chain is a recent significant consideration in sustainability due to high amount of food loss along with the distribution network. According to the Food and Agriculture Organization of the United Nations, almost 1/3 of the world's food was lost or wasted each year [12]. This means that roughly 1.3 billion tons of food is wasted every year. Chabada et al. [7] claim that two main causes of food waste at the wholesaler are due to substandard quality and short remaining shelf life of the products. Effective cold chain management would yield a decrease in food waste, therefore becoming a field of scientific studies.

Table 1 Products with required temperature and humidity ranges in cold storage

Product	Temperature (°C)	Humidity (%)
Chocolate	15–18	50–60
Flower	8–16	70–75
Vegetables	6–8	80–90
Fruits	4–6	80–90
Mushrooms	0	90–95
Fresh meat	−2–0	–
Frozen fruits and vegetables	−10–0	–
Frozen meat	−20	–
Frozen tuna	−40–60	–

Management of a food product chain is a challenging issue, especially due to the perishability property of food, their requirement of variable shelf life, certain storage temperatures, time for cooling, and specific packaging and logistics requirements. These products are quite vulnerable to storage conditions. For instance, storing under favorable temperature conditions and complying with the suitable temperature conditions in transportation operations are significant steps to avoid any food waste. Hence, refrigerated (cold) warehouses play a critical role in cold supply chains. Cold warehouse operations start with receiving of the refrigerated products and continue with storing them within ideal temperature conditions. Each product type may require a different storage temperature and condition. Table 1 depicts the ideal storage temperatures and humidity ranges for the storage of different product types as an example [19]. Obviously, when the product variety increases, cold warehouse management becomes more complex due to different storage requirements of each product type.

As mentioned, cold chain logistics strategies are commonly used for storing and transporting fresh foods, vegetables, meat, frozen foods, medicines, and drugs, etc. The main issue in cold chain logistics is the management of temperature-controlled operations (monitoring, etc.) along the supply chain. Monitoring requires devices and systems able to track the condition of the cold chain, such as temperature and humidity, throughout the stages. Cold chain products also require specific equipment and/or methods for fabrications. For example, vacuum packing is often used for the packing of meat to extend its shelf life. Unlike any other products, cold chain products are rarely available for immediate consumption. Hence, the analyses and requirements might be non-traditional in cold warehouses. Transportation of cold products requires specific operations as well as special physical environments, such as transport terminals, ports, and airports dedicated to cold chain logistics. For instance, a container in port terminals might be dedicated to refrigerated products. Terminal facilities have on-dock refrigerated warehouses. A range of transport technologies is available, and it has been improving for the transportation of cold chain goods. Other common technologies that are utilized in transportation are reefer vehicles and containers (maritime containers and unit load devices). They usually require

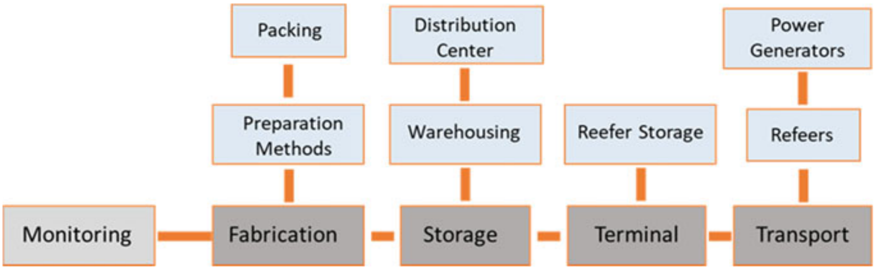


Fig. 2 Cold chain process

refrigeration plants with a power generator. Figure 2 shows the cold chain processes that are closely interacting in a sequential manner [25].

Cold Keeping Areas in Cold Chain

There are a variety of cold storage places in cold chains to keep the products cold for a period of time. These are designed from individual units to entire dedicated facilities. Refrigerated containers are the most basic and often the most cost-effective option for cold storage of small quantities of temperature-sensitive products. They can also be mobile, providing an extra advantage in flexibility. Blast freezers and chillers are ideal for companies requiring quickly cooling and storing foods before they reach the end consumer. In Figs. 3 and 4 show refrigerated container and blast freezer views, respectively.

Cold chain transportation operations should be designed to keep the ambient temperature of those cold areas constant. Shipment operations should be managed such that those temperature conditions are met properly. Otherwise, cold chain efficiency would decrease, and energy consumption, as well as cost, would increase. For example, route selection is an important issue in the shipment process, in that case, depending or in winter and summer [20]. In extreme temperatures, companies should select routes minimizing the number of times the doors should be opened. For example, there are specialty doors for cold warehouses for both on-site facilities and transport vehicles helping to maintain temperatures. The automated high-speed rapid door is a design for a cold chain that can open when it requires and automatically closes once the person/forklift/vehicle has passed through.

In the following section, we summarize the technologies that are frequently utilized in cold chain and cold facilities.

Fig. 3 Refrigerated container [21]

Fig. 4 Blast freezers [24]

Technologies Used in Cold Chain

Energy consumption and energy-saving issues have become one of the main considerations in almost all industries. However, because cold chain facilities would require the highest energy usage due to the refrigerated environment requirements, the factors eliminating energy loss should be considered carefully. Companies operating within a cold chain are investing in technologies both for minimization of energy consumption and waste. Some of those technologies are summarized below.

High-Speed Rapid Door

Increased adoption of newer technologies, including cascade refrigeration systems, high-speed doors, energy-efficient walls, and automated cranes, etc. have helped the increased efficiency and decreased operating costs in cold facilities. Every second that the door remains open longer than it is needed causes losing valuable temperature conditioned air. There are also a number of specialty doors available for both on-site facilities and transport vehicles, helping to conserve temperatures. Those automated high-speed rapid doors are only opening when required, and automatically closing once the person/forklift/vehicle passes through are magnificent technologies for cold facilities. A view of a freezer high-speed rapid door for a cold warehouse is shown in Fig. 5.

Refrigerated Trucks

Temperature monitoring during transportation is crucial in cold chains. Refrigerated trucks, vans, vehicles, and trailers are used for food, pharmaceutical, and agricultural transportation. Using temperature monitoring technologies in transportation reduce losses, save costs, and improve efficiency. Temperature sensors are installed into the trailer to track the real-time temperature data along each route of each load transported. These sensors are usually connected to GPS tracking devices. The software allows us to receive real-time alerts on temperature, whether it falls below or rises above a certain temperature threshold that the user selects.

However, for some refrigerated vehicles carrying chilled, frozen, or perishable goods, a reliable temperature monitoring system gives the warning to take immediate action to protect the refrigerated cargo and reduce losses.

For instance, Fig. 6 shows a truck monitoring system from the Guardmagic Company. Various data are collected from digital temperature sensors, fuel level sensors. These are sent to monitoring stations by a network. In monitoring stations, the received data is analyzed, and necessary reports and graphs are generated.

Fig. 5 Freezer high-speed doors [4]

Warehouse Management System (WMS)

Today, most warehouses, distribution centers, third-party logistics (3PLs), and fulfillment centers rely on warehouse management system (WMS) technology as the brains of their operations. Data from operational processes flow into the warehouse management software through automated data capture methods such as barcode scanners, mobile computers, and radio frequency identification (RFID) enabled devices to track temperature and condition of inventory. The data is then used throughout the system to track inventory through the progression of warehouse processes. Cold storage warehouse providers have more complex conditions when handling refrigerated and frozen inventory. Combined with the complications of handling food and pharmaceuticals, this creates the need for a warehouse management system that is specifically developed for cold storage warehouse management.

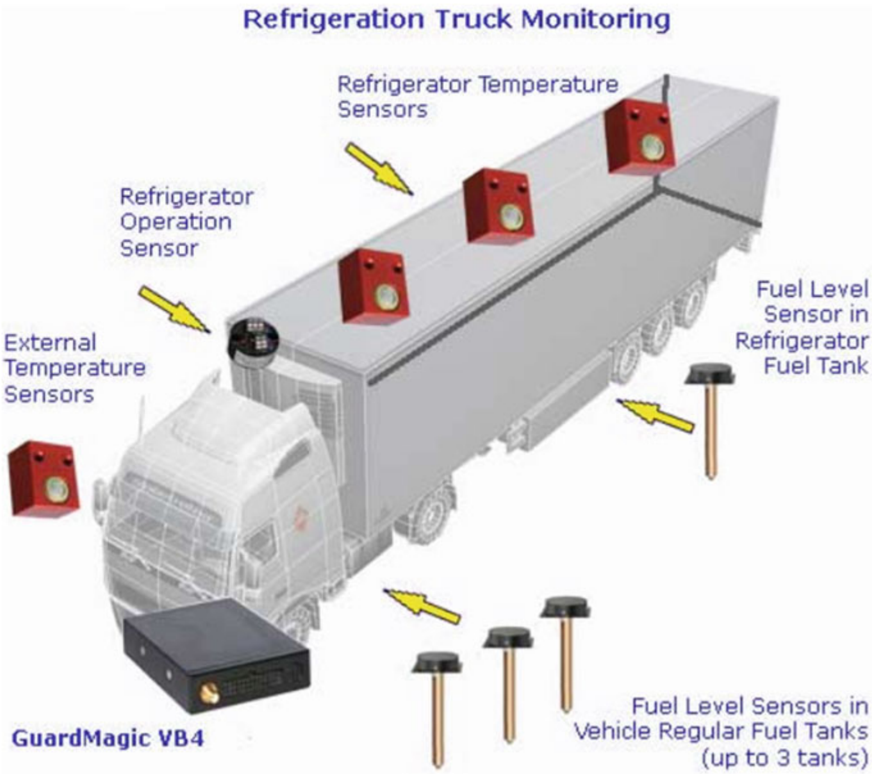


Fig. 6 Refrigerator truck monitoring system [14]

Automated Storage and Retrieval System (AS/RS)

AS/RSs are robotic systems designed to automate storage and retrieval operations. These systems contribute to cold storage in terms of size requirements, service capacities, and temperature conservation. High-density and rack assisted storage type allows deep and long designs that maximize a facility's cube capacity and minimize the footprint of a facility [10, 11]. High-density storage provides not only a smaller area for cooling but also an area that minimizes heat loss. The amount of warmer air entering the temperature-controlled zone is minimized by automatic storage [18]. This automation system provides energy saving in storage areas. Advanced robotics can take over the majority of picking operations, filling in the gaps created by insufficient staffing. Thanks to automation systems, it is possible to prevent the difficulties of using the labor force in the cold environment. Since staff no longer need to brave the cold, it significantly improves overall working conditions. Automated solutions also offer greater speed and flexibility, which can help warehouses get through upticks in order volume and optimize material flow from day to day. Figure 7 shows a long deep AS/RS technology.

Fig. 7 Automated storage and retrieval system in a warehouse [13]

Temperature Monitoring Technologies

As monitoring technologies advanced over time, many application possibilities opened up the tracking of the temperature of perishable products throughout storage and transportation in the cold chain. RFID Wireless devices can be installed in cold storage facilities to control temperature and humidity levels to help meet the quality standards. In order to provide a comprehensive monitoring solution, this method consists of wireless temperature and humidity sensors. If any threshold is exceeded, the related wireless devices can send e-mail or text message alerts. The responsible operator can examine temperature trends and variations over time with the aid of wireless cold unit tracking and historical data recording, and make adjustments when necessary [3]. Furthermore, temperature data loggers are used for temperature and humidity monitoring.

Cold Warehouse Operations

Cold storage warehouse management is a highly specialized discipline that requires extensive experience in the industry. Operations and logistics managers of cold storage facilities are responsible for both ensuring the quality and safety of their important products and for the protection and well-being of their employees who operate under these specific environmental conditions [16]. We summarize the main warehouse operations specifically on the cold warehouse case in the following sections.

Receiving

Products arrive at a warehouse, and they are unloaded from the trucks at the receiving docks. However, in a cold warehouse, receiving operations must be quick to avoid any decline in a product's shelf-life in cold storage. If the load remains exposed during the unloading process, or the reefer truck door stays open for a long time, this poses a serious issue. This problem may directly lead to food waste for the perishability of products. Also, it can shorten the shelf life of the products. Therefore, high-speed rapid doors have an important effect on finding a solution to this type of problem.

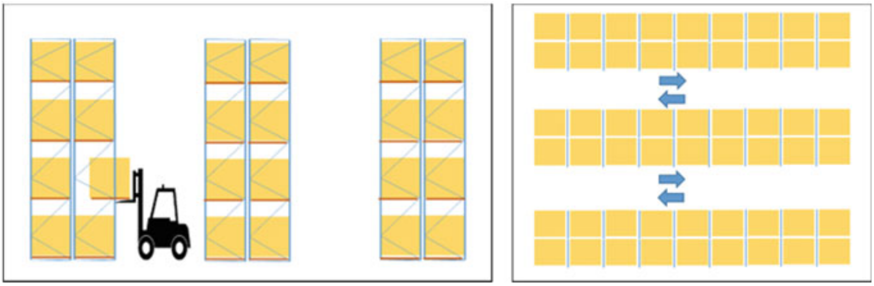
Storage

Storage is a significant operation in a warehouse that brings many problems and questions to be answered. The main issues are where the items should be stored, the types of items should be stored together, what storage policy should be implemented, how many SKUs should be stored in how much warehouse space, etc. [8]. Since the storage assignment also impacts the order picking process, its role becomes much more important. In the literature, possible storage policies are generally summarized as random storage, dedicated storage, class-based storage, cube-per-order index, and correlation-based storage [2, 5]. These storage policies should be reconsidered for the cold warehouses by taking in to account the fixed shelf life of products and different storage requirements of products.

In cold warehouses, single-deep and multi-deep AS/RS are mostly used. Multi-deep storage is beneficial for space utilization; hence energy saving takes place. In single-deep storage, products can be picked from both sides of the aisles with forklifts. Figure 8 shows a single-deep racking system.

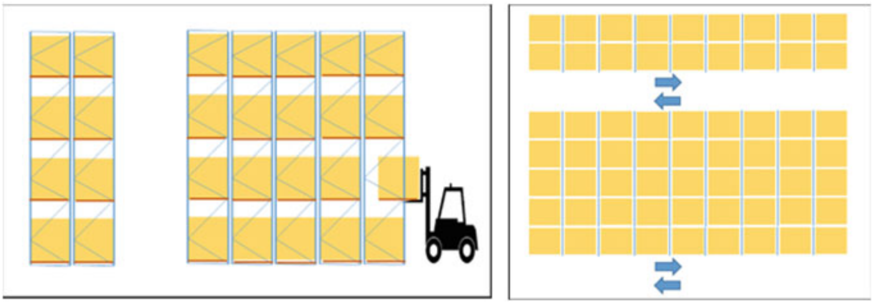
Compared to the single-deep system, a considerable aisle floor space can be saved in a multi-deep system. Thus, cold warehouse owners usually prefer a multi-deep system in order to save energy and space in their warehouses. In that system, multi-products can be stored as lined up in a row by its storage compartment design. Figure 9 shows a multi-deep racking system.

A pushback racking system is utilized well in a multi-deep storage environment. In that system, pallet storage can be done from either side of an aisle through a deep storage compartment. It provides a higher storage capacity than other types of racking systems [1].



(a) side view (b) top view

Fig. 8 Single-deep racking system



(a) side view (b) top view

Fig. 9 Multi-deep racking system

When a multi-deep storage system is used in a cold warehouse, the order picking policy becomes critical. Since there are only one entry and exit point of the pallets, the correct collection policy should be followed to minimize re-storage movements. Also, the storage policy should be considered well such that in the shipment, the product with the earliest expiration date should be retrieved easily.

Order Picking

Order picking system design and control in warehouses are complicated due to its many critical factors. Since the order picking system is highly dependent on the storage strategy of the products, the development of integrated optimal storage strategies is very important. Order picking is the most costly activity for almost every warehouses. Of all the warehouse costs, 55% are estimated to be belonging to order picking operations [9].

In the order picking operations, the decision of which strategy and sequence to pick up the product to decrease their preparation time and operation cost for shipment is critical. The order picking strategy could be order-based, priority-based, expiration date-based, distance-based, and vehicle-based. Order-based is a strategy in which products are collected from the warehouse in case of the orders receiving from the customer. The priority-based strategy is to prioritize the orders when picking the products. In the expiration date-based strategy, the expiration dates of the products are considered primarily for order picking. This strategy is may be useful for food products having expiration dates. Because traveling distance and time are also crucial for order picking, distance-based strategies, including expiration date collection policies, might be beneficial for food warehouses. Finally, the vehicle-based strategy considers the routes and travelled distance of the exterior vehicles while making the shipment.

Shipment

A shipment process comprises all processes of transporting products from warehouses to customers. If a shipment is not adequately prepared and conditioned accordingly, then the food and energy loss may increase. For example, product assignment policy for capacitated trucks and route selection are significant operations in shipment operations. In extreme temperatures, companies may prefer selecting routes that minimize the number of times truck doors must be opened. In road transportation, refrigerated trucks are mostly used while in ocean transportation, refrigerated containers and ships are preferred. In cold chain transportation, several methods are used for refrigerating trucks or containers. These are mostly water ice, dry ice, liquid nitrogen, and mechanical refrigeration systems, etc. [6].

Discussion and Conclusion

In this work, we aim to present an overview study for cold warehouses in the cold supply chain. Recently, there is an increasing interest in the efficient operation of cold chains to reduce food waste as well as decrease energy and operational costs along with the network. Due to the perishability of foods in cold food chain operations, temperature monitoring and effective temperature control management are significant problems that should be applied correctly throughout the network. Otherwise, the result would be increased food loss, energy consumption, as well as cost.

With the recent technological development, real-time visibility and tracking of a chain are possible. These technologies also enable the remote control of operations. Warehouse design should be reconsidered for the cold chain necessities as well. In an effort to reduce energy consumption and decrease utilized floor space, cold warehouses are mostly designed based on multi-deep storage racks. If storage operations in multi-deep storage rack environments are not designed well, then this may cause non-value-added operations to complete in order picking. Namely, for instance, if a product that is to be retrieved is stored at the very backside of a multi-deep rack, then, while order picking, to be able to reach that product, all the other products sorted in front of it should be taken out. To eliminate such non-value added operations, optimization of storage processes in such cold warehouses becomes important. As future work, we aim to develop an integrated optimization procedure considering both storage and retrieval processes simultaneously.

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