

Comprehending Risk Factors in Cold Chain

Wanting Lu, Yuhong Li, Kedong Chen, Alireza Ardalan

Abstract

Cold chains play increasingly important roles in the global economy. Compared to the other types of supply chains, cold chains are more vulnerable to disruptions because of their more stringent temperature and logistical requirements. As such, effective operation of cold chains is enhanced by a comprehensive understanding of the risk factors involved. This work reviews the existing research and identifies the most common risk factors in cold chains based on the Supply Chain Operations Reference (SCOR) model. This work provides a framework for understanding the risks and their sources. This framework is expected to support effective risk control.

1. Introduction

A cold chain is a special supply chain that requires managing the temperature of perishable products to maintain quality and safety from the point of origin through the distribution chain, and to the final consumer (Global Cold Chain Alliance, 2021).

With the increasing production specialization and higher consumers' demand for fresh and healthy products, cold chains have become more and more important to the global economy (Deep, 2021; Renner et al., 2019) and have been recognized as one of the most accelerating logistics directions (Costa, 2021; MarketsandMarkets, 2020) in recent years. Cold chains have been used in various sectors such as food & beverage, pharmaceutical, and healthcare. During the past decade, consumers' increasing demand for healthcare products and fresh food, accompanied with the temperature control technology and logistic improvements have pushed further development of cold chains (Renner et al., 2019). At the same time, with the expansion of multinational retail stores and the growth of processed food and pharmaceutical industries, cold chains have been playing an increasingly critical role in the global economy. It is estimated that by 2026, the global cold chain market will increase from \$225,580 million in 2019 to \$507,030 million, with a compound annual growth rate of 12.3% during the forecast period of 2021-2026 (Valuates Reports, 2021).

Risk management is essential to cold chain management as cold chain is sensitive and vulnerable to disruptions in temperature and transportation time. A small change in temperature or a short delay in production or transportation time may cause irreversible damage to products in cold chains. For example, banana is a tropical fruit that perishes quickly in warm temperatures. Strict temperatures and specific transportation times are necessary throughout the whole process of transportation and storage to ensure a specific level of ripening of bananas at the time of arrival at the destination. If the

transportation time is within 4 days, then temperature must remain between 60-64°F. If the transportation time is 6 days, the temperature should stay between 58-62°F (Wang, 2015). Moreover, since ripe bananas release ethylene, which has a ripening effect on other fruits in the same batch, they may shorten the shelf life of other fruits in the same batch (Ehrenberg, 2018; Scott, 2017). Therefore, comprehensively and effectively managing risks across the whole process are imperative to cost control, product and service quality, and the firm competitiveness and profitability.

Effective risk management requires a comprehensive understanding of risk factors in cold chains. A comprehensive understanding of risk factors requires the identification of the possible risk types and their sources. This allows management to prepare for, decrease the severity of, and even prevent future disruptions through proper investments. However, such an understanding of risk factors is limited in current research. The purpose of this article is to provide a risk factor dictionary that allows practitioners to easily trace and track both the types and sources of risks.

This article proceeds as follows. Section 2 presents a review of the literature. Section 3 presents a summary of the main characteristics of cold chains. A summary of the common risk factors inherent in cold chains based on existing literature and the SCOR model (Wisner et al., 2017) is presented in section 4. Finally, we present the conclusions.

2. Literature Review

With the growth of cold chains and the critical role of risk management in the cold chain industry, studies of risk management in cold chains are emerging. These studies classify risk factors in cold chains from different perspectives. Deng et al. (2019) studies the risk propagation mechanisms for perishable products supply chain and classifies the key risk factors in relatively short chains based on types, such as demand, raw material, human resources, equipment, inventory, process method, logistics, type of organization, information required, and environmental issues. This classification is comprehensive and allows people to easily trace the reasons for risks in short chains. Also, it supports the investigation of risks interdependence and risks propagation in this type of system. However, it fails to identify the sources of risks in complex cold chains, namely which suppliers or logistic providers incur a risk. Rathore et al. (2017) develop a risk assessment framework for a typical food supply chain in developing countries. It classifies the food supply chain risks into four large categories: supply risk, storage and transport risk, social risk, and demand risk. It allows managers to easily identify the control points of the risks. Nyamah et al. (2017) examine the key risk components, including probability and consequence, and their corresponding thresholds that affect agriculture food supply chain operation in Ghana. It investigates the impact of nine different agri-food risks on supply chain performance, including demand, supply, biological and environmental, weather, managerial and operational, logistic, public policies and institutions, and political and financial risks.

While these studies have made a significant contribution to the emerging field of risk management in cold chains, to the best of our knowledge no published study provides a comprehensive risk factor dictionary that allows practitioners to easily trace and track both the types and sources of a certain risk. To fill this gap, we build a comprehensive risk factors table in a general cold chain to support the decision-making in cold chain risk management. Specifically, we focus on the types of risk at each

point across the cold chain. Through this control point perspective, researchers and practitioners can design proper risk control methods in vulnerable points in a cold chain.

3. Cold Chain and its Characteristics

Comprehending the risk factors of a typical cold chain requires understanding the nature of the cold chain and its characteristics. We briefly discuss the cold chain and its significant characteristics in this section. A cold chain is a temperature-controlled supply chain, which handles products such as food and beverages, medicinal items, temperature-sensitive chemicals, and other temperature-sensitive items (Roambee, 2021). To maintain the quality of products, the temperature of cold chain products should be strictly controlled under specific standards during transportation and storage. Different cold chain products have different requirements for temperature. For example, temperatures of seafood and frozen meat must be kept between -20.2°F and -22°F . For vegetables, fruits, fresh meat, and dairy products, the temperature should be between 35.6°F and 39.2°F . For fresh produce and processed food, such as cakes and yogurt, the temperature should be kept between 53.6°F and 57.2°F (Roambee, 2021).

Although cold chains can carry different types of perishable products, they have common characteristics. A typical cold chain has five types of participants: supplier, producer, distributor, retailer, and customer. The main activities in the cold chain include planting/breeding, harvesting, processing, packaging, storage and distribution. Figure 1 illustrates a typical cold chain.

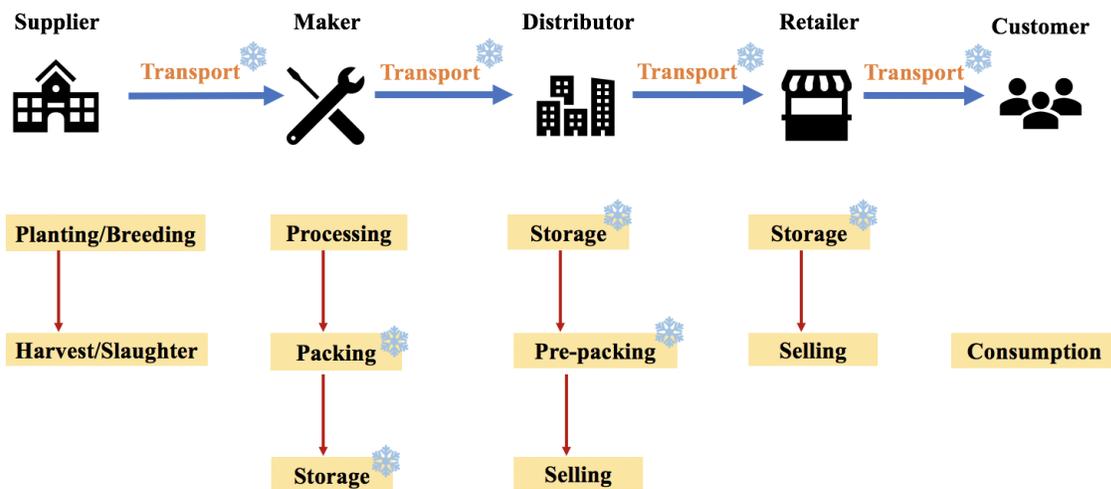


Figure 1: A Typical Cold Chain

 temperature control is required in the process

For such a typical cold chain, there are common characteristics as following.

- **Importance of Packaging**

Packaging plays a crucial role in the transportation and storage processes. For example, the temperature of some medicines should must remain in a certain range to maintain their effectiveness. Or, drugs that contain reactive components must remain frozen to prevent the components from reacting before use (Terry, 2017, Li, 2014). To meet the temperature requirements in transportation and storage, special materials such as ice bags and foam boards are used in packaging these products, resulting in higher packaging costs.

- **Timeliness**

A majority of the products that cold chain carries are perishable products, such as vegetables, fruits, flowers, processed foods, and medicinal products. The life cycles of these products are usually only a few days to a dozen days. Strict time requirements should be enforced for their transportation and delivery to guarantee the quality of the products. Delays due to weather, unavailability of transportation, or other factors result in cold chain products to deteriorate before reaching the destination. These delays cause losses and/or additional costs.

- **High-tech equipment and software**

Cold chain logistics use special equipment and applications such as pre-cooling, quick-freezing, temperature monitoring, and food traceability technologies to ensure strict requirements of temperature control and timely delivery. Moreover, as the requirements of temperature and delivery time are different for distinct products, smart logistic technologies, such as big data, cloud computing, and Internet of things are also used to ensure the efficiency and quality of cold chain logistics. These technologies also help companies to record and predict customer demand and preferences to better respond to changes in demand.

- **Complexities in planning**

The logistical processes of a typical cold chain include supply, transportation, storage, and distribution. These process elements closely interact with each other. Supply involves the acquisition of raw materials and converting them to final products. Transportation involves loading and transporting products in specialized trucks. It also involves time control, heat preservation, and route planning. Distribution involves route planning, personnel deployment, and loading trucks that have refrigeration equipment and delivering products to retailers. Well managed cold chains closely coordinate these elements. At different stages of the cold chain, the products need to be protected from physical damage, spoilage, and infection. Temperature may need to be adjusted as products move from one element of the chain to another. The complexity of cold chain operations makes them vulnerable to disruptions.

- **High cost**

Cold chain logistics normally incurs high costs because of its technology, facility, packaging, and delivery requirements. First of all, continuous investments in technologies such as refrigeration technology and ripening technology are necessary to ensure operational efficiency and business competitiveness. Facilities such as temperature-controlled storage and trucks are essential to ensure products' quality. Packaging cold chain products usually use dry ice, ice bags, and insulated

shipping boxes for temperature control in the whole process. Because of the unique characteristics of cold chains, employees involved in handling and processing products must have special training designed for cold chain operations.

4. Risk Factors of Cold Chain

We surveyed the literature to identify risk factors in cold chains and classify them according to the SCOR model. The SCOR model divides a supply chain into five processes: Plan, Source, Make, Deliver and Return. These five processes can well represent the basic processes in a typical supply chain. This paper does not consider the return/reverse logistic. Therefore, we focus on plan, source, make, deliver, and the environment. To make the risk factors traceable, we further classify them into the major participants of the cold chain, including supplier, maker, distributor, retailer, and customer. Table 1 presents the risk factors in detail.

Table 1: Cold Chain Risk Factors

Risk Source	Risk Factors	Supplier	Maker	Distributor	Retailer	Customer
Plan	Lack of strategic planning and failure to sense and respond to market changes	X	X	X	X	
	Excessive inventories or product shortages due to errors in forecasting	X	X	X	X	
	Over capacity or underutilization of capacity due to poor capacity planning	X	X	X	X	
	Communication failure	X	X	X	X	
Source	Upper-tier supplier's inability to supply	X	X	X	X	
	Non-availability of procurement center	X	X	X	X	
	Poor quality of the supplied raw materials	X				
	Poor quality of the products		X			
	Technological obsolescence	X	X			
	Contamination (virus, bacteria, etc.) /Diseases /Epidemics	X	X	X	X	
Make	Labor strike	X	X	X	X	
	Contamination (virus, bacteria, etc.)/Diseases /Epidemics	X	X	X	X	
	Communication failure	X	X	X	X	
	Production shortfall due to capacity constraints		X			
	Inability to reconfigure manufacturing processes due to changes in product /process design		X			
Delivery/ Logistics	Storage-warehouse (inadequate capacity)	X	X	X	X	

	Poor handling-loading and unloading at different locations	X	X	X	X	
	Poor packaging		X	X		
	Unavailability of vehicles/delivery delays	X	X	X	X	
	Theft or risk from outside	X	X	X	X	
	Temperature breakdown	X	X	X	X	
	Communication failure	X	X	X	X	X
	Technological risk	X	X	X	X	
Other	Natural disaster	X	X	X	X	X
	Changes in demand due to seasonality and volatility due to factors such as the Bullwhip effect or changes in customer preferences					X

5. Conclusion

In this article, we summarized the risk factors of cold chains and classified them based on the SCOR processes and types of participants. Supply chain managers can use this classification as a guide to monitor and evaluate specific processes in a cold chain to be prepared for, and to be able respond quickly to disruptions. This classification can also be used to identify the vulnerable points in the chain to guide investments aimed at making the cold chain more resilient. In addition, this classification provides targeted training for specific participants. Through the above methods, the whole process of the cold chain can be better controlled to achieve better performance at lower costs.

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