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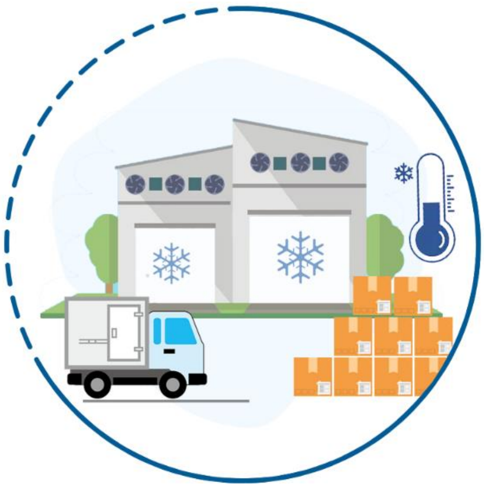
Title of thesis:

Cold supply chain: trends and systems analysis.



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Athens, Greece, June 2023

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I would like to thank Mr. Konstantinos Antonopoulos for his undivided help in the preparation of my thesis, mainly as a person and then as a professor who was by my side at every stage of my writing.

Finally, I would like to thank my family, because they supported me with patience, understanding and undivided support in order to succeed in my studies all these years.

Abstract

In this master's thesis, we are going to describe and analyze cold supply chains, their stages and systems. The products that are handled, standardized, stored, and transported in cold supply chains are perishable and sensitive to temperature changes, requiring refrigeration or freezing (meats, fish, fruits, vegetables, medicines, etc.) and need special management from the beginning of their production or harvesting, until they reach the final consumer.

In the first chapter, we are going to do an introduction to the importance of the cold chain, as well as the role of technology. Then, we are going to make a presentation, description and analysis of the cold chain and the systems used in each of the stages, in pre-cooling, packaging, storage, transportation, distribution, monitoring, quality control, and disposal. The methodology and findings are based on the international literature where extensive research has been done on the cold supply chain, new market trends and the value of product safety and quality in human life.

In the second chapter, we are going to analyze the industrial cooling. We will present the main functions of the cold chain, the products, and the temperature standards. Subsequently, we will refer to the hygiene and product protection rules that govern all stages, as well as EU directives based on legislation. Then, we will mention the stages of the cold chain, which will be analyzed in more detail in the next chapter.

In the third chapter, there is an extensive analysis of the stages of the cold chain. At each stage there is a presentation of the technology, and the systems used, based on market trends in order for the cold chains to be more efficient and having better management, risk prediction, and addressing challenges.

In the fourth chapter, a commentary is made on the advantages and disadvantages presented to the chains during the course of technological development. The usefulness of the technological systems used is commented on and ways of improvement and development for optimal operation are mentioned.

In conclusion, the fifth chapter briefly comments on the social, environmental, and economic factors that influence the stages of the chain. Also, some advice are given for better management and handling of the work at each stage. And finally, the conclusions of this postgraduate study are summarized.

Keywords

Cold chain, industrial refrigeration, temperature-sensitive products, cold storage, cold transport, quality.

Ψυχρή εφοδιαστική αλυσίδα: Ανάλυση τάσεων και συστημάτων

Φραντζή Ειρήνη

Περίληψη

Σε αυτή τη διπλωματική εργασία, θα περιγράψουμε και θα αναλύσουμε τις αλυσίδες εφοδιασμού ψυχρού, τα στάδια και τα τεχνολογικά συστήματά που χρησιμοποιούνται στο κάθε στάδιο. Τα προϊόντα που παρασκευάζονται, τυποποιούνται, αποθηκεύονται και μεταφέρονται είναι ευπαθή και ευαίσθητα στις μεταβολές της θερμοκρασίας, απαιτούν ψύξη ή κατάψυξη (κρέατα, ψάρια, φρούτα, λαχανικά, φάρμακα, εμβόλια, κ.λπ.) και χρήζουν ειδικής διαχείρισης από την αρχή της παραγωγής ή της συγκομιδής τους, μέχρι να φτάσουν στον τελικό καταναλωτή.

Στο πρώτο κεφάλαιο, πρόκειται να κάνουμε μια εισαγωγή στη σημασία της ψυχρής εφοδιαστικής αλυσίδας, καθώς και στον ρόλο της τεχνολογίας. Στη συνέχεια, θα κάνουμε μια παρουσίαση, περιγραφή και ανάλυση της ψυχρής αλυσίδας και των συστημάτων που χρησιμοποιούνται σε κάθε ένα από τα στάδια, στην παραγωγή, τη συσκευασία, την αποθήκευση, τη μεταφορά, τη διανομή, την παρακολούθηση, και τον ποιοτικό έλεγχο. Η μεθοδολογία και τα ευρήματα βασίζονται στη διεθνή βιβλιογραφία όπου γίνεται εκτενής έρευνα για την ψυχρή εφοδιαστική αλυσίδα, τις νέες τάσεις της αγοράς και την αξία της ασφάλειας και της ποιότητας των προϊόντων στην ανθρώπινη ζωή.

Στο δεύτερο κεφάλαιο, θα αναλύσουμε τη βιομηχανική ψύξη. Θα παρουσιάσουμε τις κύριες λειτουργίες της ψυχρής αλυσίδας, τα προϊόντα και τα πρότυπα θερμοκρασίας. Στη συνέχεια, θα αναφερθούμε στους κανόνες υγιεινής και προστασίας των προϊόντων που διέπουν όλα τα στάδια, καθώς και στις οδηγίες της ΕΕ που βασίζονται στη νομοθεσία. Στη συνέχεια, θα αναφερθούμε στα στάδια της ψυχρής αλυσίδας, τα οποία θα αναλυθούν λεπτομερώς στο επόμενο κεφάλαιο.

Στο τρίτο κεφάλαιο γίνεται εκτενής ανάλυση των σταδίων της ψυχρής αλυσίδας. Σε κάθε στάδιο γίνεται παρουσίαση της τεχνολογίας και των προηγμένων συστημάτων που χρησιμοποιούνται με βάση τις τάσεις της αγοράς προκειμένου οι ψυκτικές αλυσίδες να είναι πιο αποτελεσματικές, να έχουν καλύτερη διαχείριση, πρόβλεψη κινδύνου και αντιμετώπιση των προκλήσεων.

Στο τέταρτο κεφάλαιο γίνεται μελέτη δύο περιπτώσεων. Η πρώτη περίπτωση αφορά τα στάδια της ψυχρής αλυσίδας των ευπαθών εμβολίων, και η δεύτερη περίπτωση αφορά τα στάδια της ψυχρής αλυσίδας του κρέατος. Έπειτα γίνεται αναφορά στα πλεονεκτήματα και τα μειονεκτήματα που παρουσιάζονται στις ψυχρές αλυσίδες κατά την πορεία της τεχνολογικής ανάπτυξης και την χρήση των προηγμένων τεχνολογικών συστημάτων.

Στη συνέχεια, σχολιάζεται η χρησιμότητα των τεχνολογικών συστημάτων και αναφέρονται τρόποι βελτίωσης και ανάπτυξης για την πιο αποτελεσματική λειτουργία της ψυχρής αλυσίδας σε όλα τα στάδια. Στο τέλος του κεφαλαίου, γίνεται αναφορά στις προκλήσεις που παρουσιάζονται κατά μήκος της αλυσίδας, καθώς επίσης στους τρόπους που καθιστούν την ψυχρή αλυσίδα πιο βιώσιμη, με λιγότερες κοινωνικές επιπτώσεις και μικρότερο περιβαλλοντικό αποτύπωμα.

Εν κατακλείδι, στο πέμπτο κεφάλαιο σχολιάζονται εν συντομία οι κοινωνικοί, περιβαλλοντικοί, και οικονομικοί παράγοντες που επηρεάζουν τα στάδια της αλυσίδας. Επίσης, δίνονται κάποιες συμβουλές για την καλύτερη διαχείριση και διεκπεραίωση των εργασιών σε κάθε στάδιο. Και τέλος, συνοψίζονται τα συμπεράσματα αυτής της μεταπτυχιακής μελέτης.

Λέξεις – Κλειδιά

Ψυχρή εφοδιαστική αλυσίδα, βιομηχανική ψύξη, ευπαθή προϊόντα, ψυχρή αποθήκευση, ψυχρή μεταφορά, έλεγχος και ποιότητα

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List of Abbreviations & Acronyms

AGVs .... Automated Guided Vehicles
AI .... Artificial Intelligence
AS .... Automated Storage
ATC............................. Active Temperature Controlled Containers
CCTV .... Closed-circuit television
CO_2............................. Carbon Dioxide
COVID .... Corona Virus Disease
CRM............................ Customer Relationship Management
DNA .... Deoxyribonucleic Acid
E.E.............................. Ευρωπαϊκή Ένωση
ECMs .... Electronically Commutated Motors
EEC .... European Economic Community
EMA............................ European medicines Agency
EPS.............................. Expanded Polystyrene Containers
ERP .... Enterprise Resource Planning
etc............................... Etcetera
EU .... European Union
FDA............................. Food and Drug Administration
FIFO .... First in – First out
G.G............................. Government Gazette
GDP............................. Good Distribution Practices
GMP .... Good Manufacturing Practices
GPRS........................... General Packet Radio Service
GPS .... Global Positioning System
GWP .... Global Warming Potential
HACCP .... Hazard Analysis and Critical Control Points
HVAC .... Heating, Ventilation and Air Conditioning
IDS .... Intrusion Detection Systems
IoT.............................. Internet of Things

List of Abbreviations & Acronyms (2)

ISO 13485 .... Medical devices Quality Management Systems
ISO 9001 .... Quality Management Systems
ISO .... International Organizations for Standardization Standards
LED............................ Light-Emitting Diode
LEED .... Leadership in Energy and Environmental Design
ML.............................. Machine Learning
NFC............................ Near Field Communication
NH_3 .... Ammonia
^oC............................... Degree Celsius
PCM .... Phase Change Material
PCMs.......................... Phase change materials
PFID........................... Partnerships for Food Industry Development
PIN .... Personal Identification Number
PIS.............................. Passive Insulated Shippers
PPE............................. Personal Protective Equipment
PU .... Polyurethane Foam Containers
QR code .... Quick Response Code
R&D........................... Research & Development
R-12........................... Chlorofluorocarbons
R-137, R-404.............. Hydrofluorocarbons
R-22........................... Hydro chlorofluorocarbons
RFID .... Radio Frequency Identification
RIC............................. Reusable Insulated Containers
RS............................... Retrieval Systems
SCM .... Supply Chain Management
SOPs........................... Standard Operating Procedures
TS............................... Technological Systems
U.S. .... United States
UPS .... Uninterruptible Power Supply

List of Abbreviations & Acronyms (3)

USA............................. United States of America

VFDs........................... Variable Frequency Drives

VIP .... Vacuum Insulated Panels

WHO........................... World Health Organization

WMS........................... Warehouse Management System

Φ.Ε.Κ. .... Φύλλο Εφημερίδας της Κυβέρνησης

1. INTRODUCTION

In today's interconnected global economy, the efficient and reliable transportation of temperature-sensitive products is of utmost importance. This is where the cold chain comes into play, encompassing a series of processes and technologies that ensure the safe storage, packaging, handling, and distribution of perishable goods, such as food, pharmaceuticals, and vaccines, while maintaining their required temperature conditions. The successful management of the cold chain is crucial in preserving product quality, extending shelf life, and minimizing waste.

The cold chain involves several interconnected stages, each playing a vital role in maintaining the integrity of temperature-sensitive products. Along the cold chain there are complexities and challenges that require advanced technological systems that provide real-time monitoring, data analysis, and decision-making support.

An effective cold chain management system is essential for preserving the quality and safety of temperature-sensitive products during all of the stages. By leveraging advanced technologies, such as temperature monitoring systems, cold storage management software, traceability solutions, predictive analytics, and quality management systems, organizations can overcome challenges and ensure a seamless and efficient cold chain, ultimately benefiting consumers and industries reliant on the transport of perishable goods.

1.1 METHODOLOGY

The methodology of the present degree study is bibliographic research and follows some steps to examine and summarize the existing literature on the trends and systems of the cold supply chain.

The first step was defining the topic for the field that interests us. The second step was the collection of necessary literature and bibliography related to the subject that was done through the google scholar, Scopus, and science direct, and includes scientific articles, books, magazines, and other reliable sources.

The third step was the critical analysis. After collecting the literature, the quality and reliability of the sources was evaluated. The most important and relevant to our topic were selected. The fourth step was the drafting of the bibliographic research report. And the last step was the reference to bibliography and references.

2. COLD SUPPLY CHAIN

A cold chain is a temperature-controlled supply chain that includes refrigerated facilities of production, storage, and distribution, supported by special equipment that can continuously maintain the required low temperature range. The temperature must remain constantly controlled and stable to ensure the quality and safety of perishable products from point of origin through the distribution chain to the point of consumption. (Lundén, Vanhanen, Myllymäki, et al., 2014)

The dominant goal and priority of the cold chain is the safe management of a wide variety of sensitive products and goods during manufacturing, packaging, transportation, storage, monitoring, and delivery. Cold chain management is integral to development and success and requires knowledge and experience. (Asadi & Hosseini, n.d.)

Keeping and maintaining the sensitive products at the correct temperature is essential. A temperature change or instability can cause alterations and damages to the final products. The size and severity of the damage depends on the category of the product. As far as food is concerned, it can be caused textural degradation, discoloration, bruising, and microbial growth. When the product is medicinal and it is temperature sensitive, then it could pose a risk of negative side effects, it could lose its potency, decrease its effectiveness, or become even harmful to the user. (Koutsoumanis & Gougouli, 2015)

To avoid this kind of damages to the products, it is necessary to have very careful management, continuous upgrading of systems and equipment as well as continuous updating of technological developments. Investment in the cold chain, in its management, in human resources, in technological systems, is essential. Being one step ahead of technological evolution, it offers competitive advantages and greater certainty and security. (Shahed et al., 2021)

Figure 1: Cold Supply Chain

Cold chain management is the means to achieve competitive advantages of a business in the market. By emphasizing and paying attention to proper management, businesses can make major investments in the supply chains to increase internal productivity and improve customer satisfaction. According to Martin Christopher (2016), the real competition is between supply chains. Cold chains that produce at the lowest cost, add more value to the quality of the final product, and satisfy customers, are the winning network. (Shabani et al., 2012)

Supply chain management has a significant financial impact on every part of the chain. Therefore, the research and application of the principles of supply chain management with the aim of improving the chain are of great importance for any company that aims for success. The cold chain must be efficient by improving backorders, inventory levels and delivery times, be profitable by minimizing the use of resources, be effective by maximizing product quality, and be trustworthy by satisfying consumer preferences. (S. Li et al., 2006)

The systematic coordination of operations and the strategic planning of tactics constitute supply chain management. The purpose of effective management is to improve the long-term performance of all operations of the chain. (Van Hillegersberg et al., 2003)

The long-term competitiveness of a company depends on how well it satisfies customers in terms of service, cost, quality, and flexibility. The best performance of cold chain depends on the design and management. The balance across the cold chain is a constant challenge for companies that belong to the network of the cold supply chain. (Shahed et al., 2021)

To optimize the balance across the chain, many strategic decisions must be made, and many activities coordinated carefully. The prudent supply chain management and planning is required. Cold supply chain design is a distinct means by which companies innovate, differentiate, and create value (Qi et al., 2014)).

Designing an effective supply chain strategy requires knowledge and a holistic view of the parts, requirements, and links of the chain, including work teams, partners, products, and processes. There is a great challenge to draw up an effective strategic planning and management of the chain having as final goal the satisfaction and service of customers with consistency and reliability. (Thomé de Souza et al., 2018).

The main goal of Supply Chain Management is to enhance the overall profitability along the chain by boosting the profitability of all its partners. This is accomplished by understanding and meeting customer needs promptly, as well as by providing products that have great value and competitive prices. In order to achieve the above objectives, crucial traits of supply chains competing in today's globalized world are their ability to quickly adjust and adapt to constantly changing circumstances. (Ringsberg, 2014)

Supply Chain Management is essential for any business as it is crucial to effectively meet customer demands. This requires efficient planning, implementation, and control of the normal and reverse flow, as well as storage of products, services, and associated information from the origin to the consumption point. In today's globalized and digital economy, where competition extends beyond individual businesses to entire supply chains, it is imperative to organize and manage the flow of products and information effectively. This ensures competitiveness and success in a collective context, where supply chains compete against each other rather than just individual businesses. (Gogou et al., 2015)

2.1 INDUSTRIAL REFRIGERATION

As industrial refrigeration we define the science that deals with the methods and practices of ensuring a cold environment in large warehouses, buildings or means of transport, for all those perishable products that need cold storage and cold transportation, such as food, pharmaceuticals, etc. The primary purpose of industrial refrigeration is to ensure optimal cooling conditions for temperature-sensitive products in order to maintain their quality characteristics unchanged during their storage and transportation at the lowest possible cost. (Dellacasa, 1987)

It is essential that all the refrigeration systems used in the transport, storage, maintenance, and distribution of the products are manufactured and programmed separately for the specific products and meet the necessary requirements and standards. The goal is the proper maintenance and smooth operation of the refrigeration machines, with the continuous and planned supervision, and immediate intervention and repair of any possible damage. This is how the best possible performance is achieved, the minimum energy consumption at the lowest cost, and the sense of safety and security for the customer for the correct operation of the systems. (Badia-Melis et al., 2016)

An Industrial Refrigeration unit works properly when the basic features are present, and some specific requirements are met. These requirements are as follows: the study of the procedures, the infrastructures that satisfy the execution of the procedures, the knowledge of the legislation regarding the refrigeration and the safety of perishable products, and the knowledge of the rules of good industrial practice. (José et al., 2017a)

The processes in an industrial refrigeration plant are defined in primary and secondary processes that express the strategic goals and visions of the business. The study of the processes offers the greatest possible added value, because in this way the workers participate in the continuous improvement of the chain, the quality system becomes more efficient, the competitiveness is improved, and the equipment is invested more correctly for the smoothest and correct functioning of the chain. (Lundén, Vanhanen, Myllymäki, et al., 2014)

The infrastructures are chosen to satisfy the processes. If the study of the procedures is incomplete, it usually leads to a waste of equipment. Basic elements of the infrastructure of an industrial refrigeration plant are the building, the floor, the refrigerators, the storage, and handling systems such as racks and elevators, the cooling production complex such as the machine room, the network and air coolers, the inventory management systems, the delivery trucks. (José et al., 2017a)

Legislation governing the production of refrigeration is important. The main legislative issue concerns the type of coolant used for the cooling circuit. During the post-war period, Freon-type refrigerants, and in particular chlorofluorocarbons (R-12) and hydro-chlorofluorocarbons (R-22), had a great growth. But after the discovery of the ozone hole and the greenhouse effect (GWP), these gases were abolished. Then hydrofluorocarbons (R-137, R-404) and other mixtures were used which continued to have a negative effect on the greenhouse effect. Thus, there was a shift to natural cooling gases such as ammonia (NH3) and carbon dioxide (CO2).

Then there is the Legislation that governs the safety and quality of sensitive products and food, where clear reference is made to product management, appropriate temperatures, and cold chain maintenance. The concept of traceability and recall is established, thus differentiating food logistics activities from other products. Also, knowledge of the rules of good industrial practice is essential for food storage and distribution companies. (Gogou et al., 2015)

Cold rooms rely on a refrigeration system to extract heat from the space and maintain the desired low temperatures. The system consists of components such as compressors, condensers, evaporators, expansion valves, and refrigerant lines. These components work together to remove heat and circulate cold air within the cold room. (Ayou et al., 2013)

Industrial refrigeration aims to remove the thermal load at the least possible cost. Its operation is based on the steps of the cooling cycle of the figure that we list after the description. (Teng et al., 2016)

At first, the heat is transferred from the space to the refrigerant. Then, the coolant that is already inside our device evaporates (Evaporation). During the evaporation process (liquid → gas), heat is absorbed by the «liquid». This heat is transferred to the environment through condensation. (Abed et al., 2017)

Industrial refrigeration systems are designed based on some specific requirements of the industry or process they serve. Factors such as cooling capacity, temperature range, energy efficiency, and environmental considerations play crucial roles in system design and selection of components. With the aim of removing the thermal load at the least possible cost, its operation is based on the steps of the cooling cycle of the figure below.

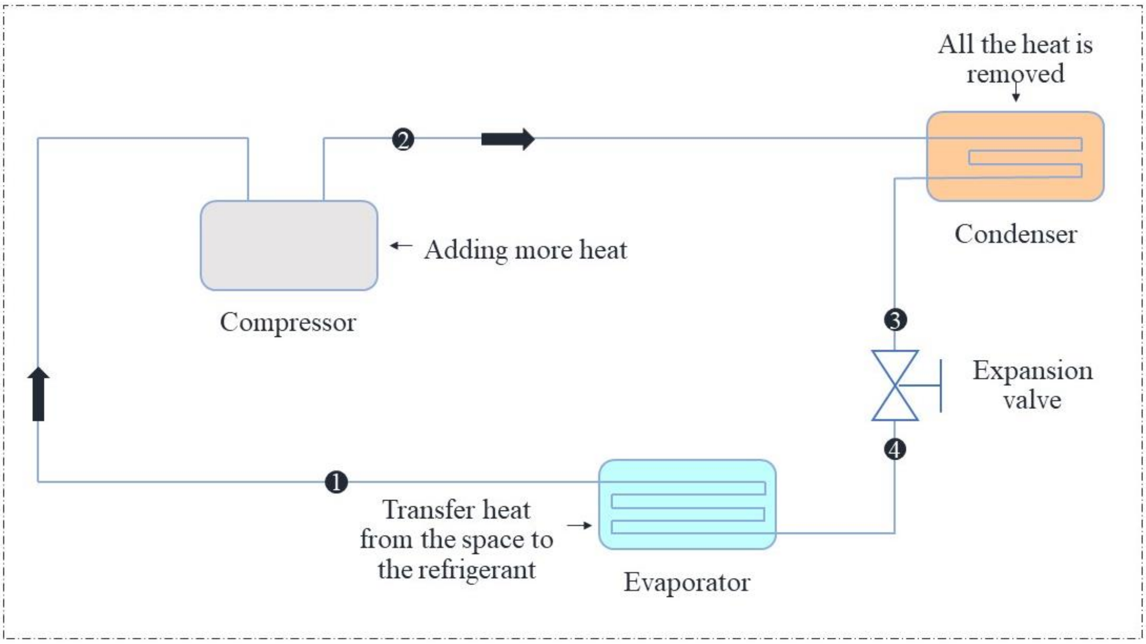

Figure 2: Basic Cooling Cycle.

Each cooling cycle includes some basic elements:

1. The expansion valve: It controls the flow of refrigerant into the evaporator, allowing it to expand and cool the space. It reduces the pressure and temperature of the refrigerant as it enters the evaporator.
2. The evaporator: It is located inside the cold room and facilitates heat exchange. It absorbs heat from the room, causing the liquid refrigerant to evaporate and turn into a gas, thereby cooling the space.
3. The compressor: It is the heart of the refrigeration system and is responsible for compressing the refrigerant gas to increase its pressure and temperature.
4. The condenser. It receives the high-pressure, high-temperature refrigerant from the compressor and removes heat from it, causing the refrigerant to condense into a liquid state.

2.2 MAIN FUCTIONS OF COLD SUPPLY CHAIN

The main functions of the Cold Supply Chain are the construction and smooth operation of a cold industry. The purpose is to ensure the safe storage, handling, and transportation of temperature-sensitive products from the point of origin to the point of consumption. (F. Li & Chen, 2011)

The first key function is the storage, which include the facilities such as cold rooms, warehouses, and refrigerated containers where temperature-sensitive products are stored under controlled conditions. These facilities maintain specific temperature, humidity, and other environmental parameters to preserve product quality and safety. (Daofang et al., 2015)

Another primary function of cold chain is the temperature control where the goal is to maintain the required temperature range throughout the entire journey of the products. This involves monitoring and controlling temperatures during the storage, loading, transportation, unloading, and distribution. (Chun Zheng Ng et al., 2019)

Inventory management is another main function. The effective inventory management is crucial in the cold supply chain. It involves tracking stock levels, monitoring expiry dates, managing product rotation (FIFO- First In, First Out), and minimizing wastage or spoilage of perishable goods. (Liu et al., 2020)

Cold packaging plays a vital role in protecting temperature-sensitive products during transportation. Packaging materials and techniques are carefully selected to provide insulation and maintain the desired temperature range. This includes insulated containers, thermal blankets, gel packs, and temperature-controlled packaging solutions. (Ndukwu, 2017a)

One more essential function of cold chain is handling and transportation. The cold supply chain manages the movement of products from one location to another. It involves loading and unloading of temperature-sensitive products, ensuring proper handling procedures, and selecting appropriate transportation modes such as refrigerated trucks, trailers, or containers. (Ammann, 2011)

The quality assurance is a very important function of cold chain. Maintaining product quality and safety involves implementing quality control measures, adhering to regulatory requirements, conducting regular inspections, and ensuring compliance with industry standards and best practices. (Ting et al., 2014)

Visibility and tracking are great functions in the cold supply chain. It involves capturing and documenting important information at various stages of the cold supply chain, including the point of origin, the temperature records, the handling procedures, and delivery details. This enables stakeholders to have visibility into the product's journey and ensures accountability in case of any issues or recalls. (Musa et al., 2014)

Last but not least, the risk management is associated with the cold supply chain. This includes identifying potential risks such as temperature deviations, equipment failures, or delays, and implementing measures to mitigate those risks. It involves contingency planning, emergency response protocols, and regular monitoring to address any deviations or issues promptly. (Coelho & Laporte, 2014)

By fulfilling these functions effectively, the cold supply chain ensures that temperature-sensitive products reach the consumers in a safe and optimal condition, preserving their quality, efficacy, and integrity throughout the entire supply chain journey. (Robertson et al., 2017)

2.3 PRODUCTS AND TEMPERATURE STANDARDS

2.3.1 Types of products

Several goods require cold transport and storage at a specific temperature to maintain their quality, freshness, and safety, and can be included in various groups. We ae going to categorize those groups below: (Klecha, 2014).

Fresh Products include fruits, vegetables, and herbs often require refrigeration to extend their shelf life and slow down the ripening process.

Dairy Products include milk, cheese, butter, yogurt, and other dairy items need cold storage to prevent spoilage and maintain their taste and texture.

Meat and Poultry include raw and processed meats, including beef, pork, chicken, and seafood, should be stored at cold temperatures to inhibit bacterial growth and prevent foodborne illnesses.

Frozen Foods include frozen vegetables, fruits, pre-packaged meals, ice cream, and other frozen food products need to be kept at sub-zero temperatures to maintain their quality, texture, and taste.

Pharmaceuticals (Vaccines and Medications) include many vaccines, medications, and biological products are temperature-sensitive and require cold storage to retain their effectiveness. This includes vaccines for diseases like influenza, measles, and COVID-19.

Floral Products include fresh flowers, plants, cuttings, and potted plants often require cold storage to preserve their freshness and delay wilting.

Bakery and Confectionery Items include some bakery products, such as cakes, pastries, and cream-filled goods, require refrigeration to prevent spoilage, maintain their shape, and extend their shelf life.

Wine and Beverages include certain wines, especially those that need to be stored long-term, benefit from being kept in a temperature-controlled environment. Some beverages, like certain types of beer and juices, may require refrigeration to maintain their flavor and quality.

Specialty Foods include certain specialty items, such as gourmet cheeses, cured meats, smoked fish, and delicate desserts, may require cold storage to preserve their unique flavors and textures.

Biological Samples include medical laboratories, research facilities, and blood banks store biological samples, including blood, tissues, DNA, and vaccines, in cold storage to prevent degradation.

Chemicals and Reagents include some chemicals and laboratory reagents may require cold storage to maintain stability and prevent reactions or degradation.

Cosmetics include certain beauty and skincare products, especially those containing natural or organic ingredients, can benefit from cold storage to prolong their shelf life and maintain their quality.

Perishable Agricultural Commodities include agricultural products like seeds, seedlings, horticultural products, and certain types of grains may need cold storage to maintain their viability and prevent deterioration.

2.3.2 Temperature Standards

Depending on the temperature range in which the products must be kept, five load groups are distinguished (Wojciechowski, 2014).

Products	Temperature	Description
Fruits	-12°C to -14°C	This group characterized by a range of temperatures that allows the monitoring of fruit ripening.
Medicines	-2°C to -8°C	This group includes most specialty pharmaceuticals including vaccines.
Products	2°C to - 4°C	The average storage temperature includes fresh fruits and vegetables, dairy products, fresh meat and fish products.
Frozen	-16°C to -20°C	Category for frozen products including meat.
Deep freeze	-28 °C to -30 °C	Group with the lowest possible temperature, designed for the transport of seafood.

Table 1: Food groups (Woiciechowski, 2014)

The temperature variation in relation to cargo service is large and must be strictly observed at each step of distribution. The above temperatures for product groups only describe the general temperature distribution for the listed products. In fact, there is an even greater variety of requirements corresponding to the transferred transport temperature. In the case of foodstuffs, special requirements are defined for the storage conditions. (Daofang et al., 2015)

It's worth noting that these temperature categories are general guidelines, and the specific temperature requirements may vary depending on the product. It's essential to follow the instructions provided by manufacturers, distributors, or regulatory bodies for each specific product to ensure proper storage and maintain product quality. The methods and techniques used to provide the product with a suitable temperature are also different (Szymczyk, 2016).

<table>
<tr><th>HIGH RISK FOOD</th><th>CRITICAL POINT CHECKS</th></tr>
<tr><td>Food prepared/ produced on the spot.
Sandwiches, pizza, cakes & salads, roast chickens, and other hot foods.</td><td rowspan="2"><u>Microbial Contamination – Microbial growth</u>

1. Temperature control throughout transport, storage, and display.
2. Personnel properly trained and knowledgeable of the risks and preventive measures.
3. Good personnel hygiene to prevent transfer of bacteria from them to the product.
4. Appropriate product shelf life to assure microbiological safety & quality.
5. Appropriate buildings and equipment so that they do not harbor bacteria & dirt and are easily cleaned.
6. Fast transport of frozen products at every stage of the transport chain.
7. Adequate cleaning to remove foci of contamination/bacterial build-up.
8. Additional safeguards where unpackaged food is involved.
9. Disinfection to prevent the transfer of bacteria by insects & rodents.
10. Proper waste disposal to avoid food contamination.
11. Immediate procedures in case the refrigeration equipment goes out of service.</td></tr>
<tr><td>Cooked products.
Containing meat, fish, eggs, cheese, cereals, cooked poultry, cold cooked meats, Meat & fish pate, Meat pie, Vegetable pies, Sandwich toppings.</td></tr>
<tr><td>Cooked products intended for further processing before consumption.
Meat, fish or poultry pies, pizzas & ready meals, partially cooked sausages, Fresh spaghetti with meat or fish, e.g., ravioli.</td><td rowspan="2"><u>Natural contamination</u>

1. Additional provision for display of food without packaging.
2. Proper handling of products to avoid contamination by personnel, buildings, or the environment.
3. Good personal hygiene to avoid contamination from hair, jewelry, clothing, etc.
4. Good cleaning systems to prevent contamination from cleaning operations. Proper control of chemical cleaners.
5. Disinfection to prevent infestation by insects & rodents.
6. Correct waste disposal to avoid risk of contamination.
7. Personnel appropriately trained and knowledgeable of the risks and preventive measures.</td></tr>
<tr><td>Smoked or salted meat.
Sliced after smoking or salting, e.g., salami or other fermented sausages.</td></tr>
<tr><td>Smoked or salted fish.
Whole or sliced after smoking or salting e.g., salmon, trout, mackerel, cod & herring.</td><td rowspan="4"><u>Natural Disaster</u>

1. Correct handling to avoid damage to the container or product.
2. Disinfestation to prevent damage to the container or product by insects or rodents.
3. Personnel properly trained and knowledgeable of the risks and preventive measures.
4. Equipment & facilities for storage so that the product is not at risk from any damage.
5. Product recycling
6. Additional measures for unpackaged food.
7. Procedures for disposal of damaged products.</td></tr>
<tr><td>Dairy Desserts.
Fresh cheeses, mousses, caramel creams, puddings, whipped cream.</td></tr>
<tr><td>Cheese.
Soft ripening or with fungi e.g., Danish blue cheese, Brie, Roquefort, Camembert.</td></tr>
<tr><td>Ready vegetables salads.</td></tr>
</table>

Table 2: High Risk Foods (ΕΦΕΤ, Αρ. απόφασης 1/11-02-2004)

<table>
<tr><th>MEDIUM RISK FOOD</th><th>CRITICAL POINT CHECKS</th></tr>
<tr><td>Hard cheeses.</td><td rowspan="4"><u>Microbial Contamination – Microbial growth</u>

1. Good personal hygiene to avoid transfer of bacteria to the food.
2. Temperature control when required during transport, storage, and display.
3. Proper management to ensure rapid transfer between cooling conditions.
4. Personnel properly trained and knowledgeable of the risks and preventive measures.
5. Adequate cleaning to remove foci of contamination / bacterial accumulation.
6. Disinfestation to prevent the transfer of bacteria by insects & rodents.
7. Appropriate equipment & facilities to facilitate cleaning, maintaining correct temperatures, etc.
8. Additional measures where unpackaged food is involved.</td></tr>
<tr><td>Creamy or lumpy cheeses.</td></tr>
<tr><td>Fresh cheeses.</td></tr>
<tr><td>Non-dairy cream cakes.</td></tr>
<tr><td>Unripened soft cheeses.</td><td rowspan="4"><u>Natural contamination</u>

1. Additional requirements for the display of unpackaged food.
2. Proper handling of products to avoid contamination by personnel, buildings, or the environment.
3. Good personal hygiene to avoid contamination from hair, jewelry, clothing, etc.
4. Entomological control to prevent infestation by insects & rodents.
5. Adequate standards of equipment and cleaning agents.
6. Good cleaning systems to prevent contamination from cleaning operations.
7. Personnel appropriately trained and knowledgeable of the risks and preventive measures.
8. Proper disposal of waste to avoid contamination of food for sale.
9. Emergency Handling Procedures.</td></tr>
<tr><td>Smoked or salted cuts of meat.</td></tr>
<tr><td>Fruit pies.</td></tr>
<tr><td>Raw meat and raw fish.</td></tr>
<tr><td>Sausages, bacon.</td><td><u>Natural Disaster</u>

1. Correct handling to avoid damage to the container or product.
2. Entomological control to avoid damage to the container or product by insects or rodents.
3. Personnel properly trained and knowledgeable of the risks and preventive measures.
4. Equipment & facilities during storage so that the product is not at risk of any damage.
5. Product recycling.
6. Additional measures for unpackaged food.</td></tr>
</table>

Table 3: Medium Risk Food (ΕΦΕΤ, Αρ. απόφασης 1/11-02-2004)

<table>
<tr><th>LOW RISK FOOD</th><th>CRITICAL POINT CHECKS</th></tr>
<tr><td>Food preserved by a process of heating and packaging in hermetically sealed containers, such as canned food, long-life ready meals.</td><td rowspan="4"><u>Microbial Contamination – Microbial growth</u>

1. Product recycling to ensure quality and safety.
2. Additional requirements where unpackaged food is involved.
3. Staff know the risks and how to deal with them.
4. Disinfection to prevent transfer of bacteria by insects/rodents.
5. Appropriate equipment and facilities for proper temperature monitoring of frozen foods.</td></tr>
<tr><td>Dried vegetables.</td></tr>
<tr><td>Packaged soups.</td></tr>
<tr><td>Pickles.</td></tr>
<tr><td>Preserves and jams.</td><td rowspan="4"><u>Natural contamination</u>

1. Additional requirements for display of food without packaging.
2. Proper waste disposal to avoid risk of possible famine.
3. Proper handling of products to avoid contamination by personnel, buildings, or the environment.
4. Entomological control to prevent infestation by insects & rodents.
5. Recycle products to avoid risk of contamination.
6. Staff know the risks and how to deal with them.
7. Proper structure of buildings so that dirt does not accumulate.</td></tr>
<tr><td>Dry pasta.</td></tr>
<tr><td>Dry cream mixes or dry drink preparation mixes.</td></tr>
<tr><td>Chocolate and candy sweets.</td></tr>
<tr><td>Bread and cookies.</td><td rowspan="4"><u>Natural Disaster</u>

1. Correct handling to avoid damage to the container or product.
2. Equipment & facilities during storage so that the product is not at risk from any damage.
3. Additional measures for unpackaged food.
4. Staff know the risks and how to deal with them.</td></tr>
<tr><td>Cakes and sweets (not containing creams).</td></tr>
<tr><td>Ice creams.</td></tr>
<tr><td>Frozen products.</td></tr>
</table>

Table 4: Low Risk Food (ΕΦΕΤ, Αρ. απόφασης 1/11-02-2004)

2.4 HYGIENE RULES AND REGULATION BASED ON GOVERNMENT GAZETTE (FEK)

In the context of this practice, in 1993 the European Union published directive 93/43/EEC which requires food businesses to implement Hygiene Rules in conjunction with the implementation of a food safety management system (HACCP-Hazard Analysis Critical Control Points) of the business.

2.4.1 Requirements for food premises, preparation, treatment, or processing areas.

The requirements include that food areas are kept clean and in good condition. The design, layout, construction, and dimensions of food premises must allow for proper cleaning and/or disinfection, protect against the accumulation of dirt, contact with toxic materials, the fall of particles into food and the formation of moisture or unwanted mold on surfaces.

They also must enable the application of good hygienic practice, in particular the prevention of contamination (cross-contamination), between and during handling from food, equipment, materials, water, supplied air, or workers and external sources of contamination, such as insects and other harmful animals, and provide, where necessary, the appropriate temperature conditions for the hygienic processing and storage of the products.

In addition, there must be a sufficient number of sinks installed in appropriate places and intended specifically for hand washing. Adequate latrines with cisterns connected to a suitable drainage system must be available. Toilets should not lead directly to food areas.

Washbasins must be equipped with materials for cleaning hands and drying them hygienically. When necessary, facilities for washing food must be separated from facilities for washing hands.

There must be suitable and sufficient means of mechanical or natural ventilation. Mechanical airflow from contaminated to clean areas should be avoided. Ventilation systems must be constructed to provide easy access to filters and other components that need cleaning or replacement.

All sanitary facilities in food areas must have adequate natural or mechanical ventilation. Food areas must have sufficient natural and/or artificial lighting. Drainage facilities must be adequate for the intended purpose and designed and constructed in such a way as not to create a risk of food contamination. Where necessary, changing rooms must be provided, in sufficient number for the staff.

Moreover, in areas where food is prepared, or processed (excluding dining rooms) there are some special requirements. Firstly, floor surfaces must be kept in good condition and easily cleaned and, where necessary, disinfected, which requires the use of impervious, non-absorbent, non-toxic materials, which are washable, unless food business operators they can prove to the competent authorities that any other materials used are suitable.

Wall surfaces must be kept in good condition, to be cleaned and, where necessary, disinfected easily, which requires the use of waterproof, non-absorbent, non-toxic materials, which can be washed. They must also be smooth to a height suitable for the work unless food business operators can demonstrate to the competent authorities that any other materials used are suitable.

Ceilings, false ceilings, and anything attached to them must be designed, constructed and coated so as not to accumulate dirt, limit water vapor condensation, and unwanted mold growth and particle detachment.

The windows and other openings of the building must be designed in such a way as to avoid the accumulation of dirt. Those that open to the outdoors must, where necessary, be equipped with mesh screens (screens) for protection against insects, which can be easily removed for cleaning. When opening windows may cause food contamination, windows must remain closed and sealed during production.

The cleaning and, where necessary, the disinfection of the doors must be easy. This requires smooth and non-absorbent surfaces to be used, unless food business operators can demonstrate to the competent authorities that any other materials used are suitable.

Food contact surfaces (including equipment surfaces) must be kept in good condition and cleaned and, where necessary, easily disinfected. This requires the use of smooth, non-toxic, easily washable materials, unless food business operators can demonstrate to the competent authorities that any other materials used are suitable.

Appropriate facilities must be provided, if necessary, for the cleaning and disinfection of work tools and equipment. These facilities must be constructed of corrosion-resistant material, be easy to clean, and have an adequate supply of hot and cold water.

Where is necessary, the appropriate measures are taken to wash food. Every sink or other similar facility for washing food must have an adequate supply of hot and/or cold potable water as needed and be cleaned regularly.

Premises and vending machines must be properly sited, designed and constructed, kept in good condition and clean, so as to avoid, as far as possible, the contamination of food and the presence of insects and other harmful animals.

In particular and where is necessary, adequate facilities are provided to maintain adequate personal hygiene (among other things, for those concerned to be able to wash and dry their hands and perform their physical needs in a hygienic manner, as well as in appropriate changing rooms).

Food contact surfaces must be in good condition and easily cleaned and, where necessary, disinfected. This requires the use of smooth, non-toxic, washable materials, unless food business operators can demonstrate to the competent authorities that any other materials used are suitable.

Appropriate means must be available for cleaning and, where necessary, disinfecting utensils and equipment. Appropriate means must also be available to keep food clean. There must be an adequate supply of hot and/or cold drinking water. Appropriate facilities or related arrangements must be in place to ensure that food is kept under appropriate temperature conditions and to control it. Food must be placed in areas and in such a way as to avoid, as far as possible, the risk of contamination.

2.4.2 Transportation and Equipment Requirements.

Transport vehicles and/or containers used to transport food must be kept clean and in good condition to protect the food from contamination. And where necessary, they must be designed and constructed so that they can be cleaned and/or disinfected properly.

Tanks on vehicles and/or containers must not be used to transport anything other than food if the other loads can contaminate the food. Bulk food in liquid, granular or powder state must be carried in tanks or / and containers / tanks used only for the transport of food. Containers must be clearly, legibly, and indelibly marked in one or more Community languages that they are used for the transport of food or be marked «for food only».

When transport vehicles and/or containers are used for the transport of products other than food, or for the transport of different types of food, the products must, where necessary, be kept separate to protect against possible contamination.

When transport vehicles and/or containers have been used to transport non-food products or to transport different types of food, effective cleaning must be carried out between loads to avoid the risk of contamination.

Food must be placed in transport vehicles and/or containers and protected in such a way as to minimize the risks of contamination.

Where necessary, the transport vehicles and/or containers used for the transport of food must have the ability to maintain them at the appropriate temperature and be designed so that, if necessary, the temperature level can be controlled.

Every object, facility or equipment with which food comes into contact must be kept clean and be constructed and maintained in such a way as to minimize the risk of food contamination. With the exception of single-use containers and packaging, be constructed and maintained so that they can be thoroughly cleaned and, where necessary, disinfected, to a degree satisfactory for the purposes for which they are intended. To be installed in a way that allows sufficient cleaning of the surrounding areas.

2.4.3 Food waste, water supply, and personal Hygiene.

Food waste and other waste must not be allowed to accumulate in food premises, except to the extent that this is unavoidable for the proper operation of the business.

Food waste and other waste must be deposited in closable containers, unless food business operators can demonstrate to the competent authorities that any other types of containers used are suitable. These containers must be properly constructed, maintained in good condition and, if necessary, easily cleaned, and disinfected.

Adequate provision must be made for the removal and storage of food waste or other refuse. Waste storage areas must be designed and used in such a way that they are kept clean at all times and prevent the ingress of insects and other vermin, as well as the contamination of food, drinking water, equipment, and premises.

Furthermore, there must be an adequate supply of «drinking water», as defined in Ministerial Decision A5/288/23.1.1986 (FEK 53/B/20.2.1986, Corrigendum Err. FEK 379/B/10.6.1986) regarding the quality of drinking water. This drinking water must be used to ensure that food is not contaminated.

Steam used in direct contact with food must be free from any substance that presents a health hazard or may contaminate the product.

The non- «drinking water», which is used for steam generation, cooling, firefighting, and other similar purposes, not related to food, must be channeled through separate networks, which are easily identifiable and not connected at all to the «drinking water», nor should suction be possible in «drinking water».

Additionally, a high degree of personal cleanliness is required of every person moving in areas where work is done with food, who must wear suitable, clean and, where appropriate, protective clothing.

It is prohibited, in any capacity, to work in workplaces with food of any person who is known or suspected to be suffering from a disease transmitted through food, or of a person suffering from e.g., from infected wounds or is affected by a skin infection, ulcers or diarrhea, when there is a direct or indirect risk of food contamination by pathogenic micro-organisms.

2.4.4 Provisions applicable to foodstuffs.

The food business must not accept any raw material or ingredient if it knows or has reasonable grounds to suspect that it is infected with pests, pathogenic micro-organisms or toxic, decomposed, or foreign substances to the extent that, after routine screening and/or preparatory procedures or processing procedures applied by food businesses in accordance with hygiene rules, it will again be unfit for consumption.

The raw materials and ingredients stored in the enterprise must be kept under suitable conditions, so as to avoid any harmful deterioration and to protect them from contamination.

All food handled, stored, packed, displayed, and transported shall be protected from any contamination which might render it unfit for consumption, injurious to health or contaminated in a way that it would not be reasonable to expect its consumption in this situation. Food in particular must be placed or protected in a way that minimizes any risk of contamination. Adequate procedures must be in place to ensure that insects and rodents are controlled.

Raw materials, components, intermediate products, and finished products, which may offer for the proliferation of pathogenic microorganisms or the formation of toxins, must be kept at temperatures that do not entail a risk to health. As far as food safety allows, food is allowed to remain outside, temperature controlled for a limited time when this is required for practical handling reasons, during the preparation, transport, storage, display and serving of food.

Food business operators ensure supervision and guidance and/or food hygiene training of food handlers, depending on the work performed.

With the gazette as the main factor, we will refer to the hygiene and quality that each organization is required to follow and comply with, with the ultimate goal of the proper functioning of the cold supply chain. In this process, we indicate that the goals of each company that wants to participate in this project can be achieved through the following:

- Implementation of the HACCP system.
- Implementation of the Hygiene Rules.
- Adequate training and education of human resources.
- Adequate and effective product control.

2.4.5 Implementation of the HACCP system.

The term HACCP is an acronym for Hazard Analysis Critical Control Points (in Greek, the term AKKSE, which is an acronym for Hazard Analysis and Critical Control Points, is suggested as a pilot). It aims to identify the risks associated with any stage of the production process, storage, and handling of food up to the final consumer and then implement effective control procedures in order to produce healthy and safe products.

HACCP is a documented and certified approach to identifying the microbiological, chemical, and physical hazards and critical control points, protective measures, and corrective actions that an effective control system requires. It is a preventive measure to ensure the safe production of food. It is based on the application of technical and scientific principles in the production process from the field to the consumer's table. So, the most basic principle that governs HACCP is prevention and not repression.

The functional and efficient development of the system is based on the application of the following basic principles:

Principles	Description
Principle 1η	Identify potential sources of risk that must be prevented, eliminated, or reduced to acceptable levels.
Principle 2η	Identify critical control points at the stage or stages where control is essential to prevent or eliminate a source of risk or reduce it to acceptable levels.
Principle 3η	Establish critical limits at the critical control points, which separate the acceptable from the unacceptable in terms of prevention, elimination, or reduction in identified sources of risk.
Principle 4η	Establish and implement effective monitoring procedures at critical control points.
Principle 5η	Determine corrective measures when it is found during monitoring that a critical control point is not under control.
Principle 6η	Establish procedures, which are carried out regularly, to verify that the measures mentioned above are working effectively.
Principle 7η	Prepare documents and files depending on the nature and size of the food business, in order to demonstrate the effective implementation of the measures mentioned above.

Table 5: Principles of application of the HACCP system (FEK)

2.4.6 Application of Hygiene Rules

As «Hygiene Rules» we define all the measures required to make food safe and healthy. These measures are necessary to control the sources of risk and cover all stages of the primary production of the respective products as well as the subsequent process until they are made available to the consumer. The European Union continuously and diligently publishing relevant legislations which oblige food companies and the control authorities of each country to comply with the aim of making the products healthy and safe for each consumer.

Hygiene rules play a critical role in maintaining the quality and safety of products within the cold chain, which refers to the storage and transportation of temperature-sensitive goods, such as food, pharmaceuticals, and vaccines, under controlled conditions.

In the cold chain personal hygiene is one of the most important measures. Individuals involved in handling cold chain products, such as workers in storage facilities or delivery personnel, should adhere to strict personal hygiene practices. This includes regular handwashing, wearing clean protective clothing, and using appropriate personal protective equipment (PPE) like gloves and hairnets. Regular cleaning and disinfection of storage areas, vehicles, and equipment are essential in maintaining a hygienic cold chain. Surfaces that come into contact with products should be thoroughly cleaned. Hygienic packaging is crucial to prevent contamination and maintain the integrity of products. Packaging materials should be clean and suitable for cold chain applications. Seals and closures should be secure and intact to prevent the entry of contaminants.

Implementing a robust quality management system within the cold chain is essential for maintaining hygiene standards. This includes regular audits, inspections, and quality control procedures to identify and rectify any issues that may arise.

By adhering to hygiene rules in the cold chain, businesses can minimize the risk of product spoilage, maintain product safety, and meet regulatory requirements. This helps to protect the health of consumers and ensures the quality and effectiveness of temperature-sensitive products.

2.4.7 Adequate management, training, and education of human resources

Human resources are the only factor that activates and harnesses all the factors of production to accomplish a company's predefined objectives. In the context of the cold chain, it is crucial to train employees in order to ensure the appropriate handling, storage, and transportation of products that are sensitive to temperature. Training human resources in the cold chain is essential to maintaining the integrity and quality of these temperature-sensitive products throughout the cold chain process. (Anastasiou & Anastasiou, 2012)

On the one hand, the cost associated with human resources is substantial, given that employees are the most expensive yet invaluable asset for a company. Businesses seek to attract the best employees while also establishing systems that enable employees to contribute optimally towards harnessing the other factors of production and ultimately accomplishing the company's objectives.

On the other hand, the changes in the business environment are constant. Businesses face the necessity to constantly adjust their strategies, policies, employment practices, and systems for utilizing their workforce. Adaptability to these changes becomes essential. That is why companies need to prioritize employee training as a means to effectively cope with and respond to these evolving dynamics. (Kasonde & Steele, 2017)

Initially, companies need to educate employees about the severity of temperature control and the impact on product quality and safety. The employees need to be taught about temperature monitoring, recording, and reporting procedures. They also need to emphasize the importance of maintaining proper storage temperature throughout the cold chain. (Lundén, Vanhanen, Myllymäki, et al., 2014)

Moreover, it is important to train the employees on proper handling and packaging techniques for temperature-sensitive products. This includes protocols for loading and unloading, stacking, and organizing goods in refrigerated storage areas or transport vehicles. Teach them how to handle packaging materials such as insulated containers, gel packs, or dry ice. (Ndukwu, 2017a)

Further, providing comprehensive training on the operation, calibration, and maintenance of cold chain equipment, including refrigeration units, temperature monitoring devices, and vehicles, is essential. Employees should be aware of the signs of equipment malfunction and how to respond to them. (Lundén, Vanhanen, Myllymäki, et al., 2014)

Also, familiarizing employees with Good Manufacturing Practices (GMP) principles and Standard Operating Procedures (SOPs) specific to cold chain operations is very important.

This includes procedures for product receipt, storage, inventory management, order picking, loading, and dispatch. Reinforce the importance of following these guidelines to maintain product integrity. (Kasonde & Steele, 2017)

Additionally, the emphasis to the significance of cleanliness and hygiene in the cold chain is a dominant element of training. Educate employees on personal hygiene practices, including handwashing, wearing appropriate protective gear, and avoiding cross-contamination. Training them on the cleaning and sanitization procedures for equipment, storage areas, and vehicles will protect the good preservation of the products. (Resource Guide, 2022)

Risk management and contingency planning is another significant training part. Teaching employees to identify potential risks and hazards in the cold chain and training them on appropriate response protocols, will prevent many mistakes. This includes procedures for power failures, equipment breakdowns, temperature excursions, and emergency situations. Employees should be encouraged to report incidents and participate in continuous improvement initiatives. (Queiroz et al., 2020)

Likewise, it is very important that employees understand and comply with relevant regulations and industry standards related to the cold chain. This may include adherence to guidelines from organizations like the World Health Organization (WHO), Food and Drug Administration (FDA), or specific local regulatory bodies.

Furthermore, training and skill development should be continuous. Cold chain technologies and best practices evolve over time. So, the employees should be encouraged to stay updated with the latest advancements, attend training programs, and engage in professional development activities. Fostering a culture of continuous learning to enhance employees' knowledge and skills, it will have the corresponding positive results in the management and flow of the cold chain. (Kasonde & Steele, 2017)

Finally, the training needs to be adapted to specific job roles within the cold chain, whether it's warehouse staff, logistics personnel, quality control officers, or drivers. Regular assessments, refresher courses, and on-the-job training can also help reinforce the knowledge and skills acquired during initial training.

2.4.8 Adequate and effective product control

The product control in the cold chain is crucial to maintaining the quality, safety, and efficacy of temperature-sensitive products through the chain.

For achieving adequate and effective product control in the cold chain the temperature monitoring is one of the keys. Implement a robust temperature monitoring system at various stages of the cold chain, including during storage, transportation, and distribution. Another key is the cold storage facilities (warehouses and refrigerators), ensuring that are properly designed, equipped, and maintained to meet the specific temperature requirements of the products. Regular calibration and maintenance of temperature control equipment are essential to minimize temperature fluctuations. (Fuertes et al., 2016)

Using the appropriate packaging materials, provide insulation and temperature stability. Insulated containers, thermal blankets, or gel packs can help maintain the desired temperature during transportation and storage. Developing and implementing clear Standard Operating Procedures (SOPs), for handling, storage, and transportation of temperature-sensitive products. Training personnel involved in the cold chain. Compliance with regulatory requirements ensures that you meet the necessary standards for product control and quality assurance.

By maintaining accurate records of temperature monitoring data, including timestamps, throughout the cold chain allows for traceability and facilitates identification of any deviations or temperature excursions. Equally important is the closely collaboration with suppliers and partners who involved in the cold chain to ensure their adherence to quality standards and temperature control protocols. At last, the feedback from customers, conduct root cause analyses for any deviations.

2.5 STAGES OF COLD SUPPLY CHAIN

Logistics companies have a significant impact on the development of both international and local trade. The quality and efficiency of operational processes of the supply chain, as well as the logistics infrastructures, are of great importance for international trade (Devlin & Yee, 2005). On the one hand, a weak infrastructure or an inefficient chain can be a significant obstacle. On the other hand, an improved, technologically upgraded, and efficient chain can increase the local and the global trade volume as well as the economies of scale in distribution and production activities (Lakshman et al. 2001).

Supply chain management is concerned with the analysis, planning and control of the level of product availability that meets market needs and company resources. A detailed analysis of the demand in terms of time, level and location is needed, and when it comes to permanent establishments, a forecast is also necessary. (Dubey et al., 2017)

Consumers have high expectations and demands. Thus, cold chains need to have the physical products available in the market, as well as being available in the right unit, in good condition and at the right time. Well, seven key sections of the cold chain need to be examined individually and coordinated, facilities, communication, materials management, inventory, production planning, consolidation, and transportation. (Blanco et al., 2005)

Initially, the activities connected to the purchase and the demand, where it is necessary to forecast the demand, the planning of the needs, the selection of suppliers, the organization of the production and management of stocks, the inventory. Warehousing includes transport management, storage, and packaging management. Then, distribution includes the management of orders, supplies, final products, transportation, and customer service.

Analyzing the cold supply chain, we have the next important and main stages. The initial stage and beginning of the cold chain start with the production and harvesting of the products. The attention that must be given to the selection and preparation of the initial cold supply products or, in the case of pharmaceuticals, to their preparation, is the basic starting stage.

Once the products have passed the quality controls and appropriate approvals, they will need to be shipped and transported to the manufacturers, in the processing stage, where they will be prepared in volume to meet the consumer's demand.

The processing stage requires experience and attention. Trained staff are required to monitor freshness and maintain safety, cleanliness. At this stage we also have the manufacturing, cooling, or freezing of the products with the appropriate packaging. Depending on the product type and quality temperature needs, at this stage, the products must be stored in the right conditions and then shipped or transported within their temperature range for the rest of the journey to the final consumer. (Mercier et al., 2017)

Temperature-controlled transport of products is another essential step. Once the products are well prepared and ready for the distribution hubs, there are many things that transporters, distributors, and drivers need to take care of. Initially, they will have to transport the products with care so that there is no damage to the packages or bumps or alterations. The constant control of the temperature is necessary, as well as the consequence of the transport time, as any delays can result in bad results for the products. (Brown et al., 2014)

There are some main considerations when choosing the way of transport or ship the temperature-sensitive loads. The nature of the product (food, medicine, etc.) the payload volume (liters, kilos, or tones) the duration of the transportation (hours or days), the temperature range, the pre-conditioning situation, single or multi-use, the payload visibility, are some information that must take into account before making important transportation decisions.

The mode of transport is of great importance. Different management is required if the trip is regional, national, or global, as well as the goods are being transported with trucks, trains, ships, airplanes, etc. For overseas travel, essential products will travel via cargo planes or refrigerated container trucks or ships ensuring that the packaging is robust and able to maintain the payload at the correct temperature over potentially long journeys. (McGregor, 2019)

Links in cold chains such as laboratories, manufacturing plants, healthcare facilities, etc. must be linked to transport logistics providers who must be properly equipped to transport the relevant material (refrigerators, freezers) to ensure that the payload will remain within the required temperature range. Combining these links and maintaining a payload within a certain temperature range constitutes a functional cold chain. (Devapriya et al., 2017)

The next station is the distribution centers where the products must remain safe and stable in temperatures for as long as they need to stay there until they are transported to the retail outlets (butchers, grocers, supermarkets, flower shops, pharmacies, etc.). This stage requires just as much attention even though it is a smaller scale local cold chain logistics. The cold chain has been maintained up until this point and must not break now. (Bortolini et al., 2016)

At the final stage, after safely reaching retail outlets and stores, products should be carefully stored at the correct temperature until they are purchased by end consumers.

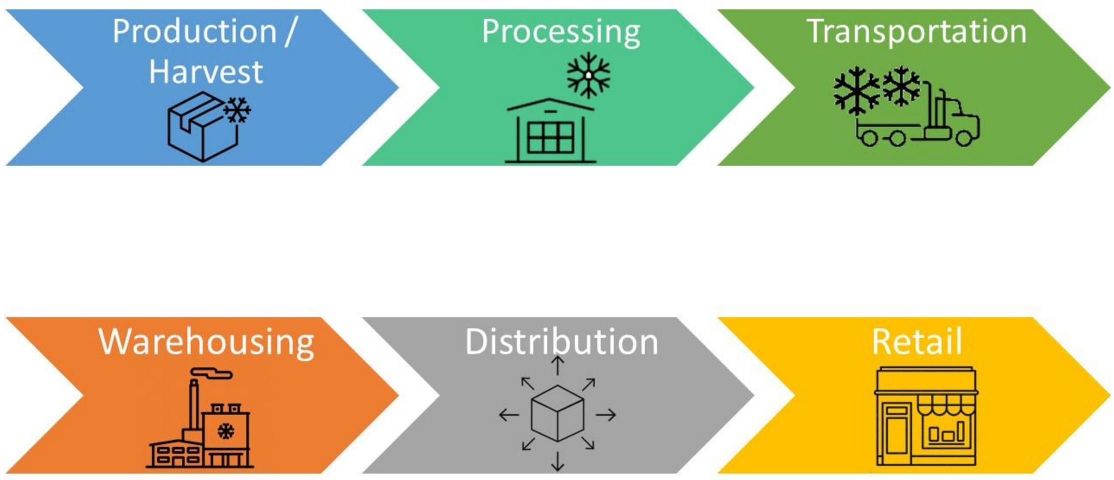

Figure 3: Stages of Cold Supply Chain.

3. TRENDS AND SYSTEM ANALYSIS

In today's competitive environment, modern technology and new logistics systems are essential tools that ensure not only faster work rates and smooth operation of the supply chain, but also greater safety conditions for both products and employees.

Technological developments push companies to constantly enhance the quality of their offerings by embracing new technological methods and tools. At the same time, the intricacy of modern production and distribution chains, coupled with the requirement for well-informed business decisions, generates the necessity for integrated management of the company's resources and information flow. This integration enables companies to effectively navigate the complexities of their operations while leveraging valuable insights to drive success.

The basic criteria for choosing the appropriate and correct equipment and technological supportive systems are the volume of products, the type of transported products (fresh, frozen), the dimensions of the refrigerated trucks that transport the products, the frequency of movement, and the loading and unloading. (Evans & Falagán, 2022)

The modern systems and equipment at the loading and unloading points, in the warehouses and in the means of transport of the goods have radically improved the flow of goods; they become operational and cover the needs of unloading areas, distribution centers and warehouses. (Ndraha et al., 2018)

The right and appropriate choice of equipment in the cold chain gives a variety of advantages. Initially, labor costs are minimized for the company as only the necessary work is done, and no time is lost. It is also important that the best possible conditions are ensured to avoid temperature changes. Another advantage is the protection of the workers and the transported products from the weather conditions. And finally, the right equipment ensures that the products are handled in accordance with the basic hygiene rules. (Dellacasa, 1987)

Another significant choice is the use of certified cold rooms that guarantees absolute safety in the transport of perishable products under refrigeration with significantly reduced operating costs. The combination of the quality construction materials with the design philosophy of the refrigerating chambers, allow on the one hand a larger transport load and on the other hand the minimum temperature loss resulting in the lowest operating time of the refrigerating machine. (Ruiz-Garcia et al., 2010a)

The choice of the most suitable cold storage rooms should be a well-considered move for the companies so that the result will be for the benefit of the business and the end consumer. The goal is the safe transport of perishable products at a controlled and graded temperature with a simultaneous reduction of the operating cost, which is achieved by saving energy resources. (Ndukwu, 2017a)

There are some basic criteria for the right choice of the cold room. The type of products, the payload, the transport temperatures (storage - freezing), the type of transport (simple transport or distribution), the transit time, the product temperature during loading, the frequency of door openings during the route, and the type of truck, are some vital criteria.

The selection and use of the appropriate cold rooms during the transport of fresh and frozen products gives added value to the services provided by the companies and ensures the following advantages. (Ndukwu, 2017a)

Fewer operating hours of the refrigerating machine resulting in reduced fuel or electrical energy consumption, maintenance at longer intervals, fewer breakdowns, smaller needs for spare equipment, and fewer reloads. Furthermore, saving fuel due to the excellent insulation of the chambers and the correct combination of the refrigerating machine are great advantages.

Moreover, the products are delivered safe and at the right temperature. Also, it is easier to comply with HACCP and other hygiene regulations. And finally, increase in payload due to extremely low cabin weight.

All in all, there are trends and systems that provide all the required specifications for safe and quality products in the areas of packaging, storage, distribution, and traceability that we will analyze them below. (Badia-Melis et al., 2018)

3.1. COLD CHAIN PACKAGING

Cold chain packaging refers to the specialized packaging and transportation systems designed to maintain specific temperature ranges for perishable products, particularly in industries such as pharmaceuticals, food, and biotechnology. It is crucial for preserving the quality, safety, and efficacy of temperature-sensitive items throughout their storage and distribution. (Industry Alliance, n.d.)

The choice of the right cold chain packaging is essential for multiple reasons. Initially, cold chain packaging maintains the integrity and efficacy of temperature-sensitive products, preventing degradation, spoilage, or loss of potency. It also ensures that perishable goods, such as vaccines, blood products, or food items, reach consumers in a safe and hygienic condition, minimizing the risk of contamination or compromised quality. (Mohebi & Marquez, 2015)

Moreover, Industries that deal with temperature-sensitive products must comply with regulatory requirements to ensure product safety and effectiveness. Cold chain packaging helps meet these standards. The effective cold chain packaging also enables efficient logistics management, allowing for the transportation and storage of perishable goods over longer distances and extended periods while maintaining quality. (Evans & Falagán, 2022)

And finally, there is cost saving. By preventing spoilage and wastage of perishable goods, cold chain packaging reduces financial losses for businesses and supports sustainability by minimizing environmental impact.

Cold chain packaging plays a vital role in preserving the quality and safety of temperature-sensitive products throughout the supply chain, ensuring they reach consumers in optimal condition. So, there are some key components in cold chain packaging that contribute to the safe and temperature stability of the products during their storage and distribution, and we are going to analyze them below. (Ndukwu, 2017b)

3.1.1 Insulated Containers

The Insulated Containers are designed to minimize heat transfer between the external environment and the contents inside. They are typically constructed with insulating materials include expanded polystyrene (EPS), polyurethane foam, or vacuum panels. They also have multi-layered walls consisting of an outer layer, insulating layer, and inner lay. They typically have a lid or door that securely seals the container, minimizing air exchange and heat infiltration.er. The insulating layer provides thermal resistance and prevents heat penetration.

Insulated containers come in various sizes and capacities to accommodate different volumes of products. They can range from small containers for individual shipments to large pallet-sized containers for bulk transportation.(Badia-Melis et al., 2016)

It is worth mentioning that Expanded Polystyrene (EPS) Containers are lightweight and offer excellent insulation properties. They are cost-effective, disposable, and suitable for short-to-medium duration shipments.

Polyurethane (PU) Foam Containers provide superior insulation and durability. They offer better thermal stability, making them suitable for longer transportation periods and more extreme temperature conditions.

Vacuum Insulated Panels (VIP) use high-performance insulation panels that provide exceptional thermal insulation. They are highly efficient and commonly used for transporting high-value and ultra-sensitive products.

Active Temperature-Controlled Containers incorporate additional features like integrated cooling or heating systems. They use electricity or battery-powered mechanisms to actively control and maintain the desired temperature range, allowing for longer transportation times and greater temperature control precision. (Lütjen et al., 2013)

Passive Insulated Shippers are containers designed to maintain temperature for a specific duration without external power sources. They rely on insulation materials, refrigerants, and the thermal mass of the packaged product to maintain the required temperature. (Rodríguez-Bermejo et al., 2007)

Reusable Insulated Containers are designed for multiple uses. They are constructed with durable materials to withstand frequent handling and are environmentally friendly alternatives to disposable options.

The choice of Insulated Container depends on factors such as the duration of transportation, temperature requirements, product volume, and the level of insulation needed. The goal is to select an insulated container that provides the necessary thermal protection to keep temperature-sensitive products within the desired temperature range throughout their journey in the cold chain. (Laniel et al., 2011)

3.1.2 Refrigerant Packs

The Refrigerants Packs, such as gel packs, dry ice, or phase change materials (PCMs), are a type of refrigerant used in cold chain packaging to help maintain the desired temperature for temperature-sensitive products during transportation and storage. These packs contain a cooling agent that absorbs heat from the surrounding environment, helping to keep the contents of the packaging at the required temperature.

Refrigerant packs are filled with various types of cooling agents that undergo phase changes or have high heat absorption capacities. Common cooling agents include water-based gels, gelatinous materials, or chemical compounds designed for low-temperature applications. Some refrigerant packs are reusable, meaning they can be refrozen or reactivated for multiple shipments. These packs are typically made with durable materials and have a long lifespan, making them cost-effective and environmentally friendly. (Brown et al., 2014)

Refrigerant packs are designed to be flexible and conform to the shape of the packaged products. This allows for better thermal contact and ensures efficient heat transfer. They are also sealed in leak-resistant packaging to prevent any leakage of the cooling agent, which could potentially contaminate the product or packaging.

To analyze more the types of Refrigerant Packs, we are going to mention that Gel packs are commonly used refrigerant packs filled with a gel-like substance. These packs are flexible and easy to use. They can be cooled by placing them in a freezer or refrigeration unit before use. (World Health Organization, 2015)

The Phase Change Material (PCM) packs contain materials that undergo phase changes (solid to liquid or vice versa) at specific temperatures. PCMs absorb and release a large amount of heat during the phase transition, maintaining a constant temperature. They are ideal for applications requiring precise temperature control.

The Dry ice, which is solid carbon dioxide, is another type of refrigerant pack used for extremely low-temperature applications. Dry ice sublimates directly from a solid to a gas, absorbing heat in the process. It is commonly used when temperatures well below freezing are required. (Insulated Products Corp, n.d.)

The Pre-Qualified Packs are refrigerant packs that are pre-conditioned to specific temperature ranges and designed for specific durations. They are pre-qualified according to validated standards and are often used for pharmaceutical or biomedical shipments.

The selection of refrigerant packs depends on the specific temperature requirements, duration of transportation, and the volume of the products being shipped. It is crucial to choose the appropriate refrigerant pack that can maintain the desired temperature range throughout the cold chain process, ensuring the quality and integrity of the temperature-sensitive products.

3.1.3 Temperature Monitoring Devices

Temperature monitoring devices are an essential component of cold chain packaging systems. These devices are used to measure, record, and monitor the temperature of temperature-sensitive products during transportation and storage. They provide real-time data that allows stakeholders to ensure that the products are maintained within the required temperature range. We are going to represent some common types of temperature monitoring devices below. (Fuertes et al., 2016)

Data loggers are compact electronic devices that record temperature readings at regular intervals. They typically have built-in sensors and internal memory to store temperature data. Data loggers can be programmed with specific sampling intervals and are often used for monitoring temperature over extended periods of time. They can be battery-powered or have rechargeable batteries. (Sedghy & Sedghy, 2018)

Wireless Temperature Sensors use wireless communication technology to transmit temperature data to a central monitoring system. These sensors are often battery-powered and can be placed inside the packaging or in the environment surrounding the products. They offer real-time monitoring and can send alerts if temperature thresholds are breached. (Badia-Melis et al., 2018)

Temperature Indicator Labels, also known as temperature-sensitive labels or temperature tags, are adhesive labels that change color or display a visual indication when exposed to specific temperature ranges. They provide a quick visual reference to determine if the temperature has gone beyond the acceptable limits.

Infrared Thermometers, also called non-contact thermometers, measure temperature by detecting infrared energy emitted by an object or surface. They are handheld devices that allow for quick temperature measurements without direct contact. (Badia-Melis et al., 2018)

Temperature Data Monitors are advanced devices that combine temperature sensing, data logging, and wireless communication capabilities. They can transmit temperature data in real-time to a centralized system or cloud-based platform, allowing for remote monitoring and control of temperature conditions.

Smart Labels and radio frequency identification (RFID) technology can be integrated with temperature monitoring capabilities. These labels or tags have embedded temperature sensors and can transmit temperature data wirelessly. They enable automated data collection and can be tracked throughout the supply chain using RFID readers. (Peltokorpi et al., 2021)

It is important to select temperature monitoring devices that are accurate, reliable, and appropriate for the specific requirements of the cold chain. These devices help ensure compliance with temperature regulations, identify potential temperature excursions, and enable timely intervention to maintain the quality and safety of temperature-sensitive products.

3.1.4 Outer Packaging

Outer packaging refers to the external protective material used to enclose and safeguard the contents of a package during transportation and handling. In the context of cold chain packaging, the outer packaging plays a crucial role in providing physical protection, insulation, and containment for temperature-sensitive products. Some key aspects of outer packaging in the cold chain will be mentioned below.

The choice of material for outer packaging depends on factors such as the nature of the product, transportation mode, duration, and temperature requirements. Common materials used for cold chain outer packaging include corrugated cardboard, plastic, or insulated containers made from expanded polystyrene (EPS) or polyurethane foam. (Ndukwu, 2017a)

The strength and durability of cold packaging is essential. Outer packaging must be strong enough to withstand the rigors of transportation, including stacking, handling, and potential impacts. It should be able to protect the contents from physical damage, especially in cases where fragile or sensitive products are being shipped.

Additionally, in cold chain packaging, the outer packaging often includes insulating properties to help maintain the desired temperature. Insulated containers or additional insulating materials may be used to minimize heat transfer and provide thermal protection to the contents. (Ndukwu, 2017b)

Depending on the nature of the product, outer packaging may need to provide resistance to moisture and water. This is particularly important to prevent damage to temperature-sensitive products that could be adversely affected by humidity or water exposure.

It is also important to ensure the security and tamper-evidence of cold packaging. Outer packaging may incorporate security features, such as tamper-evident seals or specialized closures, to ensure the integrity and authenticity of the contents. These features help to detect and deter unauthorized access or tampering during transit.

Outer packaging often includes labels and markings that provide information about the contents, handling instructions, temperature requirements, and any regulatory compliance details. These labels and markings help ensure proper handling and provide necessary information to stakeholders involved in the cold chain.

At last, the environmental considerations are crucial for cold packaging. Sustainable and environmentally friendly packaging solutions are increasingly important. Outer packaging should consider recyclability, use of eco-friendly materials, and waste reduction to minimize the environmental impact of the packaging. (Blanco et al., 2005)

It is crucial to select outer packaging that meets the specific requirements of the cold chain, including temperature control, physical protection, and regulatory compliance. Adequate outer packaging ensures that temperature-sensitive products are safeguarded throughout their journey, maintaining their quality, safety, and efficacy until they reach the end consumer. (Fuertes et al., 2016)

3.1.5 Labels and Markings

Labels and markings on cold packaging play a vital role in providing important information, instructions, and warnings related to temperature control and handling requirements. They help ensuring proper handling, storage, and transportation of temperature-sensitive products throughout the cold chain. There are some technological trends and systems used in labels and markings on cold packaging and they will be mentioned below. (Giannoglou et al., 2014)

At first, the Temperature Range Indicators are labels that indicate the required temperature range for the product during storage and transportation. They typically display both the minimum and maximum temperature limits, ensuring that the product remains within the specified temperature range.

The Fragile or Handle with Care labels alert handlers to the delicate nature of the contents, emphasizing the need for gentle handling and avoidance of rough or excessive impact that could damage the product.

This Side Up labels indicate the proper orientation of the package during transportation to prevent potential damage or leakage of the contents. They help ensure that the package is handled and stored in the correct position to maintain product integrity.

Refrigerate/Do Not Freeze labels provide instructions regarding the specific storage temperature requirements. They indicate whether the product needs to be refrigerated or should not be frozen, ensuring that the product is stored within the appropriate temperature conditions.

Expiry Date labels with the expiration date indicate the date beyond which the product should not be used or consumed. This information helps to ensure that temperature-sensitive products are used within their recommended shelf life and efficacy.

Batch/Lot Number labels containing batch or lot numbers are used to identify specific manufacturing or production runs of the product. These numbers are useful for traceability and quality control purposes, allowing for easy tracking in case of product recalls or quality issues.

Another type is the Regulatory Compliance Labels. Depending on the industry and product type, cold packaging may require specific regulatory compliance labels. For example, pharmaceuticals may require labels indicating compliance with Good Distribution Practices (GDP), while food products may require labels indicating compliance with Hazard Analysis and Critical Control Points (HACCP) or other food safety regulations.

There are also the Hazardous Material Labels. If the temperature-sensitive product falls under hazardous material categories, appropriate hazard warning labels should be affixed to the packaging. These labels communicate potential hazards and ensure compliance with regulations governing the transportation of hazardous substances.

It is essential to ensure that labels and markings on cold packaging are clear, legible, and adhered securely to the packaging. They should be easily recognizable and understood by handlers, allowing for proper handling, storage, and transportation of temperature-sensitive products. (Giannoglou et al., 2014)

3.1.6 Regulatory Compliance

Regulatory compliance in cold packaging refers to the adherence to specific regulations, guidelines, and standards established by regulatory bodies governing the handling, storage, and transportation of temperature-sensitive products. Compliance ensures that the packaging processes and procedures meet the required standards for quality, safety, and efficacy. Below are some key aspects of regulatory compliance in cold packaging.

Good Distribution Practices (GDP) guidelines provide a framework for the proper distribution and storage of pharmaceutical products. They cover areas such as temperature control, documentation, training, quality management systems, and traceability. Cold packaging for pharmaceuticals must comply with GDP guidelines to ensure product integrity and patient safety.

Hazard Analysis and Critical Control Points (HACCP) is a systematic preventive approach to food safety that identifies, evaluates, and controls hazards in the food supply chain. Cold packaging for food products should adhere to HACCP principles, which include temperature control, hygiene practices, sanitation, and traceability.

International Organization for Standardization (ISO) Standards, such as ISO 9001 (Quality Management Systems) and ISO 13485 (Medical devices - Quality Management Systems), provide guidelines for quality management and regulatory compliance. Cold packaging processes and systems may need to conform to specific ISO standards depending on the industry and product type.

Regulatory Authority Guidelines, such as the U.S. Food and Drug Administration (FDA), European Medicines Agency (EMA), or local health authorities, issue specific guidelines and regulations for the packaging and distribution of temperature-sensitive products. Compliance with these guidelines is essential to ensure product safety and regulatory approval.

Cold Chain Certification Programs often involve rigorous audits and assessments of facilities, processes, and quality management systems to ensure compliance with industry standards and best practices. Some industries have established certification programs specific to cold chain packaging and logistics.

Labeling and Product Information includes accurate and clear labeling of ingredients, expiration dates, storage conditions, warnings, and any necessary regulatory markings. Cold packaging must comply with regulations regarding product labeling and information.

Documentation and Record-Keeping includes maintaining temperature records, calibration records of monitoring devices, validation reports, shipping records, and any other relevant documentation to demonstrate compliance with regulations. Regulatory compliance in cold packaging requires proper documentation and record-keeping practices.

Compliance with regulatory requirements in cold packaging is crucial to ensure product safety, efficacy, and legal compliance. It helps protect consumers, maintain product integrity, and avoid potential penalties or legal issues. Companies involved in the cold chain must stay updated on the latest regulations and guidelines applicable to their industry and products to ensure ongoing compliance.

3.2 COLD STORAGE

Most of the concern is directed to how logistics companies would cope with keeping large volumes of products at the required temperature. The creation of cold storages solves this problem by keeping cold and frozen products at slightly higher temperatures. However, the daily challenges still exist in the warehouse and supply chain process, and that’s where technology and new systems come to provide solutions. (Rahimi-Khoigani & Hamdami, 2023)

On an industrial scale, the cold storage is a high-tech and sophisticated process that often has levels of automation. There are two key components to a cold storage, the warehouse and the equipment inside, such as the racking. Everything must contribute to keep the temperature constant. (Kim et al., 2012)

There are two categories of cold storage, the refrigerators that have controlled temperatures at 0^{o}C to 10 ^{o}C and the freezers with controlled temperatures at -30 ^{o}C to 0 ^{o}C. On the one hand, the refrigerators aim to maintain the products at an optimal temperature, so that there are no alterations and to extend their life span. On the other hand, the freezers must keep the products at a constant temperature to ensure that there will be no risk of alteration or damage to its integrity. The choice of refrigeration or freezing is based on the type of products and their storage needs.

There are a lot of challenges that need to be met. First, a particular challenge for cold storage being built today is the government's commitment to zero net carbon footprint by 2050. Second, cold storage is considered an expensive option, given the cost of energy required to keep it cold. Thirdly, the workers have to work in sub-zero temperatures, a very difficult condition for a working environment. Fourth, the temperature should remain stable not only during storage, but also in the loading-unloading and receiving-dispatching areas of the products.

3.2.1 Cold Storage Facilities

Cold storage facilities are a crucial component of the cold supply chain, contributing significantly to the safe storage and preservation of temperature-sensitive products. There are particularities related to the environmental conditions for cooling and the characteristics of the processes required for the proper preservation of the products. The advantage of the low storage temperatures is the significant reduction of water losses from the products (e.g., vegetables and fruits).

The high relative temperature slows down water losses and increases the shelf life of the products. Ideally, the storage areas maintain the highest relative humidity of 100%, which is tolerated by the products. However, under conditions of 100% relative humidity, disease-causing microorganisms grow rapidly, condensation occurs which causes increased spoilage in products, and there is also the aeration with unsaturated air, which is often necessary to remove heat and volatile gases, such as ethylene. (Rahimi-Khoigani & Hamdami, 2023)

Another particularity is to maintain sufficient air circulation within the storage space and around the products in question if effective cooling is ensured. However, high velocity air movement can drastically reduce product water losses.

Finally, the choice of the right technical storage depends on the following factors. First of all, the type of products, their temperature from harvest and their respiration rate as well as the quality of the products. Secondly, the storage temperature and humidity should be more suitable for the products and then the planned storage duration, without causing cryo-injury or sloppy microbial spoilage. Thirdly, the demands of the market in the economics of the whole process should be taken into account. (Orjuela-Castro et al., 2017)

It is not a simple process. Organizational and experienced management qualities are required. The shelf life of all products is not the same. In some of them, the cooling process must be done immediately, while in others it may take more time to extend their life span. Some even require a controlled environment in order to thrive. Practically, the quality of the production and the provision of humidity and shade conditions are the first priorities of Cold Storage. (Etemadnia et al., 2015)

3.2.2 Cold Room Equipment

Cold room equipment refers to the various types of machinery and devices used to create and maintain low-temperature environments in refrigerated or frozen storage facilities, laboratories, and other spaces requiring temperature control.

The cold rooms are built according to the needs of each company and the products, both in terms of dimensions and equipment, with the aim of the products reaching their destination unchanged. Every cold room has a refrigeration unit that provides cooling to the room. It typically includes a compressor, condenser, evaporator, and control system. This unit removes heat from the room and maintains the desired low temperature. (Ndukwu, 2017a)

The temperature of the cold rooms can be adjusted accordingly each time so that the products delivered to the customer are in excellent condition (external and internal). The Insulation of the cold rooms is essential. Cold rooms are constructed with highly insulated walls, floors, and ceilings to minimize heat transfer from the surroundings. Insulation materials such as polyurethane foam or polystyrene are used to ensure efficient temperature control.

The basic equipment of a cabin includes, among others, the Interior lighting which achieved by waterproof ceiling lights, the meat transport systems (hooks and clamps), the drainage system for transporting fish with special water reservoirs, a system for dividing the chamber into two or even three compartments with different temperatures with the corresponding cooling mechanism, Cargo lashing system, Fixed or tilting shelves, and Temperature recorder with printer and memory (one to two years).

Moreover, cold room doors are designed to provide an airtight seal when closed to prevent the entry of warm air. They are usually made of insulated materials and may include features like strip curtains or rapid roll-up doors for easy access while minimizing temperature fluctuations. (Rahimi-Khoigani & Hamdami, 2023)

In addition, the Temperature and Humidity Control systems help monitoring and regulating the temperature and humidity levels inside the cold rooms. They typically include sensors, thermostats, and humidity controllers to maintain optimal conditions.

Cold rooms often feature shelving or racking systems to organize and maximize storage space. They are designed to withstand low temperatures and may be made of stainless steel or other suitable materials.

Proper air circulation systems inside the cold rooms ensure uniform cooling and prevent the formation of cold spots. Fans or air circulation systems help distribute cold air throughout the room.

Specialized lighting fixtures are used in cold rooms to provide sufficient illumination while minimizing heat generation. These fixtures are designed to withstand low temperatures and are often enclosed in shatterproof.

Alarm and Monitoring Systems should not be missing from the cold rooms. These systems alert the Responsible employee in case of temperature deviations, power failures, or other malfunctions. Monitoring systems can track temperature, humidity, and other parameters for record-keeping and regulatory compliance.

One more useful equipment is that of defrost systems. Cold rooms equipped with freezers often require defrost systems to remove ice buildup on evaporator coils. This ensures efficient cooling and prevents ice from obstructing airflow.

A Backup Power Supply is also necessary equipment for a cold room. To prevent spoilage in the event of a power outage, some cold rooms have backup power supplies like generators or battery backup systems. These ensure continuous operation and temperature control during emergencies.

It's important that specific cold room equipment requirements can vary depending on the intended use, size, and temperature range of the cold room. Consulting with a professional refrigeration engineer or supplier can help determine the most suitable equipment for a particular application. (Zhang et al., 2023)

3.2.3 Cold Storage Management Software

Advanced software solutions are being used to manage and optimize cold storage operations. These platforms provide functionalities such as inventory management, temperature monitoring, order tracking, and warehouse optimization, enabling better resource utilization and streamlined workflows. (Ndukwu, 2017a)

The software allows for efficient tracking and management of inventory within the cold storage facility. It provides real-time visibility into stock levels, expiration dates, batch numbers, and product locations. This helps optimize storage space and reduces the risk of stock outs or wastage. (Mol, 2015)

Cold storage facilities require accurate temperature monitoring to ensure that perishable goods are stored at the appropriate conditions. The software can integrate with temperature sensors and provide real-time alerts if there are any temperature deviations, helping to prevent spoilage or damage to the stored items.

The software facilitates the management of incoming and outgoing orders. It enables order processing, picking, packing, and shipping operations, ensuring accurate fulfillment and timely deliveries. (Storoy et al., 2013)

Cold storage management software often includes reporting and analytics capabilities. It generates reports on inventory levels, temperature logs, order fulfillment, and other relevant data. These reports help in identifying trends, optimizing operations, and making informed business decisions.

The software can schedule and track maintenance tasks for cold storage equipment, such as refrigeration systems, HVAC units, and temperature sensors. It helps in reducing downtime, preventing equipment failures, and extending the lifespan of critical assets. (Mai et al., 2010)

Cold storage facilities need to comply with various regulatory standards and industry certifications. The software can assist in maintaining compliance by capturing and documenting temperature records, batch numbers, and other required information. It also enables traceability by tracking the movement of products within the facility, from receipt to dispatch.

3.2.4 Cold Storage Visibility and Traceability

With increasing demand for transparency and traceability in the supply chain, technologies like RFID (Radio Frequency Identification) and barcode systems are utilized to track and trace products throughout the cold chain. This enhances inventory management, reduces the risk of product loss, and improves food safety. (Kelepouris et al., 2007)

Cold storage facilities typically maintain specific temperature ranges to preserve the quality and safety of stored items. Traceability systems involve real-time monitoring and recording of temperature data at different stages, including during transportation, storage, and distribution. This data helps identify and address temperature excursions that could compromise the integrity of the products. (Dandage et al., 2017)

Each item or batch stored in cold storage is assigned a unique identifier or label. This identifier can be a barcode, RFID (Radio-Frequency Identification) tag, or a similar technology. The label contains relevant information such as product type, lot number, expiration date, and any other details required for traceability. (Delen et al., 2011)

Cold storage traceability systems capture, and record data related to the movement of items within the facility. This includes information on when the item arrived, who handled it, and its location within the storage facility. Data capture can be manual (e.g., using paper-based logs) or automated through digital systems that integrate with the facility's infrastructure. (Parreño-Marchante et al., 2014)

The recorded data allows for accurate tracking and tracing of stored items. If a quality issue arises or a product recall is necessary, the traceability system can identify the specific items affected, their origin, and the subsequent destinations. This information helps pinpoint the root cause of any problems and allows for targeted actions to mitigate risks and ensure consumer safety. (Bhatt et al., 2013)

Cold storage traceability systems often integrate with broader supply chain management systems. This integration enables seamless data sharing across various stakeholders, such as manufacturers, distributors, and retailers. It facilitates end-to-end visibility and enhances collaboration and decision-making throughout the supply chain. (Aung & Chang, 2014)

Many industries, such as the food and pharmaceutical sectors, have stringent regulations regarding cold chain management and traceability. Cold storage facilities need to comply with these regulations, which often require them to maintain detailed records and provide proof of proper handling and storage conditions. (Chan, 2022)

3.2.5 Cold Storage Warehouse Design

Modern cold storage facilities are designed to optimize space utilization and operational efficiency. This includes implementing high-density storage systems, such as automated racking systems and vertical storage solutions, to maximize storage capacity while ensuring easy access to products. (Y. A. Kim et al., 2012)

The choice of a suitable location that is easily accessible for transportation and close to distribution centers or transportation hubs is very important. Consider proximity to highways, ports, or rail lines for efficient logistics.

Determine the size of the warehouse based on the storage capacity required. The layout should optimize space utilization and workflow efficiency. Consider factors such as the number and size of storage chambers, racking systems, and circulation areas for both people and material handling equipment. (Zhang et al., 2023)

Identify the different temperature zones needed within the warehouse based on the types of products to be stored. For example, separate areas for frozen, chilled, and ambient temperature storage. Each zone should have appropriate insulation, ventilation, and refrigeration systems. (Rahimi-Khoigani & Hamdami, 2023)

Choose high-quality insulation materials to maintain the desired temperatures within the facility. Properly insulate the walls, roof, and floor to minimize heat transfer. Use energy-efficient doors and windows with good sealing properties.

Select reliable and energy-efficient refrigeration systems suitable for the required temperature ranges. Consider the size, cooling capacity, and backup systems for uninterrupted operation. Opt for eco-friendly refrigerants to comply with environmental regulations. (Lundén, Vanhanen, Myllymäki, et al., 2014)

3.2.6 Cold Storage Data Analytics

Data analytics and predictive modeling are being employed to optimize cold storage operations. By analyzing historical data on temperature variations, product demand, and energy consumption, operators can make informed decisions, improve forecasting accuracy, and optimize resource allocation. (Zhang et al., 2023)

Cold storage data analytics refers to the analysis and extraction of insights from data stored in cold storage. Cold storage typically refers to long-term storage solutions, such as tape libraries or disk-based archives, where data is stored for archival or compliance purposes. These storage systems are designed for low-cost, high-capacity storage, but retrieving and accessing data from them can be slower compared to online or near line storage systems. (Y. A. Kim et al., 2012)

Since cold storage systems are optimized for long-term storage rather than rapid retrieval, accessing data from these systems can be time-consuming. As part of the analytics process, data needs to be retrieved from the cold storage and prepared for analysis. This may involve data migration, transformation, and integration with other datasets. (Zeng et al., 2014)

Once the data is accessible, various data analysis techniques can be applied to extract meaningful insights. This may include statistical analysis, data mining, machine learning, and predictive analytics, among others. The choice of techniques depends on the specific goals and characteristics of the data being analyzed.

Cold storage is often used for compliance purposes, where data needs to be retained for a specific period due to legal or regulatory requirements. When performing analytics on cold storage data, it's essential to adhere to data governance and compliance policies to ensure data privacy, security, and regulatory compliance.

Cold storage is favored for its low-cost storage capabilities, allowing organizations to store large volumes of data economically. When conducting data analytics on cold storage, cost optimization is an important consideration. Organizations should assess the value of the insights they can derive from the stored data and balance it against the costs associated with data retrieval, processing, and analysis. (Ndukwu, 2017a)

Cold storage data analytics can be valuable in various domains, such as historical trend analysis, long-term forecasting, compliance audits, risk analysis, and research studies. Industries like finance, healthcare, retail, and government often leverage cold storage data analytics to gain insights from their archived data.

It's worth noting that advancements in cloud-based storage and analytics technologies have also enabled more efficient analysis of data stored in cold storage. Cloud providers offer solutions that combine the scalability and cost-effectiveness of cold storage with on-demand data retrieval and analytics capabilities, making it easier to perform analytics on archived data. (Zhang et al., 2023)

3.2.7 Cold Storage Security

Cold storage security systems refer to the security measures and technologies implemented to protect valuable assets, such as perishable goods, pharmaceuticals, or sensitive data, in controlled environments with low temperatures. These security systems are designed to ensure the integrity, safety, and confidentiality of the stored items. These include biometric access controls, video surveillance systems, and real-time monitoring of facility parameters. (Musa et al., 2014)

These technological trends and systems are shaping the future of cold storage by improving efficiency, sustainability, and product safety. As technology continues to advance, we can expect further innovations and advancements in cold storage practices. (González-Martel et al., 2021)

Access to the cold storage facility is restricted to authorized personnel only. Access control mechanisms can include key cards, biometric systems (such as fingerprint or iris scanners), or PIN-based entry systems. These measures help prevent unauthorized access and maintain a secure environment. (J. U. Kim et al., 2016)

Closed-circuit television (CCTV) cameras are installed to monitor the facility's interior and exterior areas. Cameras help deter potential intruders and provide video evidence in the event of a security breach. Advanced surveillance systems may include features like motion detection, night vision, and remote monitoring capabilities. (Xiao et al., 2016a)

Intrusion detection systems (IDS) are designed to detect and alert any unauthorized entry or tampering attempts. These systems can use sensors, motion detectors, or pressure-sensitive mats to identify suspicious activities or breaches in the facility's perimeter. (Xiao et al., 2016b)

Cold storage facilities require constant monitoring of environmental conditions, such as temperature and humidity, to ensure the preservation of stored goods. Environmental monitoring systems are equipped with sensors that detect any deviations from predefined parameters. Alerts are triggered if the conditions go beyond acceptable ranges, allowing immediate action to prevent damage or spoilage.

Alarm systems play a crucial role in cold storage security. They can be integrated with access control, surveillance, and environmental monitoring systems to generate audible and visual alerts in case of unauthorized access, environmental anomalies, power failures, or other security breaches. Alarms help to prompt a rapid response and mitigate potential risks. (Lloyd et al., 2015)

Cold storage facilities often employ specialized fire suppression systems, such as clean agent suppression or pre-action sprinkler systems, to protect against fire hazards. These systems are designed to quickly detect and suppress fires while minimizing water damage and preserving the integrity of stored goods.

Since power outages can pose significant risks to cold storage environments, backup power systems, such as uninterruptible power supply (UPS) units or generators, are commonly installed. These ensure that critical security systems, environmental controls, and refrigeration units remain operational during power disruptions.

If the cold storage facility involves the storage of sensitive data, robust data security measures are essential. This includes encryption of data in transit and at rest, secures network architecture, regular vulnerability assessments, and access controls for data handling and retrieval. (X. Li et al., 2019)

It's important to note that specific security requirements may vary depending on the nature of the items being stored and regulatory standards. Consulting with security professionals and considering industry best practices can help determine the most appropriate security system for a cold storage facility. (Giannakourou et al., 2005)

3.2.8 Temperature Recorder

Temperature recorders are commonly used in cold rooms and transportation to monitor and document temperature variations over time. These devices play a crucial role in ensuring that the cold room maintains the desired temperature range for the storage of temperature-sensitive items such as food, pharmaceuticals, and other perishable goods.(Chun Zheng Ng et al., 2019)

The fresh and frozen products are placed both during their storage and their transport, in cold rooms in which the temperatures that develop throughout the duration of the storage or transport are continuously recorded. The new generation recorders are manufactured in accordance with the latest European specifications (EN 12830/1999, EL 37/2005) and are particularly friendly to users and transport drivers.

The main characteristics of temperature recorders include the recording temperatures on a 24-hour basis and storing data for at least two years, the notification in case of temperature change, the delivery ticket and journey ticket prints in numerical or graphic form. (Badia-Melis et al., 2016)

The temperature recorders have also the ability to connect with Bluetooth system for the wireless transmission of temperatures, data, etc., when the car returns to the company premises, with GPRS-GPS system for the continuous transmission of temperature data as well as the position of the car, and also with Software systems for the numerical or graphical processing of the data and creation of filters for the export of statistical conclusions. (Mercier & Uysal, 2018)

There are various types of temperature recorders available, ranging from simple analog thermometers to advanced digital data loggers. One common type is the Analog Temperature Recorders. These are basic temperature recorders that use a bimetallic strip or a liquid-filled glass tube to indicate temperature. They have a dial or a scale where the temperature can be read manually.

Another common type is the Digital Temperature Recorders. These recorders use digital sensors to measure and display temperature readings. They often have built-in memory to store temperature data over time. Some models also include features such as alarms for temperature deviations and the ability to connect to a computer for data analysis. (Zou et al., 2023)

One more type of temperature recorder is the Data Loggers which are electronic devices that record temperature readings at regular intervals. They typically have built-in sensors or external probes to measure temperature and internal memory or storage media to store the recorded data. Data loggers can be programmed to log temperature data over specific time intervals, and the recorded information can be downloaded to a computer for analysis.

At last, Wireless Temperature Monitoring Systems consist of multiple wireless temperature sensors placed in different locations within the cold room. The sensors wirelessly transmit temperature data to a central receiver or gateway, which collects and records the information. These systems often offer real-time monitoring, alerts for temperature deviations, and remote access to temperature data.

The selecting of a temperature recorder for a cold room, needs considering of the factors such as temperature range, accuracy, data storage capacity, battery life, and any specific requirements or regulations applicable to your industry. It's also important to ensure that the recorder is compatible with the operating conditions of the cold room, such as low temperatures and humidity levels.

A reputable supplier or manufacturer of temperature recorders can provide further guidance, consulting and help as far as concern the choice of the most suitable device for the specific needs of the storage or the transportation. (Zou et al., 2023)

3.3 COLD DISTRIBUTION

Cold distribution refers to the process of delivering and supplying cold or refrigerated products to various destinations. It involves the transportation and storage of goods that require specific temperature-controlled conditions to maintain their quality and prevent spoilage. Cold distribution includes the procedures of temperature control, cold storage facilities, transportation, packaging, monitoring and quality assurance, and the distribution network. (Hsiao et al., 2017)

Initially, the temperature control maintains the desired temperature range throughout the distribution process, and it is vital for the smooth functioning of the cold chain and the safety of the products. This involves the use of refrigerated vehicles, cold storage facilities, and temperature monitoring systems to ensure that products remain within the required temperature limits.

In distribution are included specialized warehouses equipped with refrigeration units to store and preserve the perishable goods. Cold storage facilities may vary in size and capacity, ranging from small walk-in coolers to large-scale refrigerated warehouses preserving the products unchanged. (Maharjan & Hanaoka, 2020)

Except for the warehousing, cold distribution often involves the use of refrigerated trucks, vans, or containers to transport goods from the manufacturing or storage facilities to distribution centers, retailers, or directly to consumers. These vehicles are designed to maintain specific temperature ranges and may use advanced cooling technologies such as cryogenic systems or insulated containers.

Another procedure that may be involved to the distribution is the proper packaging which is crucial for maintaining the cold chain integrity. Insulated containers, coolers, or refrigerated packaging materials help to minimize temperature fluctuations during transit and protect the products from external heat sources.

In the distribution also are included the temperature monitoring systems, such as data loggers or real-time tracking devices, that are employed to ensure that products are kept within the prescribed temperature range. In addition, quality control measures are implemented to guarantee the safety and integrity of the cold chain, including regular inspections, adherence to hygiene protocols, and compliance with regulatory standards. (Golestani et al., 2021)

A well-organized Distribution Network of suppliers, distributors, and logistics providers is essential for efficient cold distribution. Coordination between various stakeholders ensures timely delivery, proper handling, and effective management of cold chain operations. (Maharjan & Hanaoka, 2020)

Cold distribution preserves the freshness, quality, and safety of perishable goods. It enables the transportation of temperature-sensitive products over long distances, facilitates international trade, and ensures that consumers receive products in optimal condition. There are many technological trends and systems that support the distribution network.

Nowadays, technological advancements have significantly influenced the cold storage industry, improving efficiency, sustainability, and safety. Some notable technological trends and systems in cold storage will be analyzed below.

3.3.1 Automation and Robotics

Automation and Robotics are significant advantages for the cold storage. Cold storage facilities are increasingly adopting automated systems and robotics to streamline operations. Automated guided vehicles (AGVs) and robotic picking systems can efficiently move and organize products within the warehouse, reducing manual labor, and increasing overall productivity. (E-Fatima et al., 2022)

Automated Guided Vehicles (AGVs) are self-guided robotic vehicles that transport goods within the cold storage facility. They can navigate autonomously using sensors, lasers, or magnetic strips on the floor. AGVs are used for tasks such as picking up pallets, moving them to designated locations, and loading/unloading trucks. They reduce the need for manual labor, increase efficiency, and minimize the risk of human error. (*Automation Is-A Response to Challenges in the Cold Chain*, 2021)

Robotic Picking Systems use advanced robotic arms equipped with cameras, sensors, and grippers to handle products in cold storage. These robots can pick and place items from pallets or shelves with precision and speed. They are particularly beneficial for order fulfillment and reducing repetitive strain injuries for workers in cold storage environments. (*This Includes: • Automation and Labor • Strategy and Fit • Order Profiles and Logistics • Warehouse Design • Cost Considerations*, n.d.)

Automated Storage and Retrieval Systems (AS/RS) are robotic systems that automatically store and retrieve items from designated locations in the warehouse. They utilize computer-controlled cranes or shuttles to handle pallets or containers and can operate in sub-zero temperatures. AS/RS systems optimize space utilization, improve inventory management, and accelerate order fulfillment.

Conveyor Systems are extensively used in cold storage facilities for efficient movement of products within the warehouse. Automated conveyor systems can sort, merge, and transport goods, eliminating the need for manual handling. They ensure continuous and smooth material flow, enhancing productivity and reducing labor requirements.(E-Fatima et al., 2022)

Robotic palletizing systems handle the stacking of goods onto pallets, while depalletizing systems unload products from pallets. These robots use sensors and vision systems to identify and handle items, optimizing stacking patterns and reducing the risk of product damage. Robotic palletizing and depalletizing enhance efficiency, reduce labor costs, and improve workplace safety.

Cold Storage Order Fulfillment Systems are automated systems that are used for order picking and fulfillment in cold storage environments. This includes technologies such as pick-to-light systems, voice-guided picking, and robotic order picking systems. These systems help increase accuracy, speed, and efficiency in fulfilling customer orders while minimizing errors.(Storoy et al., 2013)

Automation systems are employed to monitor and control temperature conditions within the cold storage facility. Sensors and IoT-enabled devices constantly monitor temperature and humidity levels, adjusting the refrigeration systems as needed. This ensures precise temperature control, reduces energy consumption, and maintains product quality.

Robots are utilized for cleaning and maintenance tasks in cold storage facilities. Autonomous cleaning robots can sweep and scrub floors, ensuring cleanliness and hygiene. Maintenance robots can perform routine inspections, identify potential issues, and assist in equipment maintenance, minimizing downtime and improving facility operations. (Mol, 2015)

Automation and robotics are revolutionizing the cold storage industry by improving efficiency, accuracy, and safety in various aspects of operations. By incorporating automation and robotics in cold storage, companies can enhance operational efficiency, reduce labor costs, improve safety, and maintain product integrity. These technologies enable cold storage facilities to meet increasing demands while ensuring the efficient management of temperature-sensitive goods. (Trebar et al., 2013)

3.3.2 Internet of Things (IoT) and Sensor Technology

Internet of Things (IoT) and Sensor Technology have a great importance in monitoring and maintaining optimal conditions within cold storage facilities. These devices can track temperature, humidity, air quality, and other environmental factors in real-time, alerting operators to any deviations from set parameters. IoT-enabled systems also enable remote monitoring and control, improving operational efficiency.

IoT-enabled sensors are used to monitor and control temperatures throughout the cold distribution process. These sensors are placed in refrigerated trucks, storage facilities, and shipping containers to ensure that the required temperature ranges are maintained. Real-time data is collected and transmitted to a centralized system, enabling timely alerts and interventions if any deviations occur. (Luo et al., 2016)

IoT technology allows remote monitoring and control of cold distribution systems. Managers can access data about temperature, humidity, and other environmental conditions from anywhere using web-based dashboards or mobile applications. They can adjust temperature settings, receive notifications, and even troubleshoot issues remotely, improving operational efficiency. (Ouaddah et al., 2017)

Sensors in cold distribution systems can monitor various parameters beyond temperature. For example, humidity sensors can track moisture levels to prevent condensation or mold growth. Additionally, sensors can monitor factors such as door openings, power outages, and system performance to ensure optimal functioning and identify potential maintenance requirements. (E-Fatima et al., 2022)

IoT enables enhanced visibility into the cold distribution supply chain. By integrating sensors with inventory management systems, companies can track products in real-time, ensuring timely deliveries and minimizing the risk of spoilage. This visibility also helps in identifying bottlenecks, optimizing routes, and improving overall supply chain efficiency. (Alaba et al., 2017)

IoT-generated data can be leveraged for advanced analytics and predictive maintenance. By analyzing historical data patterns, companies can identify trends, optimize energy usage, and anticipate potential equipment failures. Predictive maintenance helps in reducing downtime, optimizing maintenance schedules, and preventing costly breakdowns. (Grecuccio et al., 2020)

With IoT and sensor technology, it becomes easier to track and trace products throughout the cold distribution process. This is especially important in industries like pharmaceuticals, where product integrity and compliance with regulations are critical. Sensors can provide real-time information about the temperature history of a product, ensuring adherence to quality and safety standards. (Lundén, Vanhanen, Kotilainen, et al., 2014)

IoT platforms enable seamless integration with existing enterprise systems, such as inventory management, logistics, and customer relationship management (CRM). This integration improves data visibility, facilitates data-driven decision-making, and enables end-to-end optimization of cold distribution operations. (Accorsi et al., 2017)

Cold storage management software can integrate with other systems, such as ERP (Enterprise Resource Planning) or WMS (Warehouse Management System), to ensure smooth data flow and streamline operations. It should also offer scalability to accommodate the growing needs of the business. (Fu et al., 2008)

Some popular cold storage management software solutions in the market include Freshworks CRM, Datex FootPrint WMS, Deposco Bright Suite, TrakSYS, Zebra MotionWorks Cold Chain, and it is very important to evaluate different software options based on the specific requirements, budget, and scalability needs of the company before making a decision.

3.3.3 Energy Efficiency and Sustainability

Cold storage facilities are focusing on reducing energy consumption and adopting sustainable practices. Technologies such as energy-efficient refrigeration systems, LED lighting, smart controls, and insulation improvements help minimize energy waste and lower operational costs. Additionally, the integration of renewable energy sources, such as solar power, is becoming more prevalent. (José et al., 2017b)

Implementing effective insulation throughout the facility helps reduce heat transfer and minimize energy losses. Insulated panels, doors, and curtains should be used to maintain the desired temperature inside the cold storage space.

Replace traditional lighting with energy-efficient LED lighting systems. LEDs consume less energy, have a longer lifespan, and produce less heat, thereby reducing the cooling load and lowering energy costs. (Marchi & Zanoni, 2022)

Utilize advanced refrigeration technologies, such as variable frequency drives (VFDs), high-efficiency compressors, and electronically commutated motors (ECMs). These technologies optimize energy usage and adapt to varying cooling demands.

Implement smart control systems that monitor and regulate temperature and humidity levels accurately. By avoiding unnecessary cooling and maintaining optimal conditions, energy consumption can be reduced significantly. (Gwanpua et al., 2015)

Employ cold aisle containment strategies in data centers and other cold storage areas. This involves isolating cold aisles from the rest of the facility, preventing mixing of hot and cold air and improving cooling efficiency.

Explore the use of renewable energy sources, such as solar panels or wind turbines, to generate electricity for the facility. On-site renewable energy generation can offset power consumption from the grid and reduce greenhouse gas emissions.

Recover waste heat generated by refrigeration systems or other processes and repurpose it for space heating, water heating, or other heating requirements within the facility. This procedure helps increasing energy efficiency and reduces reliance on conventional heating systems. (Marchi & Zanoni, 2022)

Optimize air circulation systems to minimize temperature stratification and ensure uniform cooling throughout the storage space. Properly designed air distribution systems reduce the workload on refrigeration equipment and improve energy efficiency. (Abed et al., 2017)

Regularly inspect and maintain refrigeration equipment, insulation, and other systems to ensure they operate at peak efficiency. Addressing issues promptly can prevent energy wastage and prolong the lifespan of the equipment.

Utilize energy management systems to collect and analyze data on energy consumption, temperature variations, and other relevant parameters. This data can help identify energy-saving opportunities, optimize operations, and implement continuous improvements. (José et al., 2017b)

Incorporating these energy efficiency and sustainability measures in cold storage facilities can result in significant energy savings, reduced operational costs, and a smaller environmental footprint. Additionally, organizations should consider certifications like LEED (Leadership in Energy and Environmental Design) or other green building standards to validate and demonstrate their commitment to sustainable practices. (Dall'O' et al., 2013)

3.4 COLD TRANSPORTATION

In recent years, there have been several notable trends and advancements in cold transportation systems. These trends focus on enhancing efficiency, sustainability, and the integration of technology to improve the overall management and performance of cold supply chains. Some key trends and systems in cold transportation are represented below. (Dellacasa, 1987)

Temperature Monitoring and Tracking systems utilize sensors and IoT (Internet of Things) technology to continuously monitor and record temperature data during transportation. Real-time temperature monitoring and tracking systems have become increasingly popular. They provide real-time visibility into the temperature conditions of the cargo, allowing for immediate intervention if there are any deviations from the desired range. This helps ensure product quality and compliance with regulations. (McGregor, 2019)

Data Analytics and Predictive Analytics is playing a crucial role in cold transportation systems. By analyzing large volumes of data collected from various sources, including temperature sensors, weather forecasts, and historical data, companies can gain valuable insights. Predictive analytics algorithms can help optimize route planning, improve load distribution, and minimize temperature fluctuations, leading to more efficient operations and reduced waste. (Flämig, 2016)

Cold Chain Management Software solutions provide end-to-end visibility and control over the cold supply chain, including inventory management, order tracking, temperature monitoring, and compliance management. The adoption of specialized software for cold chain management has increased. Such systems enable better coordination among stakeholders, reduce manual errors, and enhance overall efficiency. (Van Den Berg et al., 2022)

Innovations in cold chain packaging materials and designs have improved the thermal insulation and protection of perishable goods during transportation. Advanced packaging solutions, such as vacuum-insulated panels, phase change materials, and active temperature-controlled containers, help maintain stable temperatures for extended periods. These innovations contribute to reducing energy consumption, minimizing temperature excursions, and extending product shelf life. (Unicef Supply Division, 2016)

Electric and Hybrid Refrigeration Systems focus on sustainability and has led to the development and adoption of electric and hybrid refrigeration systems. These systems reduce greenhouse gas emissions and dependence on fossil fuels compared to traditional diesel-powered refrigeration units. Electric refrigeration units, powered by batteries or electric grid connections, and hybrid systems that combine electric and alternative fuels are gaining traction as environmentally friendly alternatives.

Blockchain Technology for Traceability is being explored to enhance traceability and transparency in cold transportation systems. By recording and sharing immutable transaction data at each stage of the supply chain, Blockchain can provide verifiable information about product origins, handling conditions, and compliance with regulations. This improves trust and helps prevent fraud while ensuring the integrity of temperature-sensitive products. (Garaus & Treiblmaier, 2021)

Last-Mile Delivery Solutions is the final leg of the transportation process from the distribution center to the end consumer, and it is a critical area of focus. Companies are experimenting with innovative solutions like electric delivery vehicles, smart lockers, and drones for efficient and sustainable last-mile delivery of perishable goods. These solutions aim to reduce delivery times, enhance customer convenience, and optimize resource utilization. (Gharehyakheh et al., n.d.)

Overall, the trends in cold transportation systems revolve around optimizing temperature control, leveraging data and technology, improving sustainability, and enhancing visibility and traceability throughout the supply chain. These advancements are essential for meeting increasing consumer demands, complying with stringent regulations, and reducing waste in the cold supply chain. (Coelho & Laporte, 2014)

3.5 TRACEABILITY

Traceability refers to the ability to track and trace the movement of products, raw materials, or ingredients throughout the cold chain. It involves capturing and recording relevant information at each stage, including sourcing, production, distribution, and sale. (Bhatt et al., 2013)

Traceability is an increasingly useful tool in global food trade and is defined as “the ability to access any or all information relating to the products, throughout the entire life cycle, by means of recorded identification”. (Olsen & Borit, 2013)

The application of traceability first appeared in the field of the automotive industry in the 1960s - 1970s in the USA and was subsequently implemented in other nations such as China and Southeast Asia. They were originally used for software documentation and business modeling. Then, in the food sector, they were used in the 1990s due to food scandals, such as mad cow disease, bird flu, etc. (Olsen & Borit, 2013)

Today, traceability is applied in various industries and businesses, mainly in manufacturing companies. Nowadays, the consumer wants to be sure and to know with precision that the products he consumes are safe and of good quality. With the passage of time, regulations and safety standards for perishable products are becoming stricter. (Mai et al., 2010)

Traceability offers tracking and information at any stage of the chain the product is at. The information may relate to the detailed monitoring of the products and the notification of any danger, such as power failure, sudden temperature change, etc. so that the damage can be corrected. (Badia-Melis et al., 2015)

Technology and new systems play an important role in the implementation of traceability. For traceability to exist and be implemented throughout the cold supply chain, technological innovations are required. Portable tracking devices, wireless tracking, and Radio Frequency Identification (RFID) technologies are connected to computers and stored in a central database. (Kelepouris et al., 2007)

A very important feature of traceability is the identification of a product, regardless of whether it is at the producer, the transporter, the retailer, or the consumer, which is considered dangerous and facilitates its recall. A possible contamination of a product can create a risk for the end user if we do not respond quickly. Speed in this situation is vital for the cold chain. (Piramuthu & Zhou, 2016)

Another characteristic is that the transparency of the origin and the quality of the product is ensured and cases of fraud or misleading the consumer are eliminated. For many companies around the world, it is an important competitive advantage as it offers a plus and particularly important added value to the product. (Mol, 2015)

Nowadays, a product passes through many different stages, from its production to its final use. The transparency and traceability ensure the quality and safety of the products at every stage along the cold supply chain, which is not a simple task.

It is essential to be able to track and trace the products any time it is needed. As tracking, we define "the ability to follow the movement of the products through specified stages of production, processing, and distribution". As tracking, we define "the ability to trace the history, application, or location of an entity by means of recorded identification". (Bosona & Gebresenbet, 2013)

The purpose of traceability is to establish a clear and documented link between different stages of a process or the components of a system. It enables the ability to track and verify the origin, history, and interrelationships of various elements or activities. Traceability is commonly used in several domains in cold supply chain, including software development, management, product manufacturing, and regulatory compliance. (Badia-Melis et al., 2015)

Traceability systems serve as instrumental tools in documenting, monitoring, and maintaining the historical records of a product's journey throughout the supply chain. By implementing traceability, businesses can effectively track perishable inventory, ensuring compliance with regulatory requirements. The best traceability systems not only facilitate the retrieval of information about the raw materials utilized in a product, but also provide insights into the manufacturing processes employed, both at a comprehensive and individual unit level. (Parreño-Marchante et al., 2014)

Apart from the improvement of inventory management combined with the overview of the movement of a product, the positive effects should include the help in the analysis of production processes. Identifying potential problems along the production line is imperative so that fewer corrective actions are required and therefore more economic benefits, as contaminated products are avoided from reaching the market. Therefore, the financial implications are also avoided.

Based on the above, the European Union wants its citizens to have access to safe and healthy food. This is the reason why the European Commission has developed an integrated legislative approach to food safety and consumer protection. From 1/1/2005 according to European legislation all companies involved in the food chain must implement a mandatory traceability system. (Kelepouris et al., 2007)

Overall, the purpose of traceability is to enhance transparency, accountability, and control by establishing a comprehensive and auditable record of the relationships, dependencies, and activities within a process or system. It provides organizations with the ability to track, analyze, and manage information effectively, leading to improved quality, compliance, risk management, and decision-making. (Grecuccio et al., 2020)

3.5.1 Advanced Technological Systems of track & trace

There are several trends and technological systems that are shaping traceability and visibility in the cold chain. These advancements are aimed at improving efficiency, accuracy, and real-time monitoring of products throughout the entire cold chain process. There are some notable trends and technologies, we are going refer below. (Badia-Melis et al., 2018)

Internet of Things (IoT) technology is playing a significant role in cold chain traceability. Temperature and humidity sensors, as well as other environmental sensors, are embedded in shipping containers, vehicles, and storage facilities to monitor conditions in real-time. These sensors collect data and transmit it wirelessly, allowing stakeholders to track and monitor temperature and other critical parameters remotely. (Alaba et al., 2017)

Blockchain Technology has emerged as a promising solution for enhancing traceability in the cold chain. It creates a decentralized and immutable ledger of transactions, enabling secure and transparent sharing of data among different parties. With Blockchain, each transaction or event in the cold chain can be recorded, providing an auditable and tamper-proof record of product movements, temperature conditions, and other relevant information. (Bahga & Madisetti, 2016)

Cloud Computing and Data Analytics enables the storage and processing of large amounts of data collected from various sources in the cold chain. Combined with advanced data analytics techniques, stakeholders can derive meaningful insights, identify patterns, and make data-driven decisions to optimize the cold chain operations. Predictive analytics can also be employed to anticipate and prevent potential issues, such as temperature excursions or supply chain disruptions.

Artificial Intelligence (AI) and Machine Learning (ML) technologies are being used to analyze the vast amount of data generated in the cold chain. These technologies can identify patterns, detect anomalies, and predict potential risks. For example, AI-powered algorithms can analyze temperature data to identify optimal temperature ranges for different products and provide real-time alerts in case of deviations. (Zou et al., 2023)

Radio Frequency Identification (RFID) and Near Field Communication (NFC) technologies are widely used for product identification and tracking in the cold chain. RFID tags and NFC labels are attached to products or packaging, allowing for automated scanning and data capture throughout the supply chain. These technologies enable efficient inventory management, reduce manual errors, and enhance visibility. (Uysal et al., 2011)

Mobile Applications and Interfaces are increasingly being used to provide stakeholders with real-time visibility into the cold chain. These apps enable access to data, tracking information, and alerts on mobile devices, making it convenient for users to monitor and manage the cold chain on the go. Additionally, user-friendly interfaces and dashboards provide a holistic view of the supply chain, enhancing decision-making capabilities. (Montanari, 2008)

With the rise of e-commerce and direct-to-consumer models, traceability systems are being integrated with online platforms to provide customers with visibility into the cold chain. Through QR codes or unique identifiers, consumers can access information about the product's journey, its source, and quality assurance, enhancing trust and transparency. (Peltokorpi et al., 2021)

These trends and technologies are revolutionizing the cold chain industry by improving traceability, visibility, and operational efficiency. By leveraging these advancements, stakeholders can ensure the integrity of products, reduce waste, mitigate risks, and meet regulatory requirements more effectively.

3.5.2 Traceability and Recall Management

Traceability in the cold chain refers to the ability to track and trace the movement of products and materials throughout the entire cold chain process, from production to distribution and storage, ensuring their integrity and quality. The temperature-controlled supply chain preserves the safety of perishable goods using some key aspects of traceability following the trends of the market with technological systems in the cold supply chain.

The following trends and technologies are revolutionizing the cold chain industry by improving traceability, visibility, and operational efficiency. By leveraging these advancements, stakeholders can ensure the integrity of products, reduce waste, mitigate risks, and meet regulatory requirements more effectively.

The continuous monitoring of temperature is an essential key aspect to ensure that the cold chain remains intact. Various technologies such as temperature data loggers, sensors, and real-time monitoring systems are used to monitor and record temperature information at different stages of the cold chain.

More specifically, Internet of Things (IoT) and humidity Sensors, as well as other environmental sensors, are embedded in shipping containers, vehicles, and storage facilities to monitor conditions in real-time. These sensors collect data and transmit it wirelessly, allowing stakeholders to track and monitor temperature and other critical parameters remotely. (Luo et al., 2016)

Barcodes and RFID (Radio Frequency Identification) tags are commonly used in the cold chain to facilitate automated tracking and tracing. These technologies allow for efficient data capture, enabling accurate and real-time information exchange between different stakeholders in the supply chain. (Jedermann & Lang, 2007)

Cloud computing enables the storage and processing of large amounts of data collected from various sources in the cold chain. Combined with advanced data analytics techniques, stakeholders can derive meaningful insights, identify patterns, and make data-driven decisions to optimize the cold chain operations. Predictive analytics can also be employed to anticipate and prevent potential issues, such as temperature excursions or supply chain disruptions. (Sharma et al., 2021)

Blockchain has emerged as a promising solution for enhancing traceability in the cold chain. It creates a decentralized and immutable ledger of transactions, enabling secure and transparent sharing of data among different parties. With blockchain, each transaction or event in the cold chain can be recorded, providing an auditable and tamper-proof record of product movements, temperature conditions, and other relevant information. (Patro et al., 2021)

Artificial Intelligence (AI) and Machine Learning (ML) technologies are being used to analyze the vast amount of data generated in the cold chain. These technologies can identify patterns, detect anomalies, and predict potential risks.

For example, AI-powered algorithms can analyze temperature data to identify optimal temperature ranges for different products and provide real-time alerts in case of deviations. (Sharma et al., 2021)

Integration with E-commerce and Customer Engagement: With the rise of e-commerce and direct-to-consumer models, traceability systems are being integrated with online platforms to provide customers with visibility into the cold chain. Through QR codes or unique identifiers, consumers can access information about the product's journey, its source, and quality assurance, enhancing trust and transparency.

Another important key aspect for traceability is the identification and labeling. Each product within the cold chain should be uniquely identified and labeled with relevant information such as product name, batch/lot number, manufacturing date, and expiration date. This enables easy identification and tracking throughout the cold chain. (Giannoglou et al., 2014)

Tracking the products with Mobile Applications and Interfaces are increasingly being used to provide stakeholders with real-time visibility into the cold chain. These apps enable access to data, tracking information, and alerts on mobile devices, making it convenient for users to monitor and manage the cold chain on the go. Additionally, user-friendly interfaces and dashboards provide a holistic view of the supply chain, enhancing decision-making capabilities. (Montanari, 2008)

Additionally, many industries, especially food and pharmaceuticals, have regulations and standards in place to ensure the safety and quality of products within the cold chain. Traceability systems help in complying with these regulations by providing the necessary documentation and evidence of compliance.

Detailed documentation and records should be maintained at each stage of the cold chain, including information about the product, its origin, handling procedures, and any temperature deviations. This documentation helps in establishing accountability and enables traceability in case of any quality or safety issues. (Giannoglou et al., 2014)

Traceability in the cold chain involves sharing and exchanging data among various entities such as suppliers, manufacturers, distributors, and regulatory authorities. Integration of data systems and use of standardized data formats enhance transparency and facilitate effective traceability.

Maintain traceability of products throughout the cold supply chain is important for effective recall management in case of quality issues or safety concerns. Accurate documentation and robust tracking systems enable swift identification and removal of affected products from the supply chain. Traceability and recall management are critical aspects of supply chain management, especially when it comes to ensuring product safety and addressing potential quality issues. (Patro et al., 2021)

Recall management involves the process of identifying, addressing, and effectively managing product recalls. A recall occurs when a product is found to be defective, contaminated, or poses a safety risk to consumers. The Recall management includes some stages which we will analyze below.

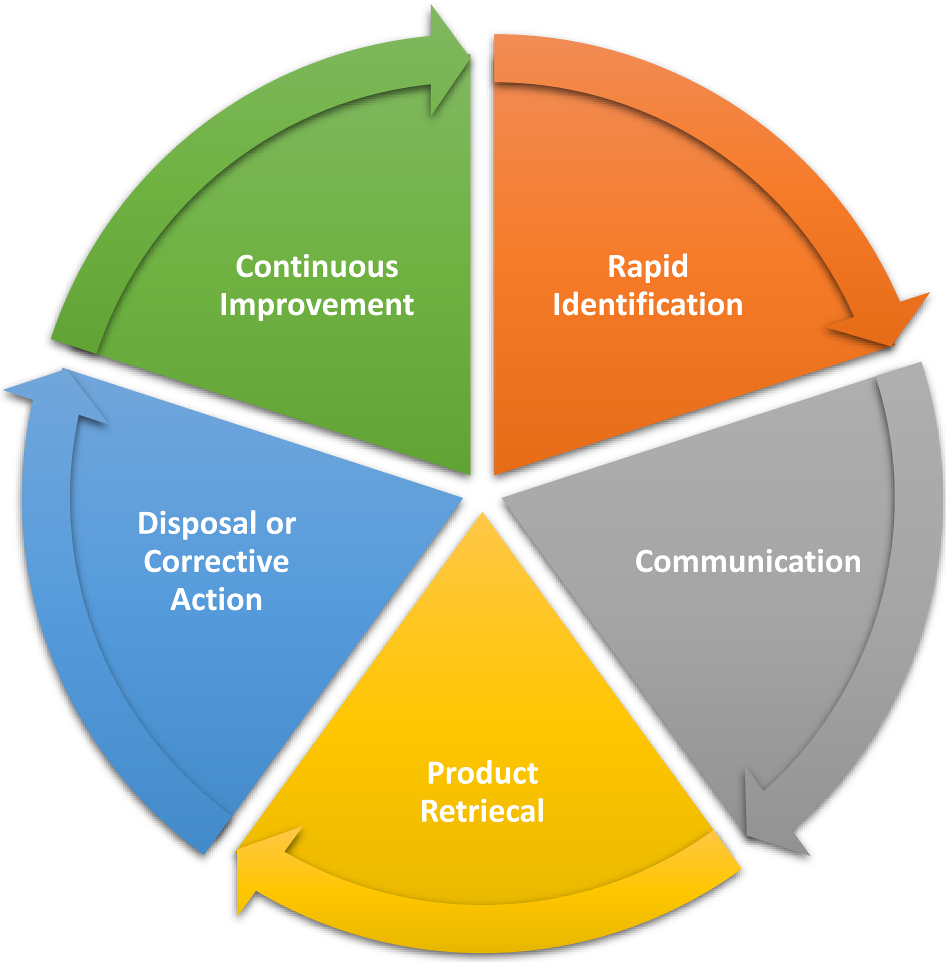

Figure 4: Stages of Recall Management in Cold Supply Chain.

The first stage refers to the prompt identification of the issue that can be initiated by internal quality control measures, customer complaints, regulatory bodies, or through routine testing. Once identified, the affected products or batches must be accurately determined and isolated.

The second stage include the effective communication to stakeholders (suppliers, distributors, retailers, and consumers) is worth taking about. Clear and concise messaging helps mitigate potential harm and maintains transparency.

In the third stage we have the coordinated procedures that are in place ensuring efficient and traceable recovery of affected products from the supply chain, including distribution centers, warehouses, retail stores, and even consumer households.

The fourth stage contains the rejection or appropriate corrective action that is determined based on the nature of the recall. Depending on the severity of the issue, options may include product destruction, rework, repair, or replacement.

In the fifth stage organizations should analyze the root causes of the recall and implement corrective actions to prevent similar issues from occurring in the future. Regular review and revision of processes, quality control measures, and supplier relationships contribute to continuous improvement.

Implementing robust traceability systems, maintaining accurate records, and having a well-defined recall management plan enable companies to respond swiftly and effectively in the event of a product recall. These measures help protect consumers, uphold brand reputation, and ensure the overall safety and quality of products within the supply chain. (Wu & Lin, 2019)

4. TECHNOLOGICAL SYSTEMS & EVALUATION

Technological systems have revolutionized the way temperature-sensitive products are transported, stored, and managed in the cold chain. The cold chain, which encompasses industries like food, pharmaceuticals, and chemicals, relies heavily on advanced technologies to maintain product quality, ensure safety, and optimize supply chain operations.

These technological systems encompass a range of tools, from temperature monitoring devices and refrigeration systems to data analytics software and supply chain visibility solutions. With their ability to provide real-time information, enable proactive decision-making, and improve overall efficiency, these systems have become indispensable in the complex and critical realm of cold chain management.

The evaluation of technological systems in the cold chain should consider factors such as reliability, accuracy, compliance with regulatory standards, data management capabilities, energy efficiency, and integration with other systems. A well-designed and properly implemented technological infrastructure can significantly enhance the safety, efficiency, and sustainability of cold chain operations.

Below, we are going to explore the importance of cold chain through some case scenarios, the advantages, the disadvantages, and the challenges associated with technological systems in the cold chain, as well as the ways a cold chain can be sustainable and more friendly to the environment safeguarding product integrity and streamlining supply chain processes.

4.1 CASE SCENARIOS

We will discuss two different case scenarios about the critical stages of the cold supply chain, the first for temperature-sensitive vaccines and the second for the meat. The cold supply chain is a crucial process that ensures the integrity and efficacy of temperature-sensitive products throughout their journey from manufacturing facilities to end-users. Failure to maintain the required temperature range during transportation and storage can result in compromised product quality and, in extreme cases, consumers harm. To illustrate this, we will follow the journey of a temperature-sensitive vaccine and meat to examine the stages involved in their cold supply chain.

4.1.1 Stages of the Cold Supply Chain in the Case of Vaccines.

The journey of vaccines begins at the manufacturing facility. There, the vaccine undergoes a stringent production process, and its final formulation is a delicate balance of active ingredients, preservatives, and stabilizers. Once the vaccine is prepared, it is dispensed into vials or pre-filled syringes and sealed aseptically. The cold chain integrity is maintained at this stage to prevent any premature degradation of the vaccine.

The next stage is the transportation of the vials or pre-filled syringes to regional distribution hubs. During this step, the vaccines are kept within a controlled and validated temperature range, typically between 2°C to 8°C (36°F to 46°F) to preserve their potency. Temperature-controlled vehicles or containers are used to ensure proper storage during transportation. Data loggers or temperature-monitoring devices are employed to track and verify that the cold chain has been maintained throughout the journey.

At the regional distribution hubs, the vaccines are stored in specialized cold rooms or refrigerators that are equipped with redundant cooling systems to avoid any temperature excursions. The regional hubs act as intermediate storage points before the vaccines are redistributed to local healthcare facilities, such as hospitals, clinics, and pharmacies.

The vaccines are transported from regional hubs to the last mile destinations, which include healthcare facilities and pharmacies. During this final stage, maintaining the cold chain becomes even more challenging, as the vaccines may be subject to varying environmental conditions and transportation delays. To minimize risks, temperature-controlled shipping boxes or containers are utilized. Additionally, training is provided to the healthcare providers on proper vaccine storage and handling.

At the healthcare facilities, healthcare professionals are responsible for administering the vaccines to patients. To ensure optimal efficacy, the vaccines must be stored in the designated temperature range until the moment of administration. Once the vaccines are reconstituted or drawn into syringes, they must be used promptly to avoid wastage.

Throughout the entire cold supply chain, close monitoring and quality assurance are crucial. Data loggers and temperature-monitoring devices record temperature data at different stages, allowing for real-time tracking and identification of any temperature excursions. Any deviations from the acceptable temperature range trigger immediate investigations to prevent product damage.

The cold supply chain for temperature-sensitive pharmaceutical products, drugs, or vaccines, involves multiple stages to maintain product integrity and efficacy. From manufacturing and packaging to last-mile distribution and vaccine administration, strict temperature control, monitoring, and quality assurance measures are essential to safeguard public health and ensure the successful delivery of life-saving medications to patients. Failure at any stage of the cold supply chain can have significant consequences, highlighting the critical importance of a well-orchestrated and closely monitored cold chain management system.

4.1.2 Stages of the Cold Supply Chain in the Case of Meat.

The cold supply chain begins with the slaughtering and processing of animals in meat production facilities. After slaughter, the meat undergoes initial processing, such as cleaning, cutting, and deboning. At this stage, proper handling and temperature control are crucial to prevent microbial contamination and ensure the quality of the meat. Meat processing plants must adhere to strict hygiene standards and implement Hazard Analysis and Critical Control Points (HACCP) plans to identify and control potential risks.

Once processed, the meat is transported to refrigerated storage facilities to maintain its freshness and prevent bacterial growth. The storage temperature is carefully regulated to keep the meat within safe limits, typically between 0°C to 4°C for beef, pork, and lamb, and -1°C to 2°C for poultry. Proper packaging is essential to minimize exposure to air and contaminants. Vacuum sealing and modified atmosphere packaging (MAP) are common techniques used to extend the shelf life of meat during storage and transportation.

Transportation plays a pivotal role in the cold supply chain. Meat products must be transported in refrigerated vehicles or containers to preserve their quality and prevent spoilage. The temperature in these vehicles is continuously monitored, and records are kept ensuring compliance with safety standards. Maintaining the cold chain during transportation is challenging, especially during long distances or when crossing international borders. Ensuring a seamless transition between different modes of transportation (e.g., trucks, ships, and airplanes) requires efficient coordination and communication.

At the distribution stage, the meat products are delivered to retailers, wholesalers, or foodservice establishments. Warehouses act as intermediate storage points, where meat may be temporarily kept before reaching its final destination. Maintaining the cold chain integrity at this stage is critical, and warehouses must have adequate refrigeration facilities and follow proper inventory rotation to prevent product spoilage.

Once the meat reaches retail stores, it is displayed in refrigerated sections to ensure customer safety and product quality. Retailers must handle the meat with care, adhering to the first-in, first-out (FIFO) principle to minimize waste and maintain freshness. Regular cleaning and sanitation of display cases are essential to prevent cross-contamination and ensure compliance with health regulations.

After purchase, consumers are responsible for maintaining the cold chain until consumption. Educating consumers about proper storage, handling, and cooking practices is crucial to prevent foodborne illnesses and preserve the quality of the meat.

Throughout the cold supply chain, several challenges may arise, such as temperature fluctuations, equipment malfunctions, and human errors. To mitigate these challenges, the following best practices should be adopted. Implementing robust quality management systems, such as HACCP, to identify and control potential hazards. Using temperature monitoring systems to ensure consistent temperature control at all stages. Conduct regular maintenance and calibration of refrigeration equipment and transportation vehicles. Train employees and stakeholders on proper handling and safety protocols. Maintain accurate and transparent documentation of temperature records, product information, and transportation details.

The cold supply chain for meat is a complex and vital process that demands meticulous planning, coordination, and adherence to industry standards. From the initial processing to consumer handling, each stage plays a crucial role in maintaining the quality, safety, and freshness of meat products. By adopting best practices and overcoming challenges, stakeholders in the cold supply chain can ensure that consumers receive safe and high-quality meat products on their tables.

4.2 ADVANTAGES OF TECHNOLOGICAL SYSTEMS

Technological systems (TS) offer numerous advantages in various aspects of our lives. It is important to mention that TS play a crucial role in maintaining the efficiency and effectiveness of the cold supply chain.

One of the main advantages is that TS enable real-time temperature monitoring throughout the chain. Temperature sensors and data loggers are used to track and record temperature variations at various stages, such as during storage, transportation, and distribution. This ensures that products are maintained within the required temperature range and helps identify any temperature excursions that could compromise product quality. (F. Li & Chen, 2011)

Furthermore, remote monitoring systems allow for continuous monitoring of temperature and other environmental conditions in storage facilities, warehouses, and transportation vehicles. This enables quick identification of any issues or deviations, allowing corrective actions to be taken promptly. (Heising et al., 2014)

Additionally, TS collect and analyze data from temperature monitoring devices and supply chain management software. By applying data analytics, patterns and trends can be identified, enabling predictive maintenance and proactive measures to prevent temperature fluctuations, equipment failures, and product spoilage.

Another benefit of TS is that advanced tracking technologies, such as RFID (Radio-Frequency Identification) and barcodes, coupled with inventory management systems, provide end-to-end traceability in the cold supply chain. This allows stakeholders to track the movement of products, monitor their temperature history, and verify their authenticity. It enhances transparency, reduces the risk of counterfeiting, and helps identify potential sources of contamination or quality issues. (Martin Backman, n.d.)

Technological systems enable automated inventory management in cold storage facilities and distribution centers. This includes inventory tracking, rotation management, and automated order fulfillment systems. By automating these processes, the risk of errors and delays is minimized, ensuring accurate and timely delivery of temperature-sensitive products. Technological advancements have led to the development of improved packaging materials and insulation technologies for temperature-sensitive products. These materials help maintain the required temperature conditions during transportation, reducing the risk of spoilage or damage. (Ndukwu, 2017a)

Last but not least is the meaning of transportation optimization**.** TS aid in optimizing transportation routes, scheduling, and load planning. Route optimization software considers factors such as temperature requirements, distance, traffic conditions, and delivery deadlines to ensure the most efficient and timely transport of perishable goods. This minimizes transit time, reduces costs, and enhances overall supply chain efficiency. (Ruiz-Garcia et al., 2010b)

Overall, Technological Systems play a vital role in ensuring the integrity and efficiency of the cold supply chain. They provide new methods of communication, new industries, and access to a large number of independent suppliers. It is observed that TS increase participation in organizational processes, reduce stereotypical classifications. Real-time monitoring, data analysis, automation, traceability, and optimization capabilities contributing to the safe and reliable transportation of temperature-sensitive products while maintaining their quality and efficacy. (Fuertes et al., 2016)

4.3 DISADVANTAGES OF TECHNOLOGICAL SYSTEMS

Despite the advantages of contributing methodically and organizationally to the cold chain, there are also disadvantages that we should mention.

Implementing and maintaining a technological cold supply chain system can be expensive. The initial investment in infrastructure, equipment, and software can be significant. Furthermore, there are ongoing costs associated with maintenance, upgrades, and training. Cold supply chain systems often are complex. TS involve intricate processes and require specialized knowledge to operate effectively. Managing the technology, maintaining proper temperature control, and ensuring compatibility across various systems can be challenging. (Serdarasan & Tanyas, 2013)

Another disadvantage of TS is that cold supply chain technology is prone to technical failures. Equipment malfunctions; software glitches, power outages, or network disruptions can lead to interruptions in the cold chain and compromise the quality and safety of perishable goods. We cannot forget of course the dependency on electricity and infrastructure; TS rely heavily on a consistent and reliable supply of electricity. In some regions, power outages or inadequate infrastructure can disrupt the cold chain, leading to spoilage or waste of temperature-sensitive products.

Operating and managing a technological cold supply chain system requires specialized skills and knowledge. Training staff to handle the technology and troubleshooting issues can be time-consuming and costly.

Adding to the above TS involve the collection, storage, and transfer of sensitive data related to temperature monitoring, product quality, and location tracking. Ensuring robust data security measures and safeguarding against potential cyber threats is crucial to maintain the integrity of the system. (Luo et al., 2016)

Some technological systems used in the cold supply chain, such as refrigeration equipment, can have a significant environmental impact. They consume substantial amounts of energy and may require the use of harmful refrigerants that contribute to ozone depletion or climate change. In certain regions or developing countries with limited infrastructure or technological capabilities, implementing, and maintaining a sophisticated cold supply chain system can be challenging. This limitation can hinder the distribution of perishable goods and impact food security. (Robertson et al., 2017)

It is important to note that while these disadvantages exist, many of them can be mitigated with proper planning, investment, and continuous improvement in technological advancements.

4.4 WAYS OF DEVELOPMENS OF TECHNOLOGICAL SYSTEMS

The development of technological systems in the cold supply chain is crucial for ensuring the safe and efficient transportation and storage of temperature-sensitive products. There are several ways to drive the development of technological systems.

Investing in Research and Development (R&D) involves conducting scientific research, exploring new technologies, and developing innovative solutions. R&D efforts can be driven by governments, academic institutions, private companies, or collaborative partnerships.

The partnerships and alliances among diverse stakeholders, such as government agencies, private companies, research institutions, and non-profit organizations, have the potential to expedite the development of technological systems. Through the sharing of expertise, resources, and knowledge, collaborations can foster breakthrough innovations and establish more resilient and efficient systems. This collective effort paves the way for advancements that can have far-reaching impacts across various domains.

TS should undergo continuous improvement to address limitations, enhance functionality, and adapt to changing needs. Collecting user feedback, monitoring performance metrics, and incorporating new technologies or methodologies are essential for TS.

Governments, venture capitalists, and organizations need to allocate financial resources, to Investment and Funding support research, infrastructure development, and the implementation of technological solutions.

Developing industry standards and regulations helps ensure interoperability, safety, and reliability of technological systems. Standards enable different components and systems to work together seamlessly, while regulations provide guidelines for compliance and ensure the protection of users and the environment.

Investing in training programs and educational initiatives helps build a skilled workforce capable of developing and operating technological systems. Providing learning opportunities, certifications, and professional development courses enable individuals to acquire the necessary knowledge and skills to drive system development.

The design of TS should prioritize the end-users. By thoroughly understanding user needs, conducting user research, and incorporating user feedback during the development process ensures that the system aligns with the requirements and expectations of its intended users. This user-centric approach enhances the usability and effectiveness of the system, resulting in a more satisfactory and impactful user experience.

Adopting cutting-edge technologies, such as artificial intelligence, machine learning, Internet of Things (IoT), and Blockchain, can drive technological system development. Leveraging these emerging technologies holds the potential to enhance efficiency, automation, data analytics, and decision-making within the system. By harnessing the power of these innovative tools, organizations can unlock new levels of productivity, accuracy, and strategic insights, leading to substantial improvements in overall system performance.

Promoting energy efficiency, minimizing environmental footprint, and considering social and ethical aspects contribute to sustainable and responsible system development. By prioritizing these aspects, organizations can ensure that their systems are designed and implemented in a manner that minimizes energy consumption, reduces adverse environmental effects, and upholds social and ethical standards. Such responsible practices not only align with global sustainability goals but also enhance the long-term viability and positive impact of the systems on both society and the environment.

Scalability and Adaptability are characteristics that systems should possess. Systems should be able to handle increased demands, accommodate the integration of new technologies, and be flexible enough to adapt to evolving requirements and dynamic environments. By embracing scalability, systems can effectively handle increased workloads and user demands. Additionally, adaptability enables them to seamlessly incorporate emerging technologies and swiftly adjust to changing circumstances, ensuring their longevity and relevance in the face of evolving needs and advancements.

Through the integration of these approaches while taking into account specific contexts and goals, technological system development can be driven forward, leading to more effective, efficient, and impactful solutions. By combining diverse methodologies, considering unique circumstances, and aligning with specific goals, organizations can drive innovation and achieve meaningful outcomes in the development of technological systems. This holistic approach ensures that the solutions address real-world challenges and deliver tangible benefits to users and stakeholders.

4.5 NECESSITY FOR TECHNOLOGICAL SYSTEMS

In today's interconnected and globalized world, the efficient management of temperature-sensitive products throughout the cold chain is of great importance. To ensure the integrity, safety, and quality of perishable products, the implementation of robust technological systems is essential. Technological advancements and innovative solutions have a vital role in optimizing the cold chain operations, improving traceability, enhancing monitoring capabilities, and minimizing the risks associated with temperature excursions.

More specifically in the cold supply chain, technological systems automate processes and enhance productivity at all stages of the chain. They can perform tasks more quickly, accurately, and tirelessly than humans, resulting in increased efficiency. They can also provide instant access to vast amounts of information and enable communication across all distances. They also provide the tools and platforms for individuals and organizations to create, test and refine new ideas to make the chain run more smoothly.

One of the most important elements that make technological systems highly necessary is their assistance in complex problem-solving and decision-making processes in the cold supply chain. They can analyze large data sets, simulate scenarios and provide insights to support informed choices and solutions. At the same time, however, they also contribute to strengthening safety and security measures.

Technological systems drive economic growth and promote global connectivity. They allow businesses to reach wider markets, facilitate international trade and create new opportunities for entrepreneurship. Technological developments have led to the emergence of digital economies, e-commerce platforms and online marketplaces, expanding financial participation and transforming industries.

By harnessing the power of technological systems specifically tailored for the cold chain, businesses can address challenges, meet regulatory requirements, and ensure the safe and efficient delivery of temperature-sensitive products to end consumers. The necessity of technological systems in the cold chain cannot be overstated, as they enable precision, reliability, and sustainability, ultimately safeguarding public health and fostering economic growth in the process.

4.6 CHALLENGES OF TECHNOLOGICAL SYSTEMS

The main challenges of advanced technological systems in the cold chain, refers to the management and transportation of temperature-sensitive goods. The management of the cold chain is difficult as it faces a variety of challenges and problems that need immediate resolution so that the product reaches safely to the final consumer.

The first challenge of a company that uses advanced technological systems is the initial cost. Implementing advanced technological systems in the cold chain, such as sophisticated temperature monitoring devices, automated storage systems, and specialized transportation vehicles, can be expensive. The initial investment required for these systems may pose a financial challenge for smaller businesses or developing regions. (Ndraha et al., 2018)

The second challenge concerns the technical expertise. Advanced technological systems often require specialized knowledge and expertise to operate and maintain effectively. Training staff to handle and solve problems these complex systems can be time-consuming and expensive. Ensuring a skilled workforce with adequate technical know-how is crucial for the successful implementation of advanced technology in the cold chain. (Ruiz-Garcia & Lunadei, 2011)

The third challenge refers to systems integration. The cold chain involves various stages, including storage, transportation, and distribution. Integrating different advanced technological systems across these stages can be challenging. Ensuring seamless data flow, interoperability, and synchronization between different systems and stakeholders can be complex and require careful planning and coordination.

The fourth challenge is about data management and analysis. Advanced technological systems generate vast amounts of data related to temperature, humidity, location, and other parameters. Effectively managing and analyzing this data to monitor and maintain the quality and integrity of the cold chain can be overwhelming. Robust data management systems and analytical capabilities are essential to derive meaningful insights and take corrective actions in real-time.

The fifth challenge is related with system's reliability and redundancy. Advanced technology systems are prone to technical malfunctions, hardware failures or power outages. Ensuring system reliability and redundancy becomes crucial to minimize disruptions in the cold chain. Implementing backup systems, redundant equipment, and contingency plans are necessary to mitigate risks and maintain product integrity.

The sixth challenge focus on cyber security risks. With the increasing connectivity of advanced technological systems, the cold chain becomes vulnerable to cybersecurity threats. Malicious actors may target the cold chain infrastructure, compromising the integrity of data, disrupting operations, or gaining unauthorized access to sensitive information. Implementing robust cybersecurity measures, including encryption, access controls, and regular security audits, is crucial to protect the cold chain from potential cyber threats. (Ndraha et al., 2018)

Addressing these challenges requires a comprehensive approach involving careful planning, investment in training and expertise, robust data management systems, reliable infrastructure, and proactive cybersecurity measures. Overcoming these challenges will enable the cold chain industry to leverage the benefits of advanced technological systems and ensure the safe and efficient transportation of temperature-sensitive products.

An additional aspect worth mentioning when considering the necessity and the challenges of technological systems is the sustainability of the cold supply chain, which we will explore below in more detail.

4.7 SUSTAINABLE COLD SUPPLY CHAIN

Supply Chain is the link that connects the products and services produced by an organization or business with the inputs (materials, energy, etc.). It is characterized as Sustainable Supply Chain to the extent that costs and risks related to environmental and social impacts in the production and supply of inputs are taken into account. In other words, as long as the sustainable performance of suppliers is considered, such a performance is a prerequisite for sustainable/sustainable products and, by extension, for a sustainable organization.

The sustainable cold chain refers to the transportation and storage of temperature-sensitive goods, such as food, vaccines, and pharmaceuticals, while minimizing environmental impact and optimizing energy efficiency. It aims to ensure the integrity and safety of these products throughout the supply chain while reducing greenhouse gas emissions, resource consumption, and waste generation.

A Sustainable Cold Supply Chain involves the adoption of energy-efficient refrigeration and cooling equipment, which effectively minimizes electricity consumption. The integration of renewable energy sources such as solar, wind or geothermal energy to power the cold chain infrastructure becomes essential. This strategic shift reduces dependence on fossil fuels, curbing greenhouse gas emissions, and promoting environmental sustainability. (Mol, 2015)

Design and construction of refrigeration facilities and transport vehicles with sustainable materials and technologies is required. This includes energy-efficient building designs, LED lighting and low-emission refrigerants. Optimizing transport routes, vehicle capacity and vehicle use is moving towards reducing fuel consumption and emissions.

By implementing these strategies, the cold chain industry can effectively diminish its environmental impact, conserve valuable resources, and contribute to a more sustainable future. This commitment to sustainability not only demonstrates responsible stewardship but also ensures the long-term viability and resilience of the cold chain sector in the face of evolving environmental challenges.

5. CONCLUSION

In today's modern, interconnected, and globalized world, the effective and efficient management of cold supply chains have a great impact in facilitating international trade. All the functions and parts of the cold chains need to be well organized, well-structured, smoothly functioned, supported by well-trained and competent employees and advanced technological systems. It is imperative for cold chains to stay abreast of market to continuously evolve and improve their operations.

All staff members and every part of the cold chain need to adhere to hygiene guidelines, laws, legislation, and temperature standards. It is essential to regularly monitor and verify the quality of the products, ensuring they are stored at the appropriate and consistent temperatures. The health of consumers depends on the consistency, safety, and quality of the temperature-sensitive products that they consume.

Every cold chain needs to monitor and follow new market trends and developments in organization, management, training, and new technological systems. In all parts of the cold chain, technological systems are constantly changing, evolving, and setting new trends. These developments are driven by the pursuit of improvement, delivering rapid service at minimal expenses, and minimizing the environmental impact. The objective is to leverage technology to achieve efficiency, cost-effectiveness, and sustainability throughout the entire cold chain process.

The modernization of technological systems presents both advantages and disadvantages. On the one hand, the rapid rates of technological development facilitate the improvement of cold chains and promote competitiveness. On the other hand, the frequent change of technological systems is costly, requires continuous training of employees, rapid adaptation, evaluation of methods that may need development and improvement, as well as efficient assimilation of all the information that is needed in the relevant time.

At the same time, there are some social and environmental factors that cold chains need to be faced with. The report is related with the pandemic of Covid-19 which in recent years has affected all sectors, the safe storage and distribution of medicines, vaccines, food and other temperature-sensitive necessary products. Another factor that affects cold chains is weather and environmental conditions. With the constantly increased ambient temperature that creates heatwaves and favors fires, the demand for perishable products grow and the obligation of the cold chains for greater efficiency, faster service, and sustainability becomes more difficult and more demanding.

However, the positive impacts of the adoption and application of evolving technological systems throughout the cold chains offer significant competitive advantages, in addition to enhancing overall efficiency. These advancements enable improved product quality, streamlined operations, enhanced traceability, and better responsiveness to customer demands. Ultimately, the effective integration of these evolving technologies provides a substantial edge in the competitive landscape, driving growth and success within the cold chain industry.

Therefore, establishing a well-structured cold chain that constantly monitors and evolves according to market trends and emerging technological systems is pivotal. Such a chain not only operates with high efficiency but also fosters competitiveness, serving as a fundamental pillar for a thriving business. Additionally, it ensures the fulfillment of customers' requirements, leading to their satisfaction and loyalty. By proactively embracing advancements, staying agile, and aligning with customer needs, businesses can establish a strong foundation for success and forge enduring relationships with their customers.

In conclusion, an effective cold chain management system is essential for preserving the quality and safety of temperature-sensitive products during storage and distribution. By leveraging advanced technologies, such as temperature monitoring systems, cold storage management software, traceability solutions, predictive analytics, and quality management systems, organizations can overcome challenges and ensure a seamless and efficient cold chain, ultimately benefiting consumers and industries that depend on transporting perishable goods.

Evaluating all of the above, it is observed that as technology evolves human work changes and decreases. Advanced technological systems and work automation replace human jobs and lead on the one hand to a greater benefit in production, and on the other hand the management of emergency situations that occur in everyday life, critical human ability and communication cannot be easily replaced. Undoubtedly, the question of the social position of the cold supply chain is raised.

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