International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 09 | September - 2022 Impact Factor: 7.185 ISSN: 2582-3930

Cold Storage Optimization for Pharmaceuticals and Produce: A Systematic Literature Review

ANISHA RAO [a], SHIVANSH ARORA [b], SHUBH GUPTA [c], SIDDHARTH SAGAR [d], SIDHANT KOTHRIWAL [e], SIYA SANSARE [f]

a) SYBBA Student, ASMSOC NMIMS University, Mumbai)
b) SYBBA Student, ASMSOC NMIMS University, Mumbai)
c) SYBBA Student, ASMSOC NMIMS University, Mumbai)
d) SYBBA Student, ASMSOC NMIMS University, Mumbai)
e) SYBBA Student, ASMSOC NMIMS University, Mumbai)
f) SYBBA Student, ASMSOC NMIMS University, Mumbai)

Abstract

This research paper is a Systematic Literature Review on the various methods of optimization of the Cold Storage Chain (CSC). A review of articles from 2000-2022 has been conducted. This paper focuses on two applications of cold-chain namely pharmaceuticals and produce. The entire range of cold chain evolution along with recent developments like the Internet of Things and blockchain technology have been reviewed. Various techniques studied in the literature are CPLEX, Bayesian network, and fuzzy MCDM methods. Newer concepts like economic benefit along with ecological benefit in terms of minimizing the carbon footprint have been introduced. From the review, it is concluded that optimization of the cold chain can help deliver life-saving healthcare to remote rural areas and greatly reduce food waste.

Keywords: Cold-Supply-chain, Cold-storage, Cold chain, Optimization of Cold-chain, Vaccine supply chain, Agricultural produce supply chain, Supply chain of pharmaceutical products.

1. Introduction

Cold storage is a facility that is meant to keep fresh or perishable items and items that require a certain level of temperature (generally low) and atmosphere for optimum effects on its utilization. Furthermore, the cold chain concept describes the preservation and dissemination of vaccines since the period of production to their administration. (Ojo et al., 2019) Equipment transport and storage, trained personnel, and efficient management procedures are three major components of the cold chain system. To guarantee the safe and efficient administration of the vaccines, each of the three elements must be organized and updated at each stop along the way. (Ojo et al., 2019) To maintain, handle, and deliver these life-saving goods requires a series of meticulously timed actions in temperature-controlled settings. We refer to this as a cold chain. The mechanism of the cold chain is widely used across the market for various products such as meat, fish, agricultural products, injections, vaccines, and other pharmaceuticals.

Vaccines are pharmaceutical-sensitive goods that gradually turn less active over some time and hence it is necessary to be kept within narrow temperature ranges from when they are manufactured to when they are consumed(Hanson et al., 2017b). Vaccines are responsible for the elimination of many life-threatening diseases such as polio, smallpox, rinderpest, etc.(Hanson et al., 2017a) Some of the major problems in the maintenance, handling, and delivery of vaccines are the unavailability of mechanisms to supervise the temperature of thermosensitive vaccines, the Scarcity of optimum equipment to ensure appropriate transportation of vaccines, and a lack of adequately educated and experienced workers to handle aforementioned vaccines. (Lloyd & Cheyne, 2017)

The entire life cycle of vaccines is made up of several links in a vast network of various equipment such as freezers, refrigerators, cold boxes, and transporters that maintain vaccines at precisely the proper temperature at all times. (Ojo et al., 2019) The optimum safe range for the majority of the vaccines is 2-8°C (35-46°F). Although excessive heat is typically the main concern, freezing was noted as an issue in an astounding 75–100% of vaccination chains. (Comes et al., 2018) Vaccines with active ingredients will be ruined automatically if frozen, however, they normally have better heat stability. At temperatures above 8°C however, the efficiency of a vaccine reduces and may prove to be damaging if not cooled and managed with expertise. (Comes et al., 2018).

There are systems in place and equipment in place to aid the storage. Some of the most active equipment required for Vaccine storage and transportation are main refrigerators as well as off-grid refrigerators. Mains refrigerators are cooled down with the help of various compressors that function by the power generated by the electric grid. Off-grid refrigerators include two major types i.e absorption refrigerators utilizing the power produced by the combustion of liquid petroleum gas or kerosene, and solar-powered adsorption refrigerators (Comes et al., 2018)

A problem created by refrigerators is storage at too cold temperatures. The rate of temperatures under the 'too cold' limit in studies that monitored temperatures during transport depicts that the shipments in developing nations were 35.3%. Shipments exposed to 'too cold' temperatures in developed countries were 16.7%. (Hanson et al., 2017b)

As per the constant increase in the economic growth of society, people have a higher pursuit of the standard of daily life, especially in the facet of the refreshing ability of food, which is eventually attracting increasing and increasing attention from society.
As the republic of China issued the "logistics industry adjustment and revitalization plan" in the year 2009, cold chain logistics has been of high value by various industries, which promotes the sustainable, non-toxic, and quick development of cold chainlogistics. Still, compared with the development of cold chain logistics in various other countries, China is still in the initial stages of cold chain logistics development, and the cost of distribution connects accounts for a high percentage of the aggregate cost of cold chain logistics, which is not something to be considered as nurturing to the healthy development of cold chain logistics. (Dou et al., 2020).

As per one of the papers, we reviewed that is (Cheng & Zhai, 2018), Energy storage is essential for the usage of reusable and renewable energy resources, which are majorly intermediate or periodical, because it plays a vital role in removing the discrepancy between energy demand and supply. Within this context, thermal energy storage (TES) is a system of storage that stores energy in the form of heat,and is widely employed in various areas, like solar thermal energy usage, waste heat recovery, and most important the cold storage. Further, There are two types of TES systems: sensible thermal energy storage (STES) which holds power in the medium of sensible thermal and latent thermal energy storage (LTES) which stores energy mainly in the form of latent or non-existent heat. Compared to the STES, LTES is taken to be more efficient in terms of energy consumption and compact due to the high storage density and close-to-isothermal behavior during the charge or discharge process of the phase change materials (Cheng & Zhai, 2018)
Cold storage is important for medicines for various diseases such as cancer, leukemia etc..Cancer has consistently been a life threatening disease for many years. To eliminate the effect and spread of cancer, one significant way is to use medicines and vaccines, to prevent cancer. However, medicines are important commodities, and their logistical linkages are very different from general logistics. Any improper handling in the process of cold storage logistics of medicines can and will have a significant effect on the integrity of medicines and endanger the safety of drug use. This makes the selection of a safe and effective drug cold chain logistics supplier for major pharmaceutical enterprises a key to making sure that the refrigerated medicines are safe(Wen et al., 2019)

To keep perishable food within the proper temperature and humidity range from the moment of collection (harvest, Slaughter, fishing, etc.) till the moment of consumption, there should not exist any gaps Specifically,

deviations in temperature or/and humidity over the required specifications and if these are not met the entire cold chain are rendered worthless.
To prevent food loss and waste, it is essential to maintain Cold Chain Logistics (CCL) integrity, and therefore the requirement arises for various links in CCL and data sharing and transparency among the concerned business and stakeholders to be developed in a coordinated manner.

The performance of European cold stores has never been analyzed exhaustively and there is little data to contrast their exhibition and different stores around the world. With the Government's focus to diminish energy and lessen emanations of nursery gasses the need to benchmark and comprehend possible energy and GHG decreases is incredibly intriguing to end clients. To empower end clients to work on the presentation of their virus stores a task called 'Further developing Cold stockpiling Hardware in Europe' (ICE-E) was created with 8 participants from across Europe. The underlying point of the undertaking was to gather information to benchmark the exhibition of cold stores in Europe. Likewise, the venture will attempt to defeat reservations about the take-up of new advancements inside the cool stockpiling area. This will be accomplished through a blend of information-based data bundles, numerical models, and schooling projects to empower cold store administrators to go with informed choices on gear and to choose and distinguish cost-effective compensations for their organizations. In extra non-specialized obstructions forestalling take-up of new advancements will likewise be analyzed. Demonstrated advances are frequently not taken up because of more extensive social, political, financial, and hierarchical context-oriented issues. To beat these issues the ICE-E venture will likewise attempt to make change and consciousness of the issues and a feeling of an organization that can start significant change. As a feature of the ICE-E project a web-based study was created and information was gathered to decide energy utilization in various virus store types, sizes, and setups. Primer outcomes from the review are introduced in this paper and contrasted with information from past studies. Further information will be gathered over the following 14 months and eventually the investigation of the outcomes will prompt a benchmark/marking framework for cold store administrators so they can look at execution against other clients inside the are (Abedi & Zhu, 2017) , (Evans et al., 2011).

According to the report of The United Nations, Food and Organisation (FAO 20150) spoilage of food mainly occurs in the post-harvest circulation stage and is caused by inappropriate weak cold chain, climate control, and post-harvest handling, particularly in developing countries as a result of inadequate infrastructure and lack of practical handling skills of these perishable goods (Goedhals-Gerber & Khumalo, 2020). As a result, proper and consistent temperature management of the market from the process of harvesting, killing, or fishing is crucial to keep food's original organoleptic characteristics intact maintain food safety, limit waste, lower the risk of contracting food-borne illnesses, and enhance the cold chain's overall economic performance. “Optimizing the CCL of fresh produce has thus become the main focus of researchers in the field, and three main research directions have been developed (i) improve the efficiency of CCL (e.g., cooling rate, cooling uniformity and stability, and packaging design) (Duan et al., 2020; Han, Ruiz-Garcia, et al., 2018),: (ii) ensure the integrity of

the cold chain and its precise control (e.g., dynamic monitoring and shelf-life prediction) (Bouzembrak et al., 2019), and (iii) promote the ecological and sustainable development of the cold chain (e.g., reduce energy consumption, cost, and environmental impact) (Wu et al., 2019). A variety of promising technologies (e.g., the Internet of Things, cloud computing, big data, blockchain, AI) is available on the market today to improve the integrated service level of CCL, which is also a major direction of future innovation and research direction for the transformation and upgrading of the CCL to digital, intelligent, efficient, and ecological systems."(Han et al., 2021)With the quick development of the economy, people's living standards are improving day by day, and the necessities for food quality are reaching new heights, mainly the freshness and nutritional value of fresh agricultural products.

SUSTAINABILITY

In a cold supply chain, we need not only need efficiency to cut energy costs but also so as reduce the effect of the generation of power in greenhouse emissions and climate change that's where arises the need of pursuing sustainable supply chain management(SSCM) in the food industry, which will not only lead to a positive impact on the natural environment but also gaining competitive advantage by long term economic benefits," as required by the triple bottom line concept (Elkington 1998) and recently proposed in the unified definition of SSCM by Hassini, Surti, and Searcy (2012) and Ahi and Searcy (2013). The purchase of energy such as heat energy etc is one of the major indicators as suggested by Yakovleva, Sarkis, and Sloan (2012) to evaluate supply chains' sustainability performance. Therefore, making cold chains energy efficient shall be the initial and most important goal towards their whole sustainability.(greening the food supply,,,,)(Meneghetti & Monti, 2015), (Abedi & Zhu, 2017) , (Evans et al., 2011).

HISTORY

The number of cold storage warehouses has been increasing exponentially in the past few years. According to a study conducted in 2010 which mainly collected data from India and USA, the total number of refrigerated warehouses is estimated to be 458 million cubic meters of which 192 million cubic meters were added in 2008-2009(Salin, 2010). A rapid growth in these numbers can also be seen in China (14% compound annual growth), which is comparatively moderate to India.

The period of 2008-2010 was seen as a time of remarkable growth in the cold storage industry especially for India as it grew at an unbelievable rate of 138% compounded annually. In countries like Peru, Guatemala, and Chile, the number of cold storage warehouses nearly doubled. (Yahia, n.d.).

REQUIREMENTS AND ADVANCEMENTS IN COLD STORAGE

World health organization (WHO) established guidelines according to which all vaccines except the polio vaccine have to be kept at 2-8°C for in-country distribution. However, many poorly regulated cold chains tend to overlook these small details which may have major consequences like accidental freezing.(Matthias et al., 2007).

In 2010, RFID technologies were said to improve the performance of the cold chain. The RFID monitoring devices could be placed in the vehicles that are responsible for transporting perishable products. This would help in monitoring the current environment of the goods which would lead to more efficient goods management and lesser rejected batches(Sustainable Radio Frequency Identification Solutions., n.d.).

New technology is known as the time-temperature integrator (TTI) which helps in revealing a rise in temperature and the storage conditions of the product. This helps in getting to know the real-time information of the product and can be used in determining the remaining shelf life of the product which in return can be used to increase the supply chain performance.(Sahin et al., 2007).

A big concern that arises when one thinks of cold storage optimization is saving costs. One of the few methods includes saving energy. Various new technologies have been introduced to reduce energy usage, one of them being variable frequency drive (VFD) which applies to evaporator fans. This enables the motor of the fan to change its speed according to the product's current condition. If the product has reached the target temperature, the VFD will automatically reduce the fan speed by 50% without sacrificing temperature control. This collectively leads to an 86% drop in energy usage and a significant reduction in heat and load on the compressor which overall results in considerable energy savings. (“Innovation in Cold Storage Technologies,” 2006).

Improving the packaging of the produce can also prove to be an efficient way of tackling the technological, economic, and developmental challenges faced. The reasons for this are the high impact of packaging on product quality and shelf life, the relatively low cost of packaging, and the ease of changing its design (Defraeye et al., 2014; Gali, etar, & Kurek, 2011). Packaging is also one of the few flexible elements in the cold chain that is not overly subject to regulations, standardization, and legislation.(Defraeye et al., 2015)

A Bayesian network is a probabilistic network of events that displays casual dependencies (Castillo et al., 1997). As numeric values can be attached to the nodes, a Bayesian network can be used for deriving

the hypothesis (Ordónez-Galán et al., 2009). The model depicts causes-effects in a relationship; hence, it can also be used as an inferential model (Malakmohammadi et al., 2009).

The use of a Bayesian network can also have several advantages when analyzing a cold chain. This model allows for reasoning even when incomplete information is provided Given the complexities, It is very common in the operation of a cold chain to have incomplete information of a few of the variables. (Sharma & Pai, 2015)(Zhong et al., 2017)

2. Literature Review

In this paper, we use the World Health Organization's (WHOpriority) categories to organize the literature on vaccine logistics (World Health Organization & PATH, 2011). We can assess the current state of research on the vaccine supply chain using priority areas and also spot interesting areas that could be further investigated to develop a flexible and reliable vaccine supply chain. We searched for published reports using the search term ‘‘vaccine” and “produce” with different combinations of ‘‘supply chain,” ‘‘optimisation,” and ‘‘cold chain equipment” and searched on the following websites using the term ‘‘cold chain”: GoogleScholar, Sci. hub, EBSCO HOST, Science Direct and Z library

In terms of operations, the importance of food distribution management has become more apparent, especially when taken in the context of high expectations of consumers, delivery time windows, and enhancement of profit for distributors. Moreover, the vehicle optimization problem which has simultaneous pickup and delivery in Cold-Storage Chains has been the subject of focus from companies aiming at reducing logistics and distribution costs whilst providing safe food products. (al Theeb et al., 2020)

Since 2010, many fresh technologies have been introduced to the market for cold chain equipment used in vaccinations. These have been commercialized in large part thanks to the Performance, Quality, and Safety (PQS) Immunization Devices Programme of the World Health Organization (WHO). (Robertson et al., 2017)

The technologies now covered by WHO PQS include vaccine refrigerators and freezers, cold boxes, vaccine carriers, coolant packs, temperature monitors, and vial-level time and temperature indicators. SDD refrigerators, vaccine cold boxes, and carriers with freeze-prevention features, large-capacity vaccine cold boxes, long-term storage cold boxes, temperature-threshold indicators, 30-day temperature recorders, and programmable remote temperature and event monitoring systems are just a few of the technologies for which new specifications have been developed since 2006. (Robertson et al., 2017)

2.1 Development of Cold Storage Chain (CSC)

In the last five years, the 1976 term "vaccine cold-chain" has been replaced with "supply chain." The name suggests that the approach of solely distributing and storing vaccinations is changing in favour of one that includes both vaccines and medications. Three elements explain this transition towards a more integrated strategy..(Lloyd & Cheyne, 2017)

In 2007, a survey of studies looking at vaccine cold chain temperatures between 1985 and 2006 detailed that of all parts shipped, antibodies in 75-100% of shipments observed vaccines have emerged at cryogenic temperatures. This 2007 review seems to have raised awareness about the risks of vaccine exposure to freezing temperatures in both developed and developing countries of varying climates. (Hanson et al., 2017) Over the last ten years, improvements in cold chain monitoring have been reported due to newer cold chain technology and more studies are implementing rigorous temperature monitoring techniques. (Hanson et al., 2017) Since 2007, the number of freeze-sensitive vaccines procured by the UNICEF Supply Division (SD) for countries' immunization programs increased by 50%. In 2015, freeze-sensitive vaccines procured through UNICEF SD totaled a value of USD 1.2 billion, highlighting the importance of monitoring vaccine exposure to ‘too cold’ temperatures. (Hanson et al., 2017)

2.2 Challenges faced by CSC

Cold storage management systems have several hurdles to cross, especially in terms of logistics. For example, India as the world’s largest vaccine maker requires a robust cold storage supply chain that it currently does not possess. Inefficient cold chain systems act as roadblocks to vaccine programs, costing upwards of $200 million yearly. (The Lancet, n.d.)

Some challenges faced by cold chain systems are poor infrastructure, need for better training of technicians, lack of standardization, insufficient capacity, lack of temperature control, and presence of multiple intermediaries (Ashok et al., 2017; Bhatnagar et al., 2018; Joshi et al., 2009; Lloyd & Cheyne, 2017b)However, the inadequacy of quality packaging, as well as that of market structure, are also important. (Yahia, n.d.)

Developing nations had to take into account that other factors such as power cuts and limited reach into rural areas narrowed down the choice of COVID vaccine. mRNA vaccines such as Moderna are stored at -20°C to remain stable thus requiring ultra-cold storage. In comparison, the AstraZeneca Vaccine can be stored at normal refrigeration temperatures of 2°C-8°C. (Sheikh et al., 2021)

2.3 Considerations for Produce

Except for a few items, most fruits and vegetables can be stored between 6 and 10 °C. Therefore, it's crucial to arrange them properly inside the cold room to maximize storage.

Depending on the type of product, how long it will be kept in storage, and whether it is packaged or unpackaged, the ideal storage conditions for a product are held in either short- or long-term storage. The majority of agricultural products should be stored at a temperature that is just above their freezing point, and it is crucial to maintain this

temperature fairly consistently to achieve good results because large temperature fluctuations and variations tend to promote early product deterioration. (Tashtoush, n.d.) Any modern energy-saving technology creation involves a thorough theoretical investigation of the necessary processes. Building mathematical models to represent these processes are the result of the investigations of such processes. (Tashtoush, n.d.)

Vegetables and fruits are frequently transported or stored together with products that produce and are susceptible to ethylene, potentially at temperatures that aren't ideal for that product. (Skog & Chu, n.d.) There could be ethylene damage and further deterioration as a result. We might anticipate that some ethylene-sensitive fruits and vegetables will last longer if the level of ethylene is reduced. Ozone generators are rapidly being promoted in the business as a remedy for this issue, although there isn't any proof to back up their claims. (Skog & Chu, n.d.) Eliminating ethylene from the air in a cold storage room by ozonizing it. (Skog & Chu, n.d.) If the liner is opened at the beginning of the shelf life period, the use of microperforated Xtend liners during cold storage of some vegetables eg. and sweet corn does not result in hypoxic fermentation. Furthermore, compared to cobs cold-stored in identical retail containers without the liner, those stored in nested packages tend to emit less ethanol and occasionally less CO2 during their shelf life. (Aharoni et al., 2000)

General suggestions for Strengthening and Adopting Cold Storage for Fresh Produce

1. Improve market infrastructures, building well-maintained roads and ample electricity supplies, as well as supply chain management. It should be encouraged to invest in off-grid zero or renewable green energy sources.

2. To avoid unnecessary food and energy loss, operators and processing workers must be adequately trained in how to use and maintain cold chain equipment safely and efficiently. However, other stakeholders, including farmers, transport firms, traders/distributors, processors, consumers, policymakers, financial institutions, and scholars should be trained in their respective areas of expertise, to take full advantage of cold storage.

3. Before being kept in cold storage, fruits and vegetables need to be sorted and graded. Only premium-grade products should be kept in storage since they offer a high return on investment when sold.

4 The introduction and maintenance of cold chains can be made much more feasible by reducing middlemen in food value chains in poor nations. The fragmentation of the value chain caused by the numerous stakeholders makes it difficult to create and finance the essential cold chain facilities and operate the cold chain efficiently.

5. The effectiveness of cold storage depends on adherence to the specified storage capacities. To ensure that chilled air may circulate freely and effectively cool the product, there must be ample space between stacked crates of produce. (Makule et al., 2022)

2.4 Methods of Analysis

Al Theeb et al.,2020 propose a three-phase approach to reduce costs and coordinate logistics. In the first phase, vehicles are categorized as transporting deep frozen products or refrigerated products based on capacity, availability of supplies, and requested demand. Next, a route is constructed taking into consideration the type of vehicle obtained in the previous phase. Finally, the model is solved by CPLEX to obtain an optimal solution.

Using production, transportation, storage, and sales as four main links, Zheng et al., 2021 evaluated CSC by constructing a Bayesian network to determine failures in the systems and found that equipment failure, weather conditions, and incorrect operation are the prominent causes of failure.

Several researchers(Alfian et al., 2020; Nosratabadi et al., 2020; Yadav et al., n.d.) have studied the application of the Internet of Things(IoT) and blockchain technology to improve the logistical challenges of CSC. However, it may come at the cost of operating costs (Sun et al., 2020) and quality degradation (Awad et al., 2020).

Andoh & Yu, 2022 recommend a two-step approach of combining optimization models with simulation techniques to reach a new model approach for last mile CSC delivery logistics.
In an alternative approach, combined interpretive structural modeling (ISM) is used alongside fuzzy VIKOR, a multi-criteria decision-making technique to identify the driving factors behind a sustainable cold chain supplier selection. (A. U. Khan & Ali, 2021)

Numerous authors have done studies to understand the various aspects of cold chain management, the factors influencing it, and effective ways to carry out the logistics. (A. S. Khan et al., 2020; Sharma et al., 2021; Theophilus et al., 2021) Dai et al., 2020 have studied vaccine supply chain management and its complexity. They have used a multiperiod Decision-Making GameModel with Delay and applied Equilibrium Points and applied Hopf Bifurcation Analysis to it. It is based on the assumption that the decision-maker does not make a decision instantaneously, resulting in delays. The results of the study clearly show that whenever the decision-making delay is above a certain level or threshold, the stability of the system is lost and it goes into chaos.

(Liu et al., 2020) An interesting study has been conducted where cold chain companies collaborate in delivering cold chain commodities by taking into consideration the carbon tax policy. The findings are suggestive of better delivery efficiency, reduction in the cost of doing business, and better competitive advantage for cold chain

logistics companies. Thus this collaboration at the industry level can be an effective way to achieve great economic and environmental benefits.

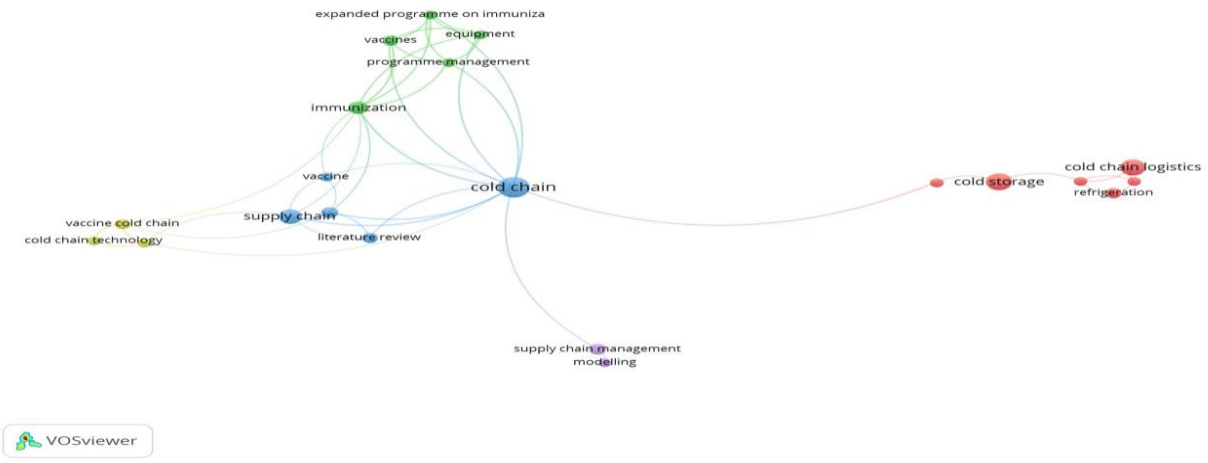
3. Research Methodology and Analysis

We have researched intensively the cold storage optimization practices and development in the pharmaceuticals and produce industry. We have used 'Google Scholar', 'Science Direct', 'Research Gate', 'Sci hub' and many other websites to find over 150 papers for our analysis. To perform the search, we used keywords like 'Cold storage optimization' and 'Vaccine industry' or 'Produce industry'.

The systematic literature review (SLR) is done for the years starting from 2010 till the current year 2022, which helps us to cover a little part of the brief history of traditional practices of the industry, the beginning of the cold storage industry in the world and how it has grown to be a vital part of the modern industry and the world.

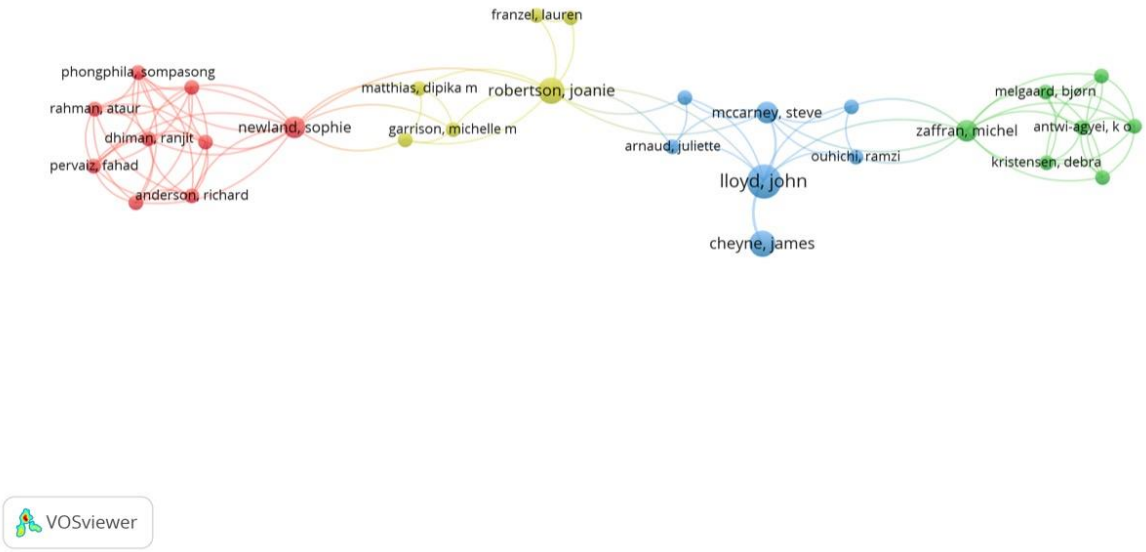
The papers discuss how cold storage management has evolved from using traditional methods to meet its needs to incorporating cutting-edge technologies, and practices, and adopting sustainable methods.

CO-OCCURRENCE OF KEYWORDS



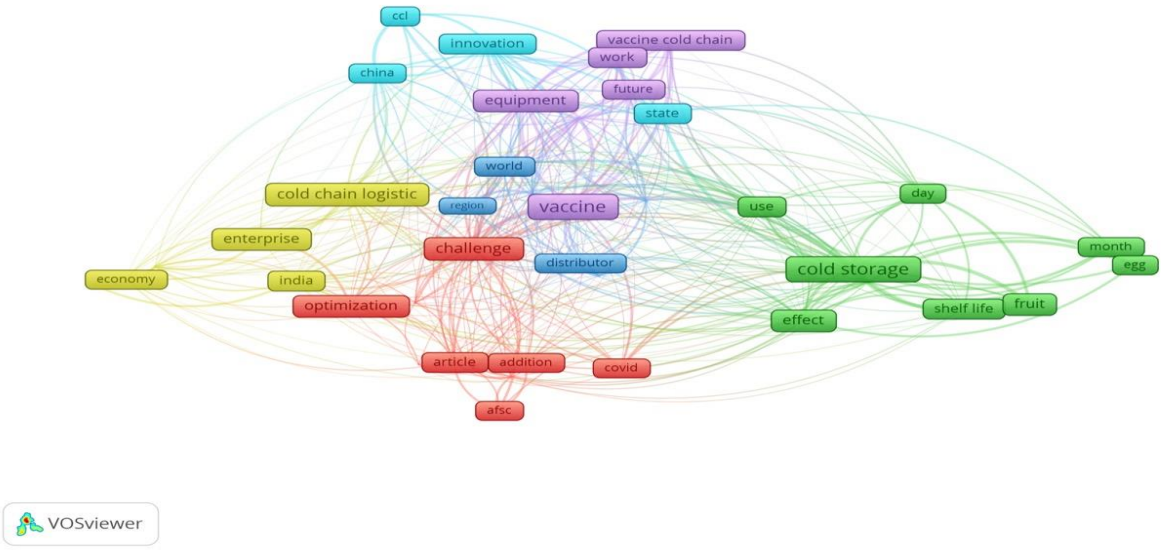
Keywords provided by the authors of the papers and occurred more than a few times in the WOS core database were enrolled in the final analysis. The keywords that were mostly used are “Cold chain ”, “Immunization”, and “Cold Chain Technology”, “Expanded program on immunity”, “Refrigeration”.

BIBLIOMETRIC ANALYSIS OF CO-AUTHORSHIP



Of all the authors who participated in the publication of Cold Supply chain related Papers, “Robertson, Joanie”, “Matthias, Dipika m”, “Newland, Sophie” and “Phongphilla, Sompason” proved to be the most insightful of all.

CO-OCCURRENCE OF TITLE AND ABSTRACT WORDS USED IN THE VARIOUS CONTRIBUTING PAPERS. (SOURCE: VOSVIEWER)



This Figure shows the Titles and Abstracts words used in various contributing Papers. Vaccine, cold chain, Cold chain logistics, Optimization, shelf life, enterprise cold storage, and distributor are popular.

4. Conclusion and Future Works

4.1 Findings

This research paper presents an overview of the cold storage supply chain system specifically in the pharmaceutical and produce sector. It studies the developments of the CSC, the challenges faced, and various models currently being adopted by the CSC sector.

Previously researched papers revealed the following :

1. The Cold Storage Chain requires delicate and precise handling that makes it difficult to transport pharmaceutical products like vaccines from Urban to Rural areas thus limiting access to life-saving healthcare. Unless the supply chain is optimized, rural regions will not have access to certain types of pharmaceutical products.
2. Optimization of cold storage can help in reducing food waste in large quantities.
3. Technology like blockchain and the Internet of Things is being integrated into infrastructure to create smoother supply chains.

4. The requirement for cold storage chains to be sustainable as well as optimal for transportation is paramount.

4.2 Limitations of this paper

1. Data collected was limited only to the English language and was limited to online sources
2. Does not take into account recently evolving strategies for fuzzy BWM models.

Future work might be able to explore how sustainable methodologies can be applied using MCDM techniques.

5. Bibliography

Aharoni, N., Lurie, S., Rodov, V., Copel, A., Aharoni, Y., Wiseblum, A., Horev, B., & Vinokur, Y. (2000). Nested modified-atmosphere packages maintain quality of trimmed sweet corn during cold storage and the shelf life... Cite this paper Related papers Controlling Humidit y Improves Efficacy of Modified Atmosphere Packaging of Fruit s and Vege… Nested modified-atmosphere packages maintain the quality of trimmed sweet corn during cold storage and the shelf life period. In Postharvest Biology and Technology (Vol. 18). www.elsevier.com/locate/postharvbio

Hanson, C. M., George, A. M., Sawadogo, A., & Schreiber, B. (2017). Is freezing in the vaccine cold chain an ongoing issue? A literature review. Vaccine, 35(17), 2127–2133. https://doi.org/10.1016/J.VACCINE.2016.09.070

Lloyd, J., & Cheyne, J. (2017). The origins of the vaccine cold chain and a glimpse of the future. Vaccine, 35(17), 2115–2120. https://doi.org/10.1016/J.VACCINE.2016.11.097

Makule, E., Dimoso, N., & Tassou, S. A. (2022). Precooling and Cold Storage Methods for Fruits and Vegetables in Sub-Saharan Africa—A Review. Horticulturae, 8(9), 776. https://doi.org/10.3390/horticulturae8090776

Robertson, J., Franzel, L., & Maire, D. (2017). Innovations in cold chain equipment for immunization supply chains. Vaccine, 35(17), 2252–2259. https://doi.org/10.1016/J.VACCINE.2016.11.094

Skog, L. J., & Chu, C. L. (n.d.). Effect of ozone on qualities of fruits and vegetables in cold storage.

Tashtoush, B. (n.d.). Natural losses from vegetable and fruit products in cold storage. www.elsevier.com/locate/foodcont

al Theeb, N., Smadi, H. J., Al-Hawari, T. H., & Aljarrah, M. H. (2020). Optimization of vehicle routing with inventory allocation problems in Cold Supply Chain Logistics. Computers and Industrial Engineering, 142. https://doi.org/10.1016/j.cie.2020.106341

Alfian, G., Syafrudin, M., Fitriyani, N. L., Rhee, J., Ma'arif, M. R., & Riadi, I. (2020). Traceability system using IoT and forecasting model for the food supply chain. 2020 International Conference on Decision Aid Sciences and Application, DASA 2020, 903–907. https://doi.org/10.1109/DASA51403.2020.9317011

Andoh, E. A., & Yu, H. (2022). A two-stage decision-support approach for improving sustainable last-mile cold chain logistics operations of COVID-19 vaccines. Annals of Operations Research. https://doi.org/10.1007/s10479-022-04906-x

Awad, M., Ndiaye, M., & Osman, A. (2020). Vehicle routing in cold food supply chain logistics: a literature review. In International Journal of Logistics Management (Vol. 32, Issue 2, pp. 592–617). Emerald Group Holdings Ltd. https://doi.org/10.1108/IJLM-02-2020-0092

Dai, D., Wu, X., & Si, F. (2020). Complexity Analysis and Control in Time-Delay Vaccine Supply Chain considering Cold Chain Transportation. Mathematical Problems in Engineering, 2020. https://doi.org/10.1155/2020/4392708

Khan, A. S., Salah, B., Zimon, D., Ikram, M., Khan, R., & Pruncu, C. I. (2020). A sustainable distribution design for multi-quality multiple-cold-chain products: An integrated inspection strategies approach. Energies, 13(24). https://doi.org/10.3390/en13246612

Khan, A. U., & Ali, Y. (2021). Sustainable supplier selection for the cold supply chain (CSC) in the context of a developing country. Environment, Development, and Sustainability, 23(9), 13135–13164. https://doi.org/10.1007/s10668-020-01203-0

Liu, G., Hu, J., Yang, Y., Xia, S., & Lim, M. K. (2020). Vehicle routing problem in cold Chain logistics: A joint distribution model with carbon trading mechanisms. Resources, Conservation and Recycling, 156. https://doi.org/10.1016/j.resconrec.2020.104715

Nosratabadi, S., Mosavi, A., & Lakner, Z. (2020). Food supply chain and business model innovation. In Foods (Vol. 9, Issue 2). MDPI Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/foods9020132

Sharma, A., Abbas, H., & Siddiqui, M. Q. (2021). Modeling the inhibitors of cold supply chain using fuzzy interpretive structural modeling and fuzzy MICMAC analysis. PLoS ONE, 16(4 April). https://doi.org/10.1371/journal.pone.0249046

Sun, L., Zhao, Y., Sun, W., & Liu, Z. (2020). Study on supply chain strategy based on the cost-income model and multi-access edge computing under the background of the Internet

Innovation in cold storage technologies. (2006). Stewart Postharvest Review, 1(3), 1–14. https://doi.org/10.2212/spr.2005.3.6

Matthias, D. M., Robertson, J., Garrison, M. M., Newland, S., & Nelson, C. (2007). Freezing temperatures in the vaccine cold chain: A systematic literature review. Vaccine, 25(20), 3980–3986. https://doi.org/10.1016/j.vaccine.2007.02.052

Sahin, E., Zied Babaï, M., Dallery, Y., & Vaillant, R. (2007). Ensuring supply chain safety through time temperature integrators. The International Journal of Logistics Management, 18(1), 102–124. https://doi.org/10.1108/09574090710748199

Salin, V. (2010). 2010 Global Cold Storage Capacity Report. http://AFCERC.tamu.edu

Sustainable Radio Frequency Identification Solutions. (n.d.). InTech.

Yahia, E. M. (n.d.). Cold Chain Development and Challenges in the Developing World.

Ashok, A., Brison, M., & LeTallec, Y. (2017). Improving cold chain systems: Challenges and solutions. In Vaccine (Vol. 35, Issue 17, pp. 2217–2223). Elsevier Ltd. https://doi.org/10.1016/j.vaccine.2016.08.045

Bhatnagar, A., Gupta, V., Tandon, P., Saksena, T., Ranjan, A., Gandhi, P., Chugh Garcha, S., & Kapoor, A. (2018). Corresponding Author: Varun Gupta, 1mg Technologies Private Limited, 4 th Floor, Last Mile Delivery of Cold Chain Medicines-Challenges and Recommendations. In Indian J.Pharm.Biol. Res (Vol. 6, Issue 1). www.ijpbr.in

Joshi, R., Banwet, D. K., & Shankar, R. (2009). Indian cold chain: Modeling the inhibitors. British Food Journal, 111(11), 1260–1283. https://doi.org/10.1108/00070700911001077

Sheikh, A. B., Pal, S., Javed, N., & Shekhar, R. (2021). COVID-19 vaccination in developing nations: Challenges and opportunities for innovation. In Infectious Disease Reports (Vol. 13, Issue 2). MDPI AG. https://doi.org/10.3390/IDR13020041 The Lancet. (n.d.).

Abedi, A., & Zhu, W. (2017). An optimization model for purchase, production, and distribution in the fish supply chain–a case study. *International Journal of Production Research*, *55*(12), 3451–3464. https://doi.org/10.1080/00207543.2016.1242800

Ansari, Z. N., & Kant, R. (2017). A state-of-art literature review reflecting 15 years of focus on sustainable supply chain management. *Journal of Cleaner Production*, *142*, 2524–2543. https://doi.org/10.1016/j.jclepro.2016.11.023

Comes, T., Bergtora Sandvik, K., & van de Walle, B. (2018). Cold chains, interrupted: The use of technology and information for decisions that keep humanitarian vaccines cool. *Journal of Humanitarian Logistics and Supply Chain Management*, *8*(1), 49–69. https://doi.org/10.1108/JHLSCM-03-2017-0006

Defraeye, T., Cronjé, P., Berry, T., Opara, U. L., East, A., Hertog, M., Verboven, P., & Nicolai, B. (2015). Towards integrated performance evaluation of future packaging for fresh produce in the cold chain. In *Trends in Food Science and Technology* (Vol. 44, Issue 2, pp. 201–225). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2015.04.008

Evans, J., Reinholdt, L., Fikiin, K., & Zilio, C. (2011). *Cold store energy usage and optimization*. https://www.researchgate.net/publication/282135670

Han, J. W., Zuo, M., Zhu, W. Y., Zuo, J. H., Lü, E. L., & Yang, X. T. (2021). A comprehensive review of cold chain logistics for fresh agricultural products: Current status, challenges, and future trends. *Trends in Food Science and Technology*, *109*(January), 536–551. https://doi.org/10.1016/j.tifs.2021.01.066

Hanson, C. M., George, A. M., Sawadogo, A., & Schreiber, B. (2017a). Is freezing in the vaccine cold chain an ongoing issue? A literature review. *Vaccine*, *35*(17), 2127–2133. https://doi.org/10.1016/j.vaccine.2016.09.070

Hanson, C. M., George, A. M., Sawadogo, A., & Schreiber, B. (2017b). Is freezing in the vaccine cold chain an ongoing issue? A literature review. In *Vaccine* (Vol. 35, Issue 17, pp. 2127–2133). Elsevier Ltd. https://doi.org/10.1016/j.vaccine.2016.09.070

Lloyd, J., & Cheyne, J. (2017). The origins of the vaccine cold chain and a glimpse of the future. *Vaccine*, *35*(17), 2115–2120. https://doi.org/10.1016/j.vaccine.2016.11.097

Meneghetti, A., & Monti, L. (2015). Greening the food supply chain: An optimization model for sustainable design of refrigerated automated warehouses. *International Journal of Production Research*, *53*(21), 6567–6587. https://doi.org/10.1080/00207543.2014.985449

Nakandala, D., Lau, H., & Zhang, J. (2016). Cost-optimization modeling for fresh food quality and transportation. *Industrial Management and Data Systems*, *116*(3), 564–583. https://doi.org/10.1108/IMDS-04-2015-0151

Ojo, T., Ijadunola, M., Adeyemi, E., Adetunji, O., Adurosakin, F., & Adeyinka, A. (2019). Challenges in the Logistics Management of Vaccine Cold Chain System in Ile-Ife, Osun State, Nigeria. *Journal of Community Medicine and Primary Health Care*, *31*(2), 1–12.

Pambudi, N. A., Sarifudin, A., Gandidi, I. M., & Romadhon, R. (2022). Vaccine cold chain management and cold storage technology to address the challenges of vaccination programs. *Energy Reports*, *8*, 955–972. https://doi.org/10.1016/j.egyr.2021.12.039

Sharma, S., & Pai, S. S. (2015). Analysis of operating effectiveness of a cold chain model using Bayesian networks. *Business Process Management Journal*, *21*(4), 722–742. https://doi.org/10.1108/BPMJ-10-2014-0105

Zhong, R., Xu, X., & Wang, L. (2017). Food supply chain management: systems, implementations, and future research. *Industrial Management and Data Systems*, *117*(9), 2085–2114. https://doi.org/10.1108/IMDS-09-2016-0391

Cheng, X., & Zhai, X. (2018). Thermal performance analysis of a cascaded cold storage unit using multiple PCMs. *Energy*, *143*, 448–457. https://doi.org/10.1016/j.energy.2017.11.009

Dou, S., Liu, G., & Yang, Y. (2020). A New Hybrid Algorithm for Cold Chain Logistics Distribution Center Location Problem. *IEEE Access*, *8*, 88769–88776. https://doi.org/10.1109/ACCESS.2020.2990988

Wen, Z., Liao, H., Ren, R., Bai, C., Zavadskas, E. K., Antucheviciene, J., & Al-Barakati, A. (2019). Cold chain logistics management of medicine with an integrated multi-criteria decision-making method. *International Journal of Environmental Research and Public Health*, *16*(23), 1–21. https://doi.org/10.3390/ijerph16234843

Comes, T., Bergtora Sandvik, K., & van de Walle, B. (2018). Cold chains, interrupted: The use of technology and information for decisions that keep humanitarian vaccines cool. *Journal of*

Humanitarian Logistics and Supply Chain Management, *8*(1), 49–69. https://doi.org/10.1108/JHLSCM-03-2017-0006

Hanson, C. M., George, A. M., Sawadogo, A., & Schreiber, B. (2017b). Is freezing in the vaccine cold chain an ongoing issue? A literature review. In *Vaccine* (Vol. 35, Issue 17, pp. 2127–2133). Elsevier Ltd. https://doi.org/10.1016/j.vaccine.2016.09.070

Lloyd, J., & Cheyne, J. (2017). The origins of the vaccine cold chain and a glimpse of the future. *Vaccine*, *35*(17), 2115–2120. https://doi.org/10.1016/j.vaccine.2016.11.097

Ojo, T., Ijadunola, M., Adeyemi, E., Adetunji, O., Adurosakin, F., & Adeyinka, A. (2019). Challenges in the Logistics Management of Vaccine Cold Chain System in Ile-Ife, Osun State, Nigeria. *Journal of Community Medicine and Primary Health Care*, *31*(2), 1–12.