Cold Chain Logistics

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1. Introduction

According to Grandviewresearch.com, the evaluation of the global cold chain market size as $210.49 billion in 2020 and its forecasted 14.8 % CAGR as of 2028 (Innovecs, 2021). Cold supply chain solutions are getting more and more popular due to a number of reasons, including the food waste, which 40% of food in the United States goes to waste which could produce methane, if thrown in the landfill, with 21 times more dangerous than CO_2. While the food loss can cost family of four $589.76 annually. Several reasons were depicted by Procuro (provider of cold chain management solutions for Food, Pharma, and Chemical Industries):

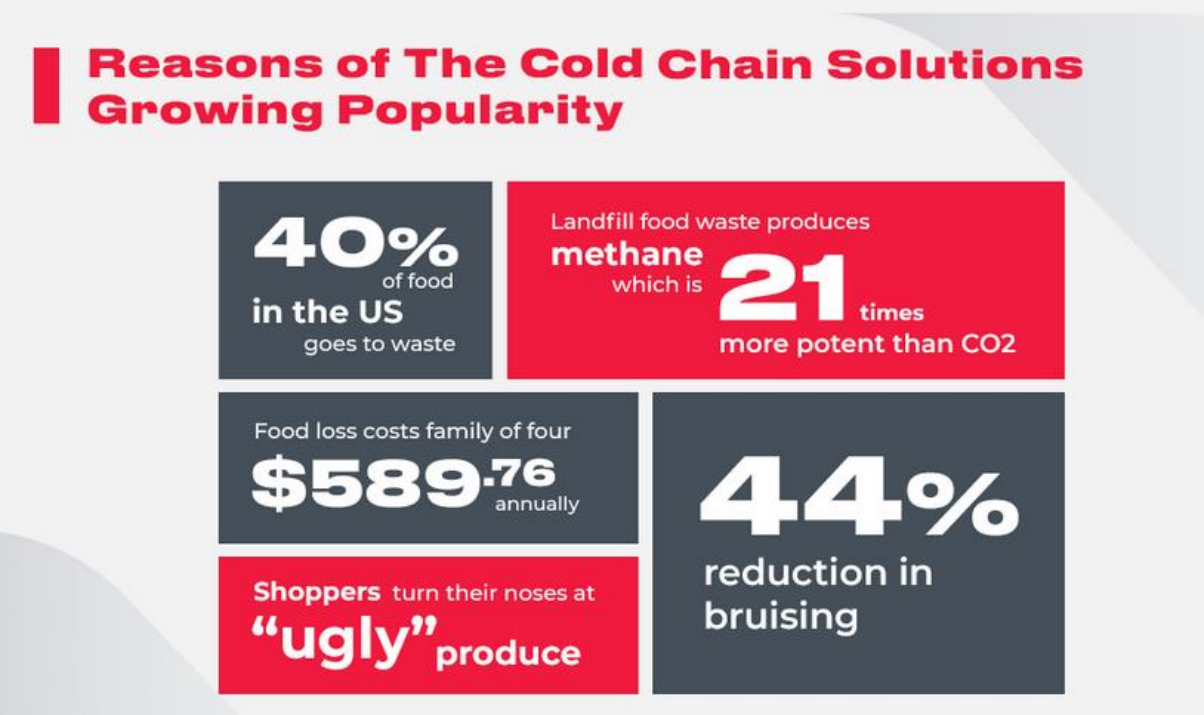

Figure 1. Reasons of Cold Chain Solutions Popularity Source: (Innovecs, 2021)

Furthermore, demand for specific products, including fruits, flowers, seafood, and other perishable is determined by their freshness. Therefore, these products are constantly kept in a defined controlled environment (Gupta, Chaudhuri and Tiwari, 2019). In order to manage the business, supply chain management requires a specific scheme for those products with limited durability and unique equipment to perform selling, storing and distributing. As a result, cold chain management is established.

Cold chain logistics could be described as a logistic system that use refrigeration technology to continuously maintain a defined temperature and humidity environment of perishable products, including vegetables, fruits, meats, fish, dairy, during the logistics. Cold chain logistics does not only cover product transportation. However, it maintains the whole supply chain process, including the supply procurement, packaging, transportation equipment, well-selected transportation routes, storage, ideal timing and transport to the end customer. It is essential to keep the temperature of the products throughout their lifecycle in a fixed or suitable range condition within the supply chain as it is sensitive to the environment, such as humidity, temperature and light. Otherwise, it most probably causes problems to the goods, which result in unconsumable or dangerous products to consume by the user in the end. Specifically, textural degradation, discolouration, bruising, and microbiological growth can occur if products are not stored at the proper temperatures. When the product is pharmaceutical, this issue becomes even more vital. Many medicines must be kept in a specific temperature range to stay effective. Thus, Cold chain logistics plays an essential role in this business operation to provide safe and of high quality at the point of consumption, leading to delighted customers, increased demand, and overall public health protection, which contributes to the workforce and economic performance in the end. Undoubtedly, it is essential to integrate the whole cold chain logistics by coordinating different stakeholders through data sharing and transparency in order to reduce loss and waste.

This study aims to overview cold chain logistics in general, providing its characteristics, stage of the chain, and implementation in different fields. Furthermore, the article describes the current development of cold chain logistics, especially with the integration of Industry 4.0. Presented information and data is primarily obtained from the published journals or proceedings.

2. Literature Review

2. 1 Cold Chain Logistics Characteristics

In order to perform successfully cold chain logistics, it is essential to define the type and characteristics of products. Primarily, there are four categories of perishable goods, including perishable foods such as dairy and beverages, flowers and ornamental plants, agricultural products and pharmaceutical products (Hosseini Bamakan, Ghasemzadeh Moghaddam and Dehghan Manshadi, 2021) as shown in Figure 2.

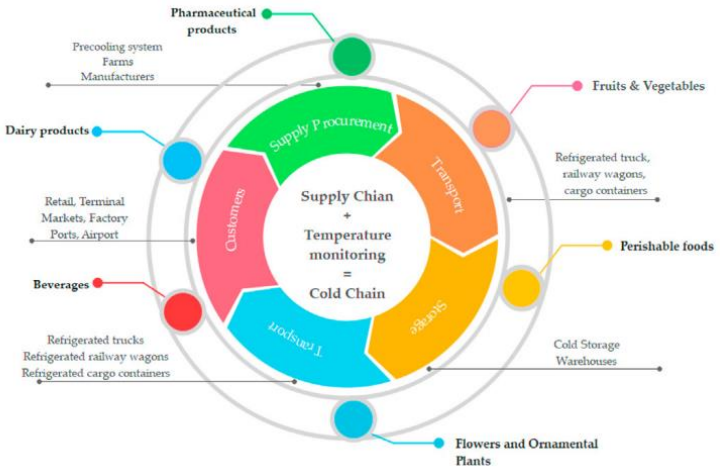

Figure 2. Perishable Products within Cold Chain Logistics (Hosseini Bamakan, Ghasemzadeh Moghaddam and Dehghan Manshadi, 2021)

Perishable foods

Cold chain logistics is important for the food supply chain, notably, if the products are perishable, such as already cooked, ready to eat, frozen to preserve their freshness and high-risk foods. Those products refer to raw vegetables, raw fruits, raw milk, fish, poultry, red meats, and others. In cold storage, perishable foods require proper humidity and ventilation management. These are hygroscopic materials, which means that their properties change dramatically depending on the humidity of the air surrounding them, not only the temperature.

Flowers and ornamental plants

Due to the large distance between greenhouses to the market, cold chain management of cut flowers and decorative plants is critical. Flowers and decorative plants have three steps in the cold chain logistics process: suppliers (growers), wholesalers, retailers, and finally customers. The presence of a temperature-controlled room is critical for the quality of cut flowers, and it starts at the farm and continues through refrigerated trucks that deliver flowers to warehouses, the airport and in-country flights, and finally to the final destination. Vehicles that transport these cold chains play a crucial role as well. Cold chain logistics necessitates the use of refrigerated distribution vehicles.

The biggest problem that these types of cold chains may confront on a regular basis is changes in environmental conditions. Flowers of various types require a certain storage temperature and time limit to ensure that their quality and vase life is preserved. Otherwise, several quality problems might appear on the products, including damaged flowers, bent stems, uneven opening, and parasites (Hosseini Mirza Hasan, 2012). Thus, logistics conditions such as the air quality, temperature, humidity, room pressure and lighting level are essential aspects

to consider in the flower chain postharvest. In detail, oxygen and carbon existence is important throughout the chain because it affects the quality of flowers as the flowers need to breathe after being cut. Besides, the sanitation and cleanliness aspect of all supporting parts, such as buckets, coolers, benches, are essential as well, since dirty buckets might reduce the lifecycle of a flower by 20% (Florint, 2020).

Fresh Agricultural Products

In the agricultural cold-chains, freshness is the most crucial factor. This sort of cold chain includes products like tree fruit, berries, melons, vegetables, fresh herbs, mushrooms, and sprouts, which must be kept in a regulated atmosphere at all times since their freshness impacts their demand at the point of sale. These items also travel a considerable distance from the point of origin to the point of sale, undergoing many stages of transportation. Refrigerated trucks are significant components of agricultural cold chain logistics in this regard (Gupta, Chaudhuri and Tiwari, 2019).

Pharmaceutical Industry

Pharmaceuticals are often delivered in chilled containers onboard planes, which are stacked in pallets. Onboard aeroplanes, flowers and other agricultural items in cardboard boxes are stacked in layers in well-ventilated pallets. Pharmaceutical producers must adhere to FDA-mandated cGMP (current Good Manufacturing Practices) requirements, while the logistics of the firm must adhere to GDP (Good Distribution Practices) regulations. This is because poorly manufactured, stored, or transported pharmaceuticals can create serious issues for patients when consumed. As previously mentioned, the most significant problem in pharmaceutical and healthcare cold chains is maintaining the required quality of the product until it reaches the ultimate user (Kapoor, RB and D, 2018).

2. 2 Stage of Cold Chain Logistics

The cold chain is a combination of four connected systems, including precooling, warehouse refrigeration, refrigerated transport, and marketing. Each stage in the cold chain is linked and interdependent, and faults in any link will escalate the loss and waste of food, human and material resources, and render any following connections in the cold chain irrelevant (Han *et al.*, 2021).

Precooling

The first step for agricultural products before going to the low-temperature environment is precooling. Precooling is used to quickly remove field heat (or corpse temperature) from fresh products following harvest, slaughter, or fishing. This procedure reduces the rate of

physiochemical reactions in the product, inhibits the development of disease, and reduces the loss of sensory attributes and nutrients. Furthermore, precooling lowers the need for cooling capacity and minimizes excessive temperature swings in the following period.

Heat-conduction cooling and phase-transition cooling are two types of precooling. No single precooling method is appropriate for all products, and the choice of the most appropriate precooling method depends mainly on the specific circumstances, such as produce species, packaging type, refrigeration temperature, cooling rate, sensitivity to water, and maturity (for fruits and vegetables) (Duan *et al.*, 2020).

Refrigerated Warehouse

A refrigerated warehouse (RW) is primarily used to maintain the quality of fresh agricultural goods after precooling by providing a stable, adequate, and long-term low-temperature environment. RWs are a critical link in the food supply chain because they enable centralized storage and products management, maintain supply and demand balance, and regulate goods movement capacity. Cold air storage (CAS) and modified-atmosphere storage are the most prevalent storage methods for fresh agricultural goods at the moment (MAS). CAS uses air as the cooling medium and its effectiveness, including cooling rate and uniformity, energy consumption, water loss rate and rate of chilling injury rely on packaging and stacking patterns, air velocity, air temperature and humidity. Meanwhile, MAS is primarily based on CAS but it extends the food shelf life longer than CAS because MAS adjust the composition of the storage atmosphere, such as high carbon dioxide and low oxygen, to inhibit the physiological and biochemical processes of food degradation as well as microbial activity inside the food product(Le Bideau *et al.*, 2018).

Refrigerated Transport

Refrigerated transport is responsible to connects the upstream and downstream throughout the cold chain logistics. There are several modes of transportation available, including maritime, air, road, and rail, and the best mode of transportation is determined by shelf life, economic value, cost, and client demand. The principal purpose of refrigerated transport is to maintain a stable and uniform temperature and humidity environment during the transportation time. That temperature and humidity are the essential characteristics determining the quality, safety, shelf-life of food products. The exterior environment and interior air circulation determine the homogeneity of temperature, humidity, and air-flow velocity within an RV.

Marketing

Before the food items reach the customer, the final, critical stage in the food cold chain is marketing. According to surveys conducted in several countries, refrigerated goods are subjected to severe temperature and humidity abuse in retail stores. Nearly 80% of fresh fruits and vegetables in Chinese stores are subjected to temperature abuse. According to studies, improper temperature and humidity control account for more than half of all unmarketable products. Furthermore, the early phases of the cold chain's accumulation and transfer of numerous risk factors have a detrimental influence on food quality and safety during the marketing process. As a result, marketing is the most vulnerable and closest link in the cold supply chain to customers; a lack of stringent quality and safety oversight in this final line of defence can cause the whole CCL to fail. Refrigerated display cabinets (RDCs) are a large storage carrier that is widely used to store, display, and sell chilled food products in retail stores across the world. RDCs are available in a variety of forms, including horizontal, vertical, open, closed, chilled, frozen, and multi-temperature cabinets, and their classification according to ISO 23953-2:2015 provides specific information on display cabinets.

Domestic Storage

Domestic storage is one of the essential parts of cold chain logistics and is performed in the household. It refers to the storage of perishable goods inside the refrigerator. When the products enter the market, the food business operator has the primary responsibility for food safety before the customer buys a product and reduce the safety risk by performing standardization and precise management, such as process hygiene, self-checking systems, hazard analysis, critical control. Then, after the fresh food is purchased by the customer, the safety and quality of food are strongly related to how they handle the products from the store to their home. Although the travel time between the market and their house is relatively small since they might prefer to shop at the nearest store, still the perishable food will spend its shelf life in the household refrigerator which might be longer than the previous cold chain section. Therefore, domestic storage is an essential part of cold chain logistics, and its good implementation can decrease food waste and the risk of foodborne disease. The most popular household equipment for this purpose is the refrigerator, which plays an important role in keeping food fresh and maintaining its quality and safety by maintaining an appropriate low-temperature environment.

According to reports, 45 per cent of food losses and 87 per cent of foodborne sickness in Europe happened at the household level. Consumer behaviour and the domestic environment have a substantial influence on the rate of food loss and foodborne disease in families, hence

efforts should be taken to eliminate these risk factors. Regular temperature verifications, cleaning, and disinfection are required in terms of customer behaviour to limit temperature swings and levels of microbiological contamination, such as bacteria and fungi, in refrigerators. Furthermore, increasing consumer awareness of proper refrigeration procedures and the influence of temperature on microbes, particularly among the elderly and pregnant women, is critical. Good housekeeping practices (e.g., strictly adhering to the shelf-life and recommended storage temperature of refrigerated foods), as well as clean and hygienic conditions for food handling, preparation, and cooking, can help reduce cross-contamination from other foods and household foodborne disease outbreaks.

2. 3 Implementation of Cold Chain Logistics

Vaccine Supply Chain

A vaccine supply chain is as a complex system consisting of locations, storage equipment, vehicles, transport routes, and personnel that handle these vaccines from the production to the points of administration (Sun, et al., 2021). The uncertainty, risks, and disruptions associated with the vaccine supply chain make it delicate and complex. Because of this, the setup and operations of a vaccine supply chain require thorough planning and implementation. The vaccine supply chain is distinctively different from other supply

Vaccines can only save lives if they remain cool. Most vaccines are developed for a temperature range of 2-8°C (35-46°F), their so-called “safe range” (Comes, 2018) Although usually heat exposure is in focus, freezing was identified as a problem in an astonishing 75-100 percent of vaccine chains. Vaccines with active ingredients will spoil automatically if frozen, but have generally better heat stability. With temperatures higher than 8°C; however, the efficacy of a vaccine decreases), and may do harm if not cooled and handled appropriately.

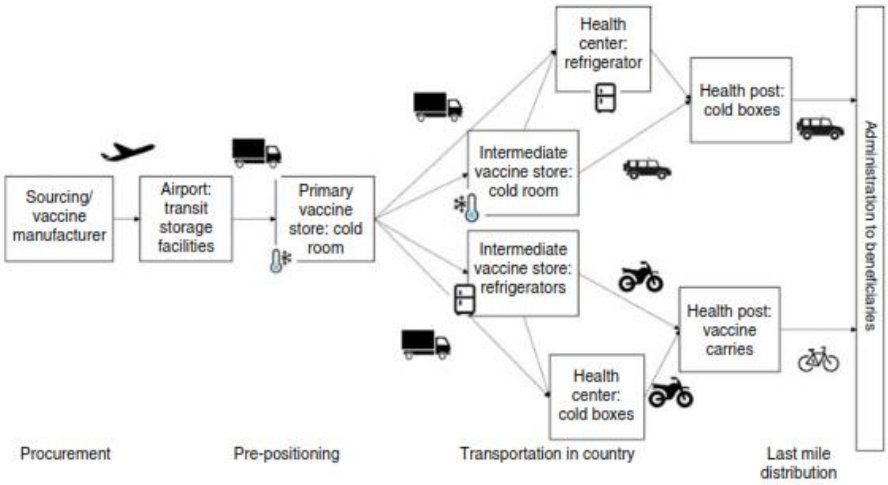

Figure 3 General structure of a cold chain in a vaccination campaign

Figure 3 shows the flow of vaccines from sourcing and the port of entry down to the health posts and eventually administration to the beneficiaries during the implementation. Throughout all cold chain stages, from the arrival at the airport to last mile distribution, vaccines must remain within the recommended temperature range. This implies that vaccines must be stored, packed and transported under cold chain conditions. Cooling systems, however, are typically not standardized. While standards and availability of equipment generally deteriorate deeper in the field, there are different options typical for the respective level.

Active systems include mains refrigerators and off-grid refrigerators. Main refrigerators are cooled by compressors that are powered by the electric grid. Off-grid refrigerators include two main subsets: absorption refrigerators powered by the burning of liquid petroleum gas or kerosene, and solar-powered adsorption refrigerators, which use electric compressors that may be driven from batteries that have stored the power generated by solar panels (solar battery-powered), or directly from the solar panels themselves.

Passive cooling devices include cold boxes and vaccine carriers. Cold boxes are larger devices (6-25 litres), generally transported by motor vehicles, while vaccine carriers are smaller (0.5-3.5 litres), and generally carried by hand or on bicycles or motorbikes. They are called passive because there is no active refrigeration mechanism – the cooling is provided by coolant packs containing phase change material (traditionally plain water) frozen into solid form.

Agriculture Food Supply Chain

The agriculture food supply chain (AFSC) is a term that refers to the production and transportation of agricultural products from farm to household consumption through a succession of steps. The raw products are produced at the production stage while being processed at the processing stage. After the processing steps, the products are stored at distribution which is then distributed to different retailers. Finally, the customer can obtain the products from the retailers.

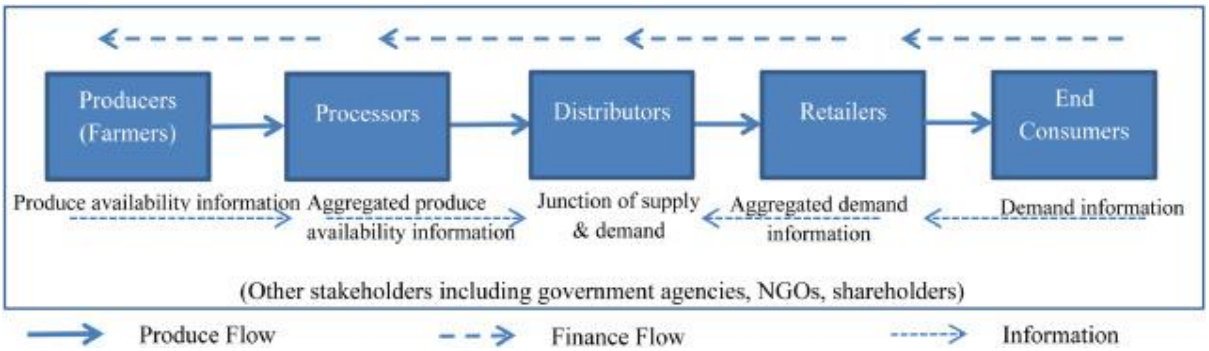

Figure 4 Stakeholders of AFSC (Yadav et al., 2021)

There are several stakeholders involved within the agriculture food supply chain, including the farmers, consumers, agricultural suppliers, food processors, food distributors, government, and others. Each stakeholder faces unique challenges in carrying out the numerous related operations. For instance, the farmers faced issues about the lack of financial and human resources, fertilizers and insecticides, raw materials, information sharing and the risk of theft. The other things they faced are difficulties in marketing, product transportation, consumer price, negotiating power, and infrastructure facilities, including the refrigerated warehouse. While, the intermediaries face complexities, including warehouse management, inconsistency of supply and demand, dealing with the perishable nature of the products. Last, the customers possess safety and quality issues, price fluctuation and low standardization of the products (Yadav *et al.*, 2021).

In general, there are two specific groups of food supply chain (Van der Vorst, Da Silva and Trienekens, 2007):

1. Agri food chains for fresh agricultural products

   Fresh agricultural products refer to fresh vegetables, flowers and fruit. Generally, auctions, wholesalers, importers and exporters, retailers and speciality stores make up these chains. All of these processes, in essence, keep the inherent traits of the thing cultivated or manufactured unchanged. Handling conditioned storing, packaging, shipping, and notably trade of these items are the major procedures.

2. Agrifood chains for processed food products

   Processed food products such as meats, snacks, desserts, canned food are handled with this chain. Within this supply chain, the agricultural products are used as production input to produce higher added value consumer products. Mostly, the shelf-life of items is usually extended through conservation and conditioning techniques.

2.4 Industry 4.0 in CCL

The use of IoT for cold chain logistics can help businesses streamline the logistics process. It can help overcome some of the major challenges currently faced in the cold chain logistics providers by enabling real-time monitoring, providing data insights, and helping businesses make informed decisions quickly. Here's a look at some of the key features that IoT brings to cold chain logistics.

Temperature Monitoring

The implementation of IoT solutions enables businesses to monitor the temperature of the food items, which is perhaps the most critical parameter in cold chain logistics. Sensors can be used on transportation modes such as trucks, rail cargo, or air cargo to monitor the temperature of the food items. The sensors gather and share this data in real-time. Hence businesses have complete control over temperature regulation and monitoring processes. This ensures that the items stay at the optimum temperature throughout the logistics cycle, thereby increasing their longevity. IoT-enabled actuators can automatically adjust the temperature of the cold storage facilities and containers to match the required level if there are any discrepancies. IoT solutions also require minimum human intervention and help businesses to utilize human resources for other tasks efficiently.

Real-Time Data Access

All the data collected by IoT devices is analysed and shared with other devices in real-time. This ensures that businesses can have visibility over the logistics process as they can get notified of any issues emerging in the transportation process as soon as they arise. Managers and technicians can make quick decisions to fix these issues, and this ensures that the food quality and freshness are not compromised, which may result in a financial loss for the businesses.

Automated Reports

IoT devices are as much about the software as they are about the hardware. The data collected by the IoT devices can be used to auto-generate reports by advanced artificial intelligence software running on these devices. With artificial intelligence and machine learning, cold chain

logistics processes can be improved by analysing the data collected from IoT devices. Analysing process-related data can point out inefficiencies, if any, in the current logistics process, and businesses can make strategic decisions to eliminate them.

Shipment Tracking

It is essential for businesses to have complete knowledge of their shipments. The use of IoT for cold chain logistics serves this purpose. With IoT devices, businesses can monitor their shipment 24*7. They can make any changes in the logistics schedule quickly if the chain is moving at a slower pace than planned. This helps reduce the time lost in planning and modifying the schedule when the tracking data is not easily accessible. Stakeholders can coordinate easily with different members of the supply chain and efficiently manage the system.

The complexity and significance of cold chain logistics make it a strong use case for IoT platforms and devices (Jeffery, 2021). IoT devices connect and protect the end-to-end supply chain process. These platforms, designed to track assets, connect objects, share information, and perform actions in real-time, identify, monitor and fix potential weaknesses in the supply chain.

For instance, mobile sensors are deployed to maintain vaccine temperature and ensure the vaccine's authenticity in route. These sensors, placed on vaccine packages, containers, and pallets, collect and determine vaccine temperature data during the distribution process, from the warehouse, into the healthcare provider's hands. The collected data is then shared with the vaccine stakeholder alongside specific location details, so they are aware at any given time where those packages are in the supply chain. IoT provides vital information in real-time on the vaccine's status and health to ensure an effective roll-out at its end destination.

2. 5 Block Chain in CCL

As with any transaction between two or more parties, transporting biopharmaceutical products from a selling manufacturer to the buying end-user involves numerous steps, administrative processes, and just like a house sale, trust between all parties. A typical cold chain might involve a manufacturer, at least one logistics company, storage facilities, and an end user recipient, with each step requiring checks, handovers, signatories, and logging. Many of these processes are underpinned by manual data entry processes – in some cases, pen and paper exercises.

Keeping track of a payload in transit, ensuring its safety and ultimate efficacy upon arrival with a buyer, and ensuring all records are safely stored and kept is a major undertaking requiring a huge amount of human resource. While cold chains are becoming more and more digitised, with intelligent data loggers allowing for GPS tracking and internal temperature monitoring, what happens to a box in transit, and all the surrounding administration represents risk to both seller and buyer.

So how is blockchain technology applicable to cold chain logistics? And, how does it solve these problems? Some of the key problems blockchain could solve are:

- Payment processing (removing time and cost)
- Dispute resolution (a decentralised 'database' verified only by the key actors)
- Administrative efficiency (removing manual data entry and cumbersome digital or hard copy data storage)
- Order tracking (real-time payload tracking ensuring better security)

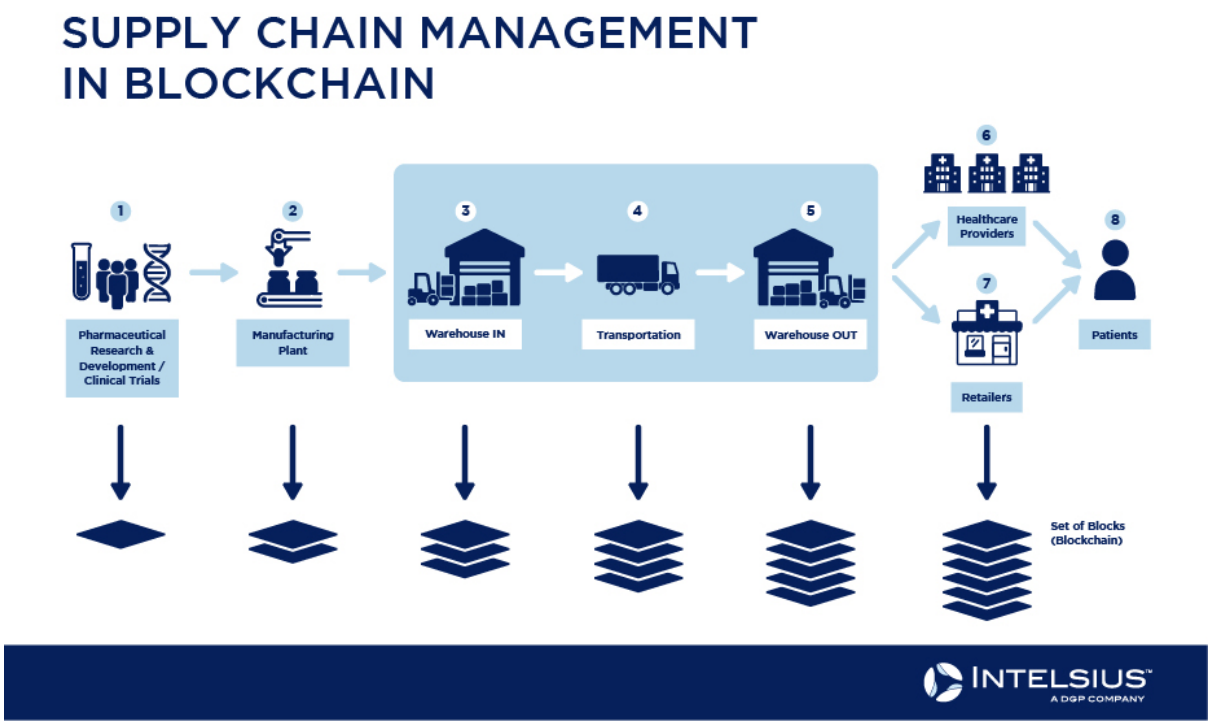

Figure 5. Implementation Blockchain in Cold Chain

One of blockchains most highly regarded features is that unique blockchains can be created between trusted parties without so-called trusted third parties, with either open or closed access networks available to a group of partners.

For example, it is possible to create a blockchain with only a handful of verified users, and as the chain is immutable and encrypted, any attempt to gain access without permissions would be extremely difficult, and even if it was achieved, as the records are immutable (unlike a standard database), records are impossible to permanently delete or alter. That means you can keep your circle small, and limited to those who need access, and managed in a way that suits you with confidence in the records being created as every new block is added

2.6. Cold Chain Logistics Challenges

Although cold supply chain practices have introduced a lot of benefits and advantages to the related industries supply chain efficiency and competitiveness, these advantages come at price, below are a few issues to be addressed when considering a cold supply chain design and implementation: (Tamimi, et al., 2010)

The Use of Non-Environmental Gas Compounds

All cold chain equipments must contain at least one type of "organic gas compounds", these gas components are called CFC gases, and it was recently discovered that these components can cause a serious environmental damage if released to the atmosphere, therefore, a new generation of cold chain equipment was introduced in 1996 to replace those using CFC gases, The new equipment is considered as CFC-free which comes for a higher price of course. The symbol shown below is used on refrigerators, air conditioners and drug carriers to highlight that the equipment has been made using CFC-free gazes and hence; has no harmful environmental effect.

Frosting

Ice can slowly build up on the freezing surface of the refrigerator during its operation; this frost layer must be continuously removed as it lowers the cooling efficiency of the cold chain equipment, that is why regular defrosting is important which have to be added to the equipment maintenance total cost.

Safety Concerns

Since all of the cold supply chain equipment are powered by electricity, a qualified electricity technician has to be used to confirm the proper installation and deployment of all connections, plugs and switches, safety kits and circuit breakers has to be considered to protect the personnel and the equipment in case of any failure.

Continuous Control and Monitoring of Temperatures

Maintaining correct temperatures during storage and transportation is a very important task for the cold supply chain cycle; temperature readings must be continuously taken in order to:

- Ensure that the vaccines are stored at the correct temperature condition.
- Ensure that the cold chain equipment is operating successfully.

Continuous monitoring of temperatures should be a regular task, and should be performed at the start and end of each day, although there are a lot of monitoring devices and equipment to help measuring, controlling, and recording the cold chain equipment temperature, it still needs extra man power overhead than the regular non-temperature-controlled supply chain logistics.

3. Conclusion

In this study, the authors have reviewed general practice of cold chain logistics. Cold chain logistics is a logistic system that uses refrigeration equipment to maintain a regulated temperature and humidity environment for perishable products is known as cold chain logistics. Perishable products can be flowers and ornamental plants, fresh agricultural products and pharmaceutical industry.

Within cold chain logistics, generally there are four connected system. First step is precooling, aiming to remove field heat from fresh products. Further, it is followed by refrigerated warehouse, used to maintain the quality of fresh products. Next step is refrigerated transport, connecting the upstream and downstream logistics with stable and uniform temperature and humidity environment. Marketing, is a process of selling the fresh products in the retailer, by maintaining the freshness of the products before it was bought by the customer. Last, is the domestic storage where the customer keeps the products in a stable environment.

In order to advance the process of cold chain logistics, industry 4.0 can be implemented. Several essential activities benefitted by the Industry 4.0 are temperature monitoring, real-time data access, automated reports, shipment tracking. Specifically, blockchain technology can help in payment process simplification, administrative efficiency and order tracking.

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