YAŞAR UNIVERSITY
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MASTER THESIS

CONCEPTUAL FRAMEWORK MODEL FOR PERFORMANCE IMPROVEMENT OF A COLD CHAIN MANAGEMENT IN SUPPLY CHAIN BY USING FUZZY DEMATEL METHOD

CANSU ÇAKILCI

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YÜKSEK LİSANS TEZ JÜRİ ONAY SAYFASI

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ABSTRACT

CONCEPTUAL FRAMEWORK MODEL FOR PERFORMANCE IMPROVEMENT OF A COLD CHAIN MANAGEMENT IN SUPPLY CHAIN BY USING FUZZY DEMATEL METHOD

Cansu Çakılcı
Master of Business Administration
Advisor: Assoc.Prof.YÜCEL ÖZTÜRKOĞLU
2020

Consumers have a right to desire that the food products they purchase is impeccable quality and safe. Storing and transporting of perishable products, such as dairy products, meat or frozen products at appropriate temperature range is very important in parallel with this purpose. Inappropriate refrigeration can growth bacteria that can cause the foods to deteriorate easily or increase the risk of foodborne illnesses. Therefore, designing an uninterrupted, rigorous and appropriate refrigeration is essential at every stage of cold chain in order to ensure food safety and its quality. Additionally, cold chain is a strategic tool for three important dimensions of sustainability; social, economical and the environmental.

The main aim of this study is to identify the possible criteria affecting cold chain performance and explain the causal relationships between each criteria and importance degree of criteria by using fuzzy DEMATEL. In this study, 12 main criteria with 35-sub-criteria is determined as independent variables as a result of making a comprehensive literature review in order to explain cold supply chain performance.

The estimation results showed that 5 criteria is determined as cause groups.These are packaging, refrigeration systems, staff, technical issues and other criteria, including weather conditions, legal regulations and regulatory requirements of the organizations. Staff is the most influence criteria among these criteria. ‘Traceability’ is the most important criteria for organizations in cold chain according to importance order of fuzzy DEMATEL.

Keywords: cold chain, food safety, Fuzzy DEMATEL.

ÖZ

BULANIK DEMATEL YÖNTEMİ İLE TEDARİK ZİNCİRİNDE SOĞUK ZİNCİR YÖNETİMİNİN GELİŞTİRİLMESİ İÇİN KAVRAMSAL ÇERÇEVE MODELİ

Cansu Çakılcı
Yüksek Lisans, İŞLETME Tezli (İngilizce)
Danışman: Doç.Dr. YÜCEL ÖZTÜRKOĞLU
2020

Tüketiciler satın aldıkları gıda ürününün kusursuz kalitede ve güvenilir olmasını arzularlar. Bu amaç doğrultusunda, et, süt, yumurta gibi temel besin gıdaları ve dondurulmuş ürünlerin uygun sıcaklıkta üreticiden tüketiciye kadar soğultulması çok önemlidir. Öngörülen sıcaklık limitleri aşıldığında ürünün kolay bozulmasına veya bazı hastalıkların ortaya çıkmasına sebep olabilecek bakteriler üreyecektir. Bakteriler sıcak ortamda daha kolay kendini gösterebileceğinden tüm tedarik zinciri boyunca kesintisiz, titiz ve uygun soğutma şarttır.

Soğuk zincir, sosyal, ekonomik ve çevresel sürdürülebilirlik açısından temeldir. Soğuk zincirin temel görevi; gıda güvenilirliğini sağlayarak tüketiciyi olumsuz sağlık etkilerinden korumaktır. Senkronize olunmuş, izlenen ve iyi yönetilen bir soğuk zincir, gıda ürünlerinin fiziksel ve biyolojik yapısını koruyarak, gıdada güvenilirliği sağlayacaktır. Bu durumda, ürünün satın alınabilirliği artacak ve çevre açısından gıda atık oranı azalacaktır.

Çalışmanın amacı, soğuk zincir yönetimini etkileyen performans kriterlerini tanımlamak ve bu kriterler arasındaki nedensellik ilişkisini fuzzy DEMATEL yöntemini kullanarak çözmektir. Çalışmamızda, ‘soğuk tedarik zinciri performansı’ bağımlı değişken olarak alınmış olup, detaylı bir literatür taraması sonucunda ise soğuk zincir performasını açıklayıcı olarak, 12 temel kriter ve 35 alt-kriter bağımsız değişken olarak belirlenmiştir.

Analiz sonucunda, paketleme, soğutma sistemleri, personel, teknik açıdan yaşanabilecek problemler ve diğer etkenler başlığı altında adlandırdığımız mevsimsel

etkiler, yasal düzenlemelerin eksikliği ve kurum içinde düzenleyici şartların bulunmaması sebep kriterleri, soğuk hava depolarının özelliği, elleçleme faaliyetleri, dağıtım faaliyetleri, gecikmelere sebep olabilecek olağan durumlar, izlenebilirlik, tüketici kaynaklı hatalar ve tesislerin hijyen koşulları ise sebep kriterleri tarafından etkilenen etki kriterleridir. Kriter önem sıralaması incelendiğinde ise, işletmeler açısından soğuk zincir için en önemli kriterin izlenebilirlik olduğu saptanmıştır.
Anahtar sözcükler: soğuk zincir, gıda güvenilirliği, Fuzzy DEMATEL.

ACKNOWLEDGEMENTS

I would like to extend thanks and respect to my esteemed advisor, Assoc.Prof. Yücel ÖZTÜRKOĞLU for her guidance with its precious knowledge and experience during planning, execution and completion of my thesis study. Thank you so much for her love, toleration, positive energy as well as valuable advices and supports about planning my future career.

I would like to thank my dear mother, Müge ÇAKILCI and my dear father, Süleyman ÇAKILCI for their love, trust, material and moral support during the duration of my education. As in all areas of my life, I am very much thankful to my dear engaged, Fırat TURAN for his love, understanding and supporting to me during my thesis study.

Cansu Çakılcı

İzmir, 2020

TEXT OF OATH

I declare and honestly confirm that my study, titled "Conceptual Framework Model For Performance Improvement of a Cold Chain Management in Supply Chain By Using Fuzzy DEMATEL Method" and presented as a Master's Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Cansu Çakılcı

Signature

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MAY 22, 2020

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LIST OF ABBREVIATION

AC	: Active Packaging.
BRC	: British Retail Consortium.
CDC	: Centers for Disease Control and Prevention.
CSC	: Cold Supply Chain.
DC	: Distribution Center.
DEMATEL	: The Decision Making Trial and Evaluation Laboratory.
ESSIAD	: Ege Soğutma Sanayicileri İş Adamları Derneği.
FEFO	: First Expiration First Out.
FIFO	: First In First Out.
FSA	: Food Standard Agency.
GFSI	: Global Food Safety Initiative.
HACCP	: Hazard Analysis and Critical Control Points.
HUY	: Humberside Airport.
ICT	: Information and Communication Technologies.
IFS	: International Food Standard.
IFST	: Institute of Food Science & Technology.
IISD	: International Institute for Sustainable Development.
IP	: Intelligent Packaging.
ISO	: International Organization for Standardization.
KEF	: Keflavik Airport.
LIFO	: Last In First Out.
MCDM	: Multi-criteria Decision Making.
NRDC	: Natural Resources Defense Council.
PCM	: Phase Change Material.
PP	: Passive Packaging.
Precooling	: Prompt Cooling After Harvesting.
R&D	: Research and Development.
RFID	: Radio-Frequency Identification Tags.
TCGF	: The Customer Goods Forum.
TTI	: Time Temperature Indicator.
UK	: United Kingdom.

ULD	: Unit Load Device.
US	: United States.
UTIKAD	: Uluslararası Taşımacılık ve Lojistik Hizmet Üretenleri Derneği.
WHO	: World Health Organization.

INTRODUCTION

The cold chain food industry has been increasingly improving with increased world population, significant growth of frozen foods and increased customers expectations with increased health consciousness as well as rising global competition. Fresh food products, including fruits, vegetables, seafoods, meat, dairy products and frozen foods need a controlled temperature, humidity and atmospheric conditions because of their perishable nature. Therefore, the anticipated temperature range should not be exceeded throughout cold supply chain, from farm until folk to ensure the quality, security and taste of the food products.

The cold chain is a supply chain where refrigeration and freezing technology is necessary for moving perishable food products from supply to final consumption. The cold chain is a series of distribution activities which keep accurate temperature range at the same time (Kumar,2018). Refrigeration, food safety and food waste are directly linked. More specifically, temperature abuses, because of inappropriate and delayed refrigeration can cause to growth foodborne pathogens (bacteria, viruses, and parasites) and create the spoilage microorganisms. Thus, the product render inedible. On the other hand, when the safety risk is not known and not reported, the food product can be consumed which causes foodborne illnesses (Mercier et al.,2017). It is estimated that annual number of illnesses, hospitalizations and deaths in United States (US) because of foodborne pathogens. The approximately by 48 million (47.8 million) gets sick, 127,839 are hospitalizated and 3,037 die each year (CDC,2016). From another perspective, food waste approximately by 12% occured during distribution of products because of inappropriate refrigeration in US (Mercier et al.,2017 trans by NRDC, 2012). In deed, cold chain is an essential tool for achieving social (guraantee human health by preventing and controlling occurrence of harmful foods), economic (cost reduction) and ecological goals (reduction in waste) (Shashi et al., 2016).

Many studies widely discussed about social, economic and the environmental impact of traditional supply chain and some practical implementations in supply chain remained at the top of research agenda. In spite of increasing awareness and importance of cold chain, there have been few studies about supply chain that deal with perishable products. Most of them only tracked to temperature fluctuations along the cold transport. Therefore, the main purpose of this study is to determine the potential criteria affecting cold chain performance and explain the causal relations

between criteria by using fuzzy DEMATEL which is an efficient multi-criteria decision making (MCDM) technique.

Our study titled ‘Conceptual Framework Model For Performance Improvement of a Cold Chain Management in Supply Chain By Using Fuzzy DEMATEL Method’ is consist of 7 chapters. Chapter 1 involves perishable product categories and precooling system. The logistics activities in cold chain are addressed in Chapter 2. Technological tools for traceability and food safety certifications are given in Chapter 3. A framework model for cold chain is proposed in Chapter 4. Chapter 5 explains the methodology (Dematel) of the model. The implementations of the model are presented in Chapter 6. The results of study and managerial suggestions for organizations are given in Chapter 7. Finally, the study completed with discussion of the fundamental findings and making recommendations in further studies.

CHAPTER 1. OVERVIEW OF THE COLD CHAIN

1.1. Infrastructure in Cold Supply Chain (CSC)

Every day, millions of tons of perishable products are produced, stored, transported and distributed worldwide. Perishable products are temperature-sensitive commodities and deteriorate the most quickly owing to inappropriate refrigeration or temperature abuses. Therefore, maintaining in an appropriate, safe and specified ranges of temperature at every stages of cold supply chain is essential in preserving the required quality and quantity of products.

"Perishable items are those items, which have a fixed or specified life time after which they are considered unsuitable for utilization" (Paam et al.,2016 trans by Kurniawan et al.,2015). Perishables are divided into many different food product categories, including dairy products and eggs, meat and poultry, fish and seafood products, fruits and vegetables and all cooked foods and even leftovers. There are various temperature standards to suit them along storage and transport in order to ensure their freshness, marketability and desirability (Jedermann et al.,2009). Proper refrigeration slows the growth of bacteria on food, involving pathogenic bacteria and spoilage bacteria. While pathogenic bacteria causes to foodborne illness, spoilage bacteria causes to deterioration of foods and flavor, color and texture changes, weight loss, softening and excessive ripening (Insight Medical Publishing, w.date).

Table 1. Optimal Storage Temperature of Perishable Items

Perishable Food Commodities		Storage Temperature Range
Dairy Products	Milk	**3 to 4°C**
	Cream, yoghurts, butter, cheese and eggs	
	Ice cream	**≤ - 18°C**
Meat & Poultry	Beef, lamb and pork	**1 to 3°C**
Marine Products	Fish and seafoods	**1°C**
	Live seafoods, e.g.crabs and yabbies	**1 to 3°C**
Fruits & Vegetables	Broccoli	**1°C**
	Tropical fruits, e.g. pineapples and bananas	**12 to 14°C**
	Lettuce	**≤ 5°C**
	Frozen vegetables and fruit	**≤ -18°C**
	Root vegetables, e.g. potatoes, onions and carrots	**-**
	Others	**5 to 9°C**
Cooked Foods	-	**3 to 4° C**

Source: TAFE NSW Sydney (w.date).Classifying Commodities.

Pharmaceutical products, flowers and plants, chemicals and some electronic components are other temperature-sensitive items (Makadia, 2018).

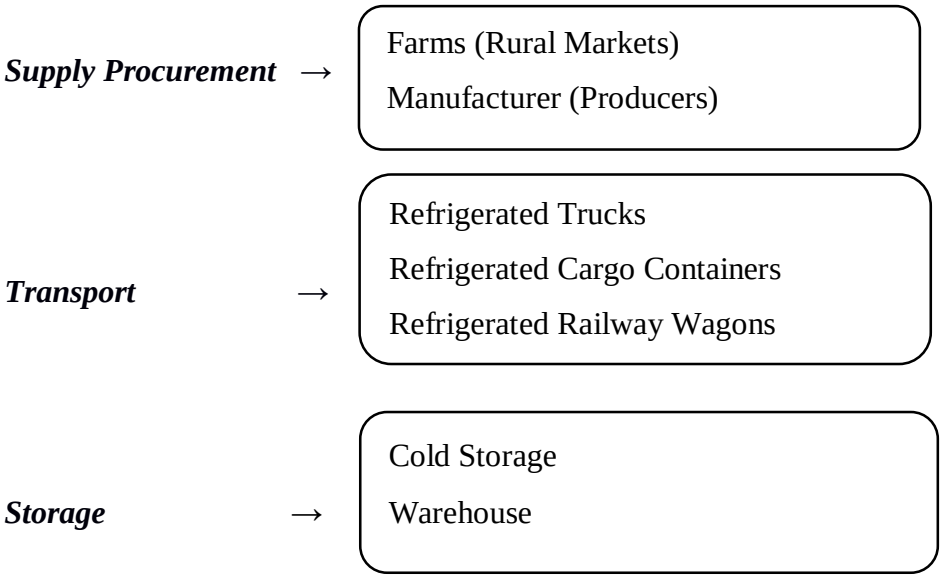
Cold chain is a logistics process because of transporting, handling and holding of perishable products throughout a supply chain within a desired low-temperature range (Bozorgi et al.,2014).

Figure 1. Cold Chain Logistics

The Figure 2 illustrates a basic cold chain infrastructure with its all counterparts. The cold chain begins with supplier and ends with end customers like a traditional supply chain. However, an uninterrupted series of logistics activities with temperature-controlled in cold chain is cricual. The cold chain helps ensuring food quality by reducing food spoilage and the chance of contracting a foodborne illness as well as achieving a sustainable and lasting relationship with customers.

Figure 2. Cold Chain Process

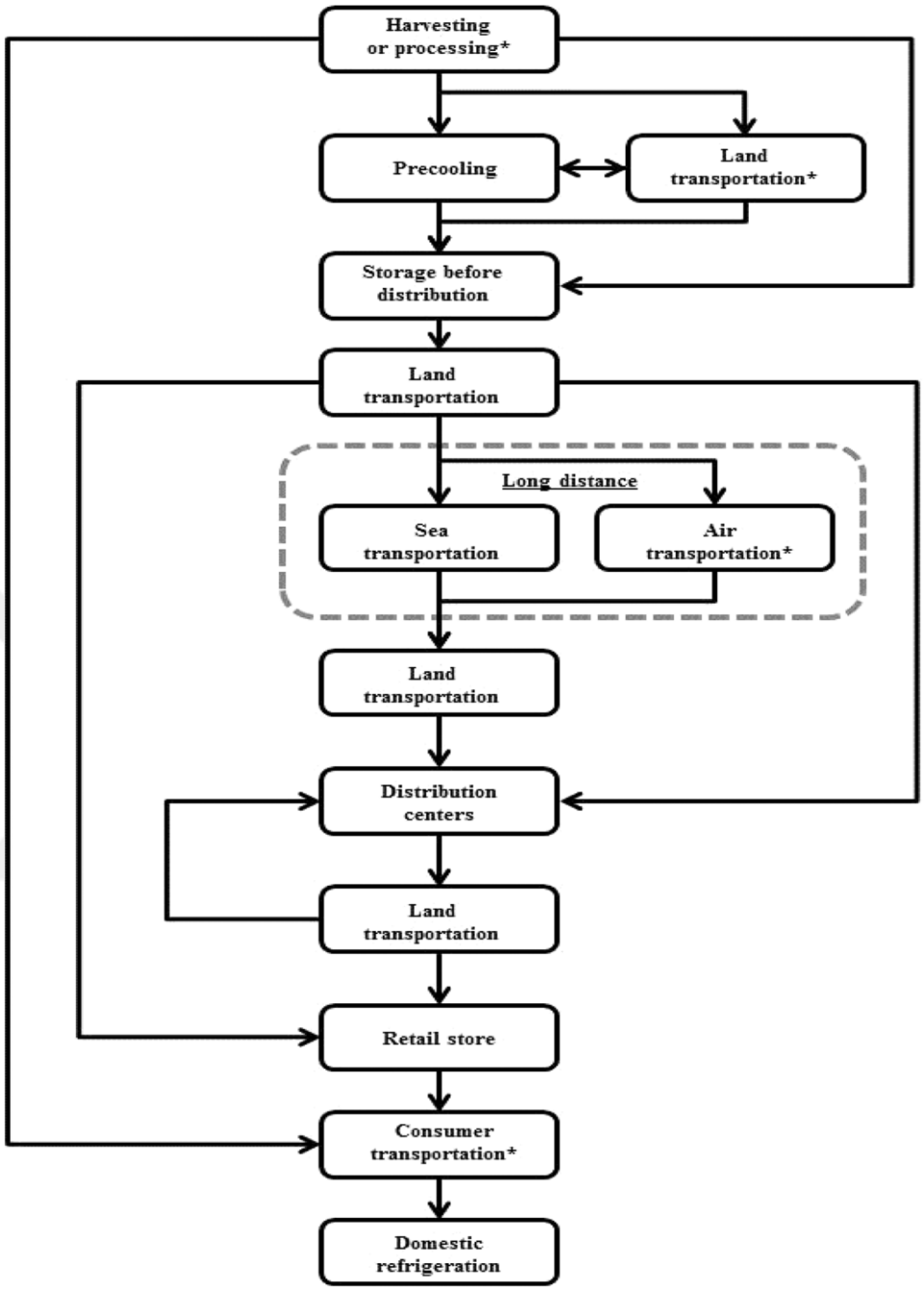
Supply Procurement → Precooling → Transport → Storage → Transport → → Market (Retailers, Wholesalers and Distributors) → End Customer



Source: Brzozowska et al.(2016).Managing Cold Supply Chain.

After harvesting or manufacturing processing, a typical cold chain begins with precooling operations and perishable products are departed to cold storage area for maintaining its specified temperature range. Perishables stay there for a particular period of time. Perishable food products can be transported by using intermodal transportation (usage of two or more modes of transportation) according to destination and groups of perishable products. However, land transportation is an indissoluble part of cold supply chain cycle. Depending upon market demand, one or more storage area and distribution center (DC) may be required. Provided appropriate temperature range along a cold chain, wastage of perishable foods will not be occurred at an earlier stage. Hence, cold chain ends when perishables are put in domestic refrigerator. As seen in Figure 3, a roadmap of classical cold chain process with its main steps and alternatives in detail is shown.

Figure 3. Overview of the Fundamental Steps in Cold Supply Chain



Source: Mercier et al. (2017). Time-Temperature Management Along the Food Cold Chain: A Review of Recent Developments, p.650.

1.2. Precooling System

Precooling (prompt cooling after harvesting) which is one of the critical process assists to remove the pip heat of fruits and vegetables gradually following harvesting. In particular, it is very important for fruits and vegetables because they can deteriorate in as much as 1 hour (Prasad et al.,2018). The appropriate and adequate precooling is required to maintain the quality of fruits and vegetables. More specifically, it helps to ruin the growth of spoilage microorganisms, the pathogens and the bacteria. Otherwise, it has been shown to increase losses and render fruits and vegetables inedible. Pelletier et al. (2011) observed temperature and humidity conditions of strawberries on three different pallet units, including prompt, delayed and non-precooling from California to the DC in Florida. The observations highlighted that delayed and non-precooled strawberries have significantly higher water loss by approximately 50% and lower visual quality than fully or partially precooled strawberries.

There are many different precooling techniques; room cooling, forced-air cooling (or pressure cooling), hydrocooling (or water cooling), icing (ice cooling or direct contact with ice) and vacuum cooling (Prasad et al.,2018). The selection of the precooling method is influenced by the type of products to be cooled. The characteristics of precooling methods with application area for some fruits and vegetables is shown in Table 2.

Table 2. Precooling Methods

Methods	Commodity Types and Samples
Room cooling	All fruits and vegetables (e.g. tomatoes, pumpkins, cabbages, beets and peppers)
Forced-air cooling	Fruits and fruit-type vegetables (e.g. potatoes, cucumbers, spinach, strawberries, peppers, lettuce, peas, carrot and bean)
Hydrocooling	Stem, leafy vegetables, fruit-type vegetables and some of fruits (e.g. cucumbers, beans, carrots, broccoli, sweet corn and radishes)
Icing	Stem, roots flower-types vegetables (e.g. asparagus, green onions, leeks, broccoli, sweet corn, radishes, parsnips, rutabagas and brussels sprouts)
Vacuum cooling	Stem and leafy flower-types vegetables (e.g. lettuce, chinese cabbage and leeks)

Source: Dumont et al. (2016).Reducing Postharvest Losses, p.136.

Quick freezing (or shocking) refers to temperature of the products are to be dropped quickly, not gradually. This is a difference between precooling and shocking. This operation is mandatory for the products that are stored at -18℃ such as ice-cream.

CHAPTER 2. LOGISTICS ACTIVITIES IN COLD CHAIN

The cold chain is a science, a technology and a series of specific logistics activities (Rodrigue and Notteboom,2017). It is a process since cold chain is provided all the needful facilities, means and materials, including refrigerated storage, cold warehousing, refrigerated transportation services and insulated boxes and understood all the requirements of customers and biological and chemical processes correlated with perishables. In this chapter, cold transport, cold storage and packaging operations which are main parts of a cold chain are inclusively examined.

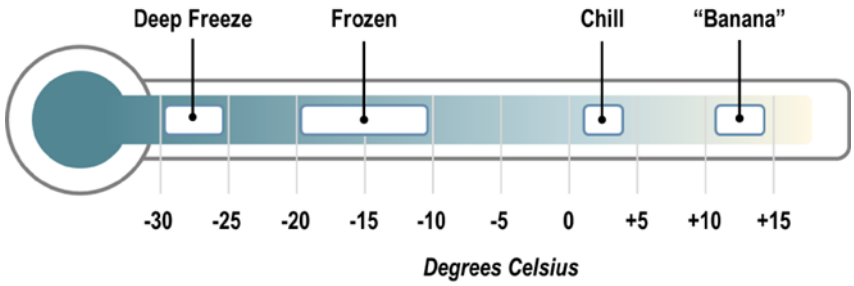
2.1. Transportation in Cold Chain

Refrigerated transportation (or reefer freight) is an absolute necessity for transporting of perishable food products in minimize temperature abuses by monitoring and controlling appropriate temperature range and humidity conditions. Transporting of these products is done by land, air or sea which have refrigeration units, energy needed to run them and needed insulation capabilities to ensure cargo and process integrity requirements.

There are many important parameters related to how to select the most suitable transportation mode to move perishables safely; travelled distance between origin and final destination, the type, size and weight of shipments as well as needed exterior temperature environment. For instance, land transportation is commonly preferred for short-distance trips or perishable foods with longer shelf-life, while a container ship and airplane are more suitable for longer distances.

There are many various product categories which require specific temperature range along cold transport chain. The logistics parties should have adequate scientific knowledge regarding products and their shipping conditions before reaching the end customers. The most suitable temperature levels can be distinguished based on four groups of perishable cargo; “deep freeze” (-28ºC to -30ºC) for transporting seafood and ice cream, “frozen” (-16ºC to -20ºC) for transporting frozen meat, “chill” (2ºC to 4ºC) for transporting fruits, vegetables and fresh meat and “banana” (12ºC to 14ºC).

Figure 4. Optimal Temperature Standards in the Cold Transport Chain



Source: Quesnel. (2017). Cold Chains: How Various Industries Keep Products Cold During Shipping.

Higher temperature cases than desired temperature range has been observed during commercial transportation for many different reasons, such as staff negligence, loading and unloading operations or improper handling. However, whole processes may be gone as planned. There are studies regarding this issue are summarised as follows;

Derens et al. (2006) monitored temperature flows on prepacked meat and yogurt through small temperature recorder from production point to retailer, approximately by 1000 km and later, Derens re-examine for smoked salmon in 2009 with Morelli.

Raab et al. (2009) observed average temperature range of chicken breasts from manufacturer to DC at two different position of pallet units inside the refrigerated vehicle and reported differences in temperature of up to 10ºC between the air near the cooling device and the air near the doors of the truck.

Abad et al. (2009) reported temperature flows by using temperature data loggers throughout 3 days in fish logistics chain and observed temperature increases of 2ºC during loading of fish boxes and of 3ºC during unloading of them.

Koutsoumanis et al. (2010) measured time-temperature conditions of pasteurized milk along the entire cold chain in Greece and reported the average temperature during road transportation was exceed than 6ºC because of inappropriate loading and unloading practices.

Mckellar et al. (2012) observed temperature conditions of 27 packaged lettuce along the commercial cold chain, until retailer during the winter months (January and February) in Canada. In 2014, the study carried out summer months (July and August)

by Mckellar et al. When we looked at the conclusions among these two studies, the winter performance is satisfactory owing to protecting freeze conditions. During summer months, higher temperature ranges were observed approapriately by 6.3ºC for July and 5.9ºC for August and shrinkage and pathogen growth because of temperature abuses during loading and unloading practices along the cold chain could occur in summer months.

Nunes et al. (2014) investigated the real-time temperature fluctuations of blackberries inside pallets placed at different positions from the Mexico to California by using time-temperature indicators and observed significant heterogeneity of the temperature of up 4-5ºC among pallets.

Gogou et al. (2015) controlled the temperature fluctuations of meat products during commercial transportation in Greece.

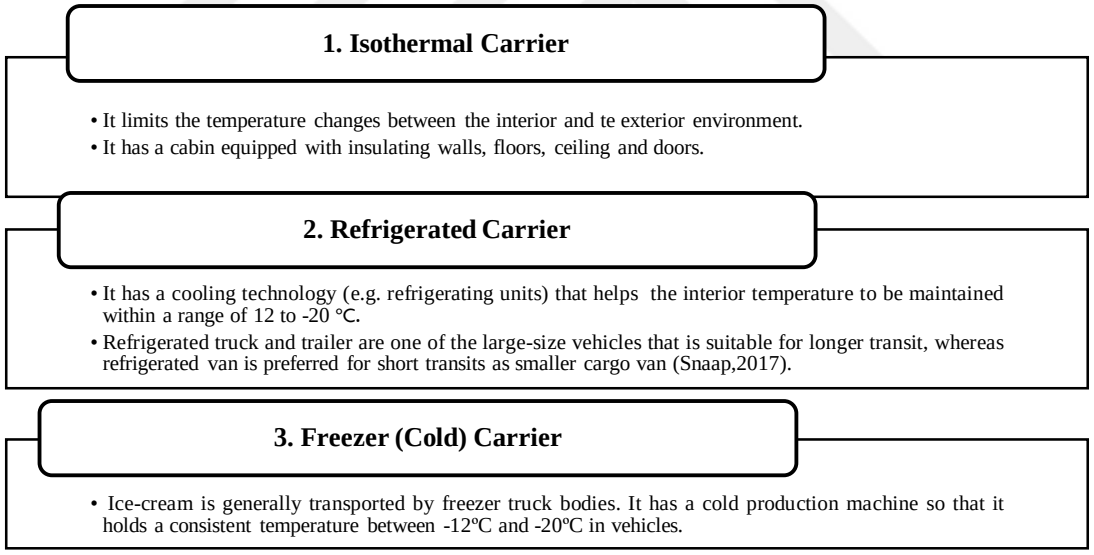
2.2.Types of Transportation in Cold Chain

2.2.1. Land Transportation

Land transportation is the most preferred transportation mode and it involves trucks (e.g. small-rigid and larger-rigid), vans, semi-trailers. The small rigid vehicles and vans have refrigeration units directly powered by the vehicles engine whereas semi trailers and larger rigid vehicles have not dependent engine-powered refrigeration units. Some of them have supported with electricity so that they are mains-powered while parking or in precooling (WHO,2014). Also, all these vehicles should be equipped with data loggers and electronic temperature monitoring systems.

There are three types of refrigerated carriers which are guarded a consistent temperature range for perishable products and provided ideal temperature along entire the cold chain operations, namely, isothermal, refrigerated and freezer (or cold) are shown in Figure 5.

Figure 5. Refrigerated Vehicles in Cold Chain



Source: TIBA. (2015). How to Transport Perishable Goods.

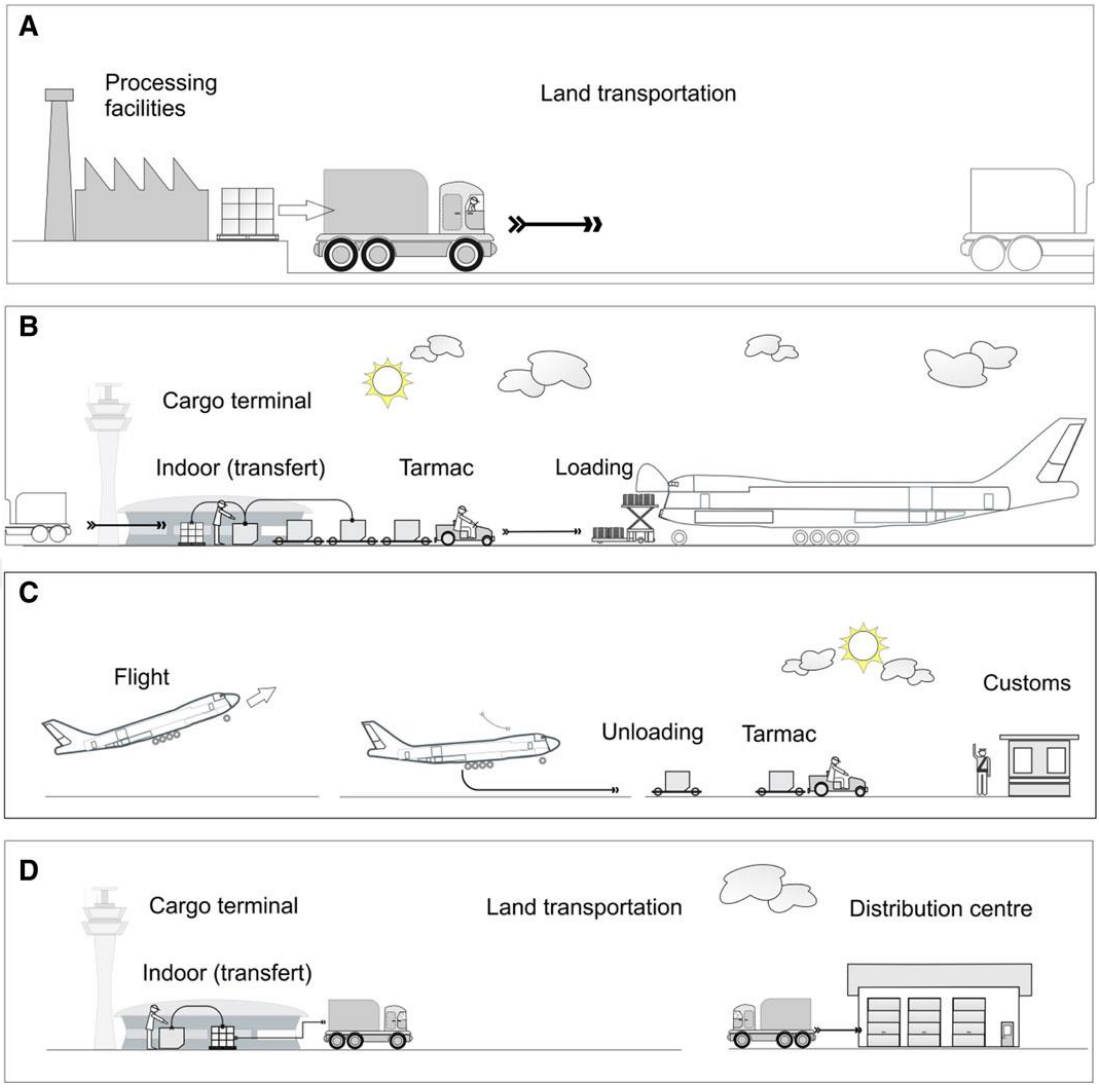
2.2.2. Air Transportation

Air transportation provides many important advantages for transporting of perishable food products especially in supply of perishable foods in regions that are distant from the production facility or harvesting (Mercier et al.,2017). It is a regional link which moves to the large amount of products around the world with shortest shipping time. Airplanes which are the quickest and safest means of air transportation are commonly used for transporting of perishable foods with shorter shelf-life. It provides a safe, efficient as well as quick transit time.

There is a special center where for handling of perishable product, is equipped with freezers and refrigerated chambers that can be controlled the appropriate temperature for many various types of perishable cargo at each airport (TIBA,2015). These perishable products are also guarded at required quality and quantity at all times by highly-skilled and specialized personnel.

Airport operations are divided into two categories; operations on the tarmac and operations in cargo terminal. More specifically, the terminal operators are responsible for identifying and arranging the perishable cargo inside the cargo terminals such as perishables are weighted, labeled and placed them into unit load devices (ULDs). The ULDs are transported to a passenger flight or aircraft for delivery. After a flight, the perishables are unloaded from planes and immediately carried to handling center to control in terms of its quality and quantity. Finally, perishables are loaded and transported to DC through land transportation. The Figure 6 illustrates transits of perishable products both land transportation and air transportation.

Figure 6. Transfer of Perishable Products through an Air Transportation



Source: Mercier et al.(2017).Time–Temperature Management Along the FoodCold Chain: A Review of Recent Developments, p.654.

Air transportation has remained limited for transporting of perishable products because of environmental cost as well as higher economical cost, although it has such a big advantage than other transportation modes. In addition, some studies highlighted that air transportation has poor time-temperature control during operations on ground at the airport before and after the flights. Mai et al. (2012) recorded the temperature range of fresh fish along air freight, from manufacturer in Iceland to distributors in England and France and observed temperature abuses because of unloading and loading operations and absence of acceptable storage conditions at the airports. The temperature abuses depending on unchilled storage is at the arrival at Keflavik airport (KEF) by approximately 11°C and Humberside airport (HUY,UK) by approximately 10°C which caused to increase the temperature inside packaging boxes. The ground

operations before and after the flight, including reloading and unloading practices with shorter durations (nearly 2-3 hours) are other notable impact of temperature fluctuations during air transportation.

2.2.3. Sea Transportation

Sea transportation involves refrigerated vessels which is equipped with specialized systems to circulate properly air flow, carries to ensure perishable products until intended destination without any biological and physical damage.

There are three types of sea transportation vehicles; multi-purpose ships, refrigerated ships and reefer ships. The first is multi-purpose ships are used to move both passengers and cargo. In such ship, refrigerated part is located under the areas reserved for passengers. Second one is refrigerated ships are placed with refrigerated containers. Finally, there are reefer ships use specific ramps for loading and hauling the cargo and it is estimated that it is the most preferred than other ship models (Chopra, 2019). The reefer ships came to existence because of lacking of production and process capacity of these perishable products of some countries.

It is commonly preferred for perishable food products with longer shelf-life than transportation time because it is the slowest transportation mode as well as it has a cost-efficiency mode. Amador et al. (2009) monitored temperature of pineapples throughout 3 days from Costa Rica to Florida (US) by temperature sensors and smart tag. These sensors and tags were placed to three different points in the pallet; upper corner, middle point from bottom to up and lower corner. Defraeye et al. (2016) investigated the temperature fluctuations of oranges in refrigerated container in sea transportation during 21 days (from 2 July until 23 July). Both two studies reported that the temperature that close the bottom of pallets is lower than close the top of pallets due to vertical air-flow in refrigerated containers.

2.3. Storage in Cold Chain

The suitable and special technical (or functional) refrigeration equipments in a special facility allowing to store the perishable products within an acceptable temperature range, appropriately management of the storage space and insulation of walls capable of maintaining adequate temperature are essential requirements for ensuring the load integrity and protecting the safety of food products.

The cold storage rooms are commonly used for fruits and vegetables, while freezer (or frozen) rooms are used for storing of dairy products, delicatessen products and meat products. The personnel should take necessary precautions while entering both freezer and cold room (e.g. wearing proper protective clothing and doing necessary hygiene requirements). Personnel should not work for length of time unless needed both two rooms.

The refrigeration units, the capacity and dimensions of the installation in a cold storage warehouse can vary because of changing the temperature and humidity conditions of perishable products.

Table 3. Cold Storage Conditions for Fruits

Fruits Type	Storage Temperature (°C)	Relative Humidity (%)	Holding Time	Water Content (%)	Freezing Point (°C)
Apple	**-1/+4**	**90**	**3-8 (month)**	**84**	**-1.1**
Apricot	**0**	**80**	**1-2 (week)**	**85**	**-1.1**
Banana	**14/16**	**85-95**	**1-2 (month)**	**70**	**-0.8**
Seeded grape	**-1/1**	**90-95**	**3-6 (month)**	**82**	**-2.1**
Pear	**7/10**	**90**	**2-3 (week)**	**83**	**-**
Peach	**-0.5/0**	**90**	**2-4 (week)**	**89**	**-0.9**

Source: ESSIAD (2019). Cold Chain Process in Food Storage.

The storage capacity, appropriate and stable construction are main parts of warehouses in a well-functioning cold chain. It is required that the appropriate and high capacity storage area (generally 80-120 tonnes) for the pallet units and storage shelves should be characterized by appropriate distance, strenght and stable construction (Brzozowska et al.,2016). For instance, the required interval between two shelves is almost 3.20 meter. The more shelving distance is short, the more storage

operator can damage pallet units with material handling vehicles. The rule clearly states that the distance between pallet units and wall is 4 centimeter at least.

Depending on the operating conditions, carrying out the loading and unloading operations and refrigerated chambers, the selection of the most suitable and right door type as well as appropriate refrigeration units are important elements of low-temperature warehouses (Refrigeration Industry,2017). The cold storage doors are responsible for the thermal insulation and the balance of the cold chambers equipped with the refrigeration units. These refrigeration doors only should open when necessary and items that used frequently store near the door.

The cross contamination is happened when the bacteria or microorganism are unintentionally transferred from one package to another (FSA, 2017). The transfer of bacteria is commonly observed between raw and ready eat foods. However, the appropriate cold storage is a critical process to prevent this hazardous situation. For instance, store raw meat (beef) above pork and pork above poultry respectively. Store dairy products (e.g.milk) seperately from meat products (Houston Department of Health and Human Services, w.date). The pest control as well as hygiene requirements in storage area is also very important factor for food safety. The cold storage warehouses are regulary received the pest control service by professional suppliers who create a suitable environment in the storage area regarding preventing and reproduction of pests (UTIKAD,2017). The maintenance of refrigeration units should be periodically provided and walls and grounds in the warehouses should be cleaned by sanitary and appropriate hygienic requirements.

The cold docks and blowers help to avoid any potential temperature loss throughout loading and unloading operations with loading ramps in the receiving and preperation area of warehouses. The loading ramps help the refrigerated trucks to be loaded quickly and practically. In addition to these, cold storage rooms regarding appropriate temperature and humidity conditions should be monitored by heating and cooling systems in everytime of the year from everywhere. Thus, emergency action should immediately be done when necessary.

The shelf-life is defined as "is the time during which a perishable food remains safe, comply with label declaration of nutritional data and retain desired sensory, chemical, physical and microbiological characteristics when stored under the recommended conditions" (IFST,1993). The cold chain inventory management

process based on time-temperature measurement, including FIFO (First In, First Out), FEFO (First Expiration, First Out) and LIFO (Last In,First Out) directly affecting the shelf-life of perishable products.

Table 4. Inventory Rotation in Distribution Center

Type	Brief Description
FIFO	The items that have arrived at DC first, will leave first.
FEFO	The items that is closest to the expiration date will be shipped first.
LIFO	The items that have arrived at DC last, will be shipped first.

Source: Onal et al. (2015).The Economic Lot-Sizing Problem with Perishable Items and Consumption Order Preference, p.881-882.

Although FIFO is the most popular routing system it is not efficient for perishable foods because time spent at warehouses is only small factor affecting its shelf-life. The perishable items that have just arrived in DC can have shorter remaining shelf-life from production sites to DC because of inappropriate or delayed precooling, temperature abuses during transportation or unsuitable packaging. Therefore, FEFO is accepted as the best way for significantly waste reduction and improve its quality (Nunes et al.,2014; Mercier et al.,2017).

2.4. Packaging in Cold Chain

2.4.1. The Traditional Role of Packaging

Packaging has many important functions along the entire supply chain, including protection and preservation, promotions and information, convenience, utilisation and handling and waste material reduction (TCGF,2011). According to Grönman et al., the primary function of packaging 'is to protect and distribute the right product to the right end-user in a safe, cost-efficient and user-friendly way', whilst it serves a variety of other purposes.

Packaging is one of the vital logistics operations in food preservation towards any physical and biological damage during preperation, handling, storage and transportation throughout supply chain. More specifically, packaging has ability to protect breakage (mechanical protection), spoilage (preventing humidity, gases, flavours, light and aromas), contamination and theft which will meet the requirements of the product. A combination of different materials in a variety of packaging structure is used in parallel with this purpose (Verghese et al.,2015).

Packaging is mainly divided into three main categories; (TCGF,2011)

- Primary Packaging: Primary packaging is the last piece of packaging between products and customers. It is directly contacts with the products (e.g. a plastic bag, steel can or glass jar).
- Secondary Packaging: Primary packaging is protected by secondary packaging and it is a discarded material when the product is started to used (e.g. stretch wrap or shrink film).
- Tertiary Packaging: Primary and secondary packaging is protected by tertiary packaging during distribution of the products (e.g. a corrugated cardboard box).

2.4.2 Packaging Systems

2.4.2.1. Active Packaging (AC) and Passive Packaging (PP)

The traditional functions of packaging have been evolving over the past years because customers are more demanding fresh and toxic-free and highly environmentally-friendly food products with increased health consciousness and sustainability awareness around the world. For such reasons, a well-designed packaging process on the basis of being fit-for-purpose is unavoidable. Active packaging (AC) and passive packaging (PP) allow to maintain the quality of foods, improve food safety and waste reduction by ensuring an optimal, safe and specified ranges of temperature throughout cold supply chain.

Active packaging is an innovative approach to prolong the shelf-life of perishable foods and improve its sensory properties or safety while keeping the quality of packed foods with the addition of various active substances inside the packaging materials (Realini and Marcos,2014). Active packaging has two fundamental technologies as active scavenging systems (absorber) and active releasing systems (emitter), are explained with its all food implementation as follows;

Table 5. Active Packaging Technologies in Cold Chain

Active Scavenging Systems (Absorber)	
Active Packaging Types	**Food Applications**
Ethylene Absorber	Climacteric fruits and vegetables.
Moisture Scavenger	Strawberries,mushrooms,tomatoes, seeds,maize,grains,meat and fresh fish.
Oxygen Scavenger	Fruit and vegetable juices, cooked meat products, bakery products and cheese.
Active Releasing Systems (Emitter)	
Active Packaging Types	**Food Applications**
Antioxidant Releaser	Fresh fatty fish and meat, nuts, seeds and oils.
Antimicrobial Packaging Systems	Fresh seafood, fresh and processed meat, fresh and processed fruits, vegetables, dairy products, bakery products, grain, cereals and ready-to-eat meals.
Carbon Dioxide Emitter	Meat and fresh fish.

Source: Yildirim et al. (2017). Active Packaging Applications for Food, p.168.

Passive packaging systems are insulated packaging (e.g. insulated polystyrene, insulated plastic containers, insulating covers, insulated shipping boxes and thermal insulated trolleys) improves the conditions of packed perishable products by keeping the optimal temperature range without any active temperature-control inside the container. Also, refrigerants are used with passive packaging systems in providing a temperature-controlled environment along cold transport. The main refrigerants involve dry ice, gel packs, phase change material (PCM), liquid nitrogen, eutectic plates (or cold plates) and quilts (Rodrigue and Notteboom, 2017; Quesnel et al. (2017)).

Table 6. The Major Refrigerants in Passive Packaging Systems

Refrigerants	Features
Dry Ice	- Dry ice which is the solid carbon dioxide is almost (-) 80ºC. - It is capable of maintaining suitable frozen temperature range. - It is used for dangerous goods, pharmaceuticals and foodstuffs. - Dry ice is not melt.
Gel Packs	- Gel packs is soft-sided pouch involving a liquid which has a variety of thicknesses,sizes and shapes. - It provides long-lasting protection for temperature-sensitive items.
Liquid Nitrogen	- Liquid nitrogen is -196 ºC, capable of maintaining cold temperature over a long period of time. - It is commonly used for transporting of biological products such as organs and tissues.
Eutectic Plates	- Plates are filled with a liquid maintaining a stable and cold temperature for short period of time and plates may be reused many times.
Quilts	- Quilts are insulated pieces which are placed around loads for maintaining appropriate temperature range.

Source: Rodrigue and Notteboom (2017). The Cold Chain and its Logistics.

2.4.2.2. Intelligent Packaging (IP)

Intelligent packaging (or smart packaging) which is monitored internal and external status of packed food products along storage, transportation and distribution is one of the innovative solutions. Thus, the quality and safety of foods is controlled. The customers, retailers and processors take information about the quality of the foods by using applications of intelligent packaging which warns to them when needed (in case of emergency).

The intelligent packaging is consist of multiple smart technologies with differentiated functions; data carrier devices, sensors and indicators (Cerqueira et al.,2018). The main intelligent technologies with types and application area is shown in the following table.

Table 7. Intelligent Packaging Technologies

Intelligent Technologies		Food Applications
Interactive Packaging	Bar code Label	All packaged foods.
	Radio-frequency identification (RFID) tags	All packaged foods.
	Sensor-enabled RFID tags	Fruits, vegetables and meat.
Sensors	Biosensors	Fish and meat products.
	Oxygen sensors	All packaged foods.
	Temperature sensors	Dairy products, fish and meat.
Indicators	Freshness indicators	Mango, kiwi, pears, melon, avocado and meat and fish products.
	Gas indicators	All packaged foods.
	Time-temperature indicators (TTIs)	Fish and meat products.

Source: Cerqueira et al.(2018). Intelligent Packaging, p.8.

Interactive packaging is designed to connect between partners in supply chain and products and stores more accurate and more efficient information regarding storage, distribution and traceability of the foods within the food supply chain. Hence, interactive packaging is intended to guarantee food quality and theft preventation and to help ensuring to waste reduction (Kalpana,2019). The Bar code label, RFID smart tag and sensor-enabled RFID tag which are automatic identification devices, are main developing categories of intelligent systems.

- ***Bar code label*:** A 2D barcode which is a graphical image attached on products, stores information about product and its content, including product identification and stock management (Cerqueira et al.,2018). Also, information can be

read with barcode labelling, by using electronic camera based readers or a suitable optical scanning devices.

- ***Radio Frequency Identification (RFID)*:** There are a wireless microchip, an antenna and a reader module in RFID technology. It includes a wireless microchip which attached to an antenna in the smart tag stores information on the tag regarding product identification, and then the antenna transmits the information to a reader by using radio waves (Kraisintu and Zhang,2011). The RFID tag is used to monitor storage and distribution process, make a greater shelf-life prediction as well as inventory management.

- ***Sensor-enabled RFID Tag*:** The RFID tags are linked to sensor to measure data, including temperature, relative humidity, light exposure, pH, volatile compounds, pH and gas molecules concentrations (Cerqueira et al.,2018). The sensor-enabled RFID tags are widely used in cold chain because it tends to contribution both directly and positively to social welfare by reducing and controlling occurrence of harmful foods.

A sensor "is a device used to detect, locate or quantify energy or matter, responding to a measured signal of a chemical or physical property" (Cerqueira et al.,2018). Sensors involve a receptor and a transducer collecting detailed information about product packaging and its content, such as operating history of the packaged poducts and changes in the environmental conditions like carbon dioxide or time and temperature. The oxygen sensors, temperature sensors and biosensors are attached to the package so that it can be continously monitored the quality and safety of foods.

- ***Oxygen Sensors*:** The oxygen sensor is intended to the detection of oxygen level inside packed products.

- ***Temperature Sensors*:** The temperature sensors are used to measure the temperature inside packed products. It can be applied frozen products without the exception of dairy products, meat products and seafoods.

- ***Biosensors*:** The biosensors which are bio-analytical devices are developed by combining the processing ability of biological process with electronic techniques. These sensors are intended to identify the microbial quality of packed foods. It is based on antibody-antigen reactions which indicates the presence of a pathogenic bacteria. "The bacterial toxin is bound to the antibodies and immobilized

on a thin layer of film, resulting in a visual signal in the presence of a pathogenic bacteria" (Ucuncu,2020).

Indicators are substances whose solutions change colour because of pH, temperature or gas or microbiological situations. Thus, indicators can provide quantitative or semi-quantitative and visual information about all packaged materials. Freshness indicators, gas indicators and time temperature indicators (TTI's) are major parts of indicators.

- ***Freshness indicators*:** The freshness indicators are used to determine losses affecting directly to freshness by the reason of many chemical, biochemical, physical or physicochemical during the shelf-life. More specifically, these indicators are used to detect for CO_2, O_2 , amines, ethylene ammonia or ethanol detection. It is based on the basis of the colour change of the label on the packaging in the presence of metabolites caused by ripening and microbiological spoilage. The quality of packed foods are provided throughout distribution chain by using freshness indicators identifying history of time and temperature range and microbiological functions.

- ***Gas Indicators*:** These indicators are used to provide information related to the absence of altered gas concentration or particular gas changing colour because of enzymatic and chemical reactions.

- ***Time-Temperature Indicators*:** The history of time and temperature along the supply chain is shown through these indicators. The data concerning this issue is downloaded to a computer and created picture of the food depending on high or low temperature fluctuations at the end of shipping. Time temperature indicators help reducing the food waste, consumer convenience and management during whole the food supply chain, ensuring the higher safety by monitoring the temperature changes.

CHAPTER 3. TRACEABILITY SYSTEMS IN COLD CHAIN

3.1. Overview of Traceability in Cold Chain

The cold chain is a special process which requires more technological solutions to a better management of cold storage and transportation process. The technological systems in supply chain help monitoring and controlling the appropriate temperature range in real-time from inception to delivery for many different perishable product groups as well as providing better control on products located at a particular (or given) time period.

Traceability in cold supply chain is becoming significantly important. In particular, food industry where safety risk is intensive. It is a crucial point because it slows contamination, pathogens and spoilage microorganisms by determining hazards as possible as as well as operationalizing standards by increasing transparency across cold supply chains. The real time and seamless managed and controlled a cold chain process supported by information and communication technologies (ICT) will contribute significantly to the growth of the cold chain market in terms of freshness and security of foods, waste reduction and reduction in potential negative economic impact.

Traceability which is both sub-criteria of quality management and risk management tool is used to protect human health at the highest level in perishable food products (Bevilacqua et al.,2009;Yarali,2019).

'Traceability' as a term has so far defined by several researchers and organisations regarding their area and goals as follows;

"Traceability is the ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales or internally in one of the steps in the chain" (Moe, 1998).

"The ability to track any food, feed, food producing animal or substance that will be used for consumption, through all stages of production, processing and distribution" (European Commision, 2007).

"Traceability is the history of a product in terms of the direct properties of that product and/or properties that are associated with that product once these products have been subject to particular value-adding processes using associated production means and in associated environmental conditions" (Regattieri et al.,2007).

"Traceability is the ability to access any or all information about a product throughout its life cycle by using a system of recorded identifications" (IISD,2015).

"Traceability system is in order to realize the traceability with trusted information in the entire food supply chain and effectively guarantee the food safety by gathering, transferring and sharing authentic data of food products in production, processing, warehousing and distribution" (Tian,2018).

"Traceability is traced and tracked of the vegetable and animal products, food and feed, the animal or plant which the food is obtained, the substance which intended or expected to be found in food and feed during all stages of production, processing and distribution" (Yarali,2019).

Therefore, traceability is a tracking system which are guarded the quality of all raw materials and added components by tracking, tracing and controlling the anticipated temperature range, relative humidity and other atmospheric conditions from source to final distribution in cold chain logistics.

3.2. Measurement Tools in Cold Chain

Perishable products should have a constant refrigeration range to ensure the required food quality and its safety especially in storage and transportation. This can only be achieved with continuous temperature and humidity controlling, monitoring and recording in real-time by using thermometers, hygrometers and data loggers. Thus, it can directly contribute to food providers, society and environment in terms of cost reduction, customer satisfaction and waste reduction (Testo, w.date).

Thermometer is a simple device and it is used for monitoring temperature. It has two different types depending on the specific applications; non-contact temperature measuring instruments and portable temperature measuring instruments.

- ***Non-Contact Temperature Measuring Instruments*:** These devices measure the temperature from a specified distance, without non-contact with product. These are designed only for achieving a single purpose. Infrared thermometers which are a good

example for non-contant temperature measuring instruments are only suitable for surface temperature of products.

- ***Portable Temperature Measuring Instruments*:** These are commonly used by hand. It can be with fixed or exchangeable probes. The thermometers with fixed probes are only suitable for measurement of single situations, such as internal temperature measurements for chilled foods. The devices with exchangeable probes are commonly suitable especially in multi-purpose situations like measuring for air temperatures, internal temperatures, surface temperatures or temperature indication between packages.

Hygrometers are used for measurement of humidity and moisture quickly, precisely and reliably.

Dataloggers can be used to measure some important optimum conditions for specific products, including temperature, humidity, CO_2 and air. Dataloggers are necessary in storage and transportation processes. Since, logistics experts can see immediately whether transport temperature have remained constant during delivery. These are tested, recorded to data and sent the data to a wireless storage area.

3.3. Business Certification of Food Safety Management Systems

The food quality and safety has become a major issue for doing business and gaining a competitive advantage with increased global competition as well as customer confidence. The food products should be cooled at specified temperature limit along the entire cold chain to ensure the safety and quality of food products. The food safety certification, including HACCP, BRC and IFS which is a third-party verification for that purpose. It is based upon a detailed food inspection process by food inspectors. It is allowed to assess, monitor and prove whether appropriate refrigeration is done (Global Food Safety Resource, 2014).

Table 8. Food Quality Certifications

Food Quality Certification	
HACCP	Hazard Analysis and Critical Control Points
BRC	British Retail Consortium
IFS	International Food Standard

Hazard Analysis and Critical Control Points (HACCP) is a systematic preventive approach that was developed in 1959 by a group of engineers and food scientists from the Pillsbury Company, the National Aeronautics and Space Administration and the Natick Research Laboratories. The fundamental purpose of HACCP is to guarantee food quality and safety throughout whole cold supply chain by preventing physical, chemical and microbiological risks (Tian, 2018).

The HACCP concept has significantly evolved around the world. In particular, it is widely used in food industries as well as pharmaceuticals and cosmetics. The HACCP is differ from traditional " only final product " quality control approach that is comprehensively developed to identify various potential hazardous factors from farm to folk including, supply of raw materials, production, preperation, handling, storage and transportation and to eliminate food safety hazards by effectively ensuring the protection and control of system.

The " record keeping procedures " containing written HACCP plan associated with risk analysis, critical control points, critical limits, verification operations is one of the essential requirements of HACCP system to help ensure the consistent safety and quality of foods and processes (Yarali,2019). Besides, HACCP provides an information platform for all cold supply chain members related to implementations including, monitoring and verifying of their daily work.

The British Retail Consortium (BRC) is the global standard for food safety which is fundamentally developed by food industry retailers, food service organisations and manufacturers in UK in 1992. The first BRC standard is published in 1998 but, it is globally approved by the Global Food Safety Initiative (GFSI) in 2003, which means the standard meets "benchmark" factor for acceptance. The BRC standard is designed as a " total quality management " program regarding food quality, safety, hygiene and integrity requirements (Safe Food Alliance,2018). The standard involves mainly seven special issues including, HACCP system, quality management system, environmental standards, product control, process control, packaging and personnel implementations (Yarali,2019).

The International Food Standard (IFS) is a common food safety standard that is developed by German food industry retailers in 2002 and supported by French retailers in 2003 and the major Italian trade association in 2007. The IFS standard is a

uniform way to evaluate the quality level of their suppliers, which are audited by independent auditor institutions. Also, it is allowed to ensure the quality and safety of retailers and wholesalers branded products and production processes (Yarali,2019).

CHAPTER 4: CONCEPTUAL FRAMEWORK MODEL

The purpose of this study is to identify the criteria affecting the food quality and its safety within cold supply chain and to explain causal relationship between criteria and importance order as well. In total 12 main criteria and 35 different sub-criteria is defined by searching literature. In particular, technological devices related to traceability, transportation and storage capabilities and efficiency, packaging and refrigeration systems are highlighted in relevant researches and in many various internet sources. Among other things, food safety and quality business certification and personnel play a significant role in a cold chain, so we added these two criteria on other important criteria. These evaluation criteria with its sub-criteria is given in the following table.

***Packaging (C1)*:** Packaging is very important logistics activity in protecting physical and chemical properties of foods as it moves through the cold supply chain to end users. Appropriate, adequate and good quality material selection are factors affecting strongly hygiene,safety and freshness of foods.

Table 9. Packaging with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
1	**Packaging**	Material selection **(P1).** Inadequate packaging **(P2).** Inappropriate packaging **(P3).** Dirty packaging **(P4).**
Author		
Redlingshöfer and Soyeux (2012),Realini and Marcos (2014),Bag and Anand (2015),Verghese et al. (2015), Brzozowska et al. (2016), Ali et al. (2017),Mercier et al. (2017),Yildirim et al. (2017), Rodrigue and Notteboom (2017),Onursal et al. (2018), Cerqueira et al (2018), Raut et al. (2019).		

Table 10. Cold Storage with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
2	**Storage Specifications and Loading Capacity**	Inadequate cold storage capacity and unstable contruction **(SSLC1)**. Non-functional refrigeration equipments and lack of temperature variability-controlling facilities/providers **(SSLC2)**. Insulation of walls **(SSLC3)**.
Author		
Carullo et al. (2009), Ismail et al.(2011), Bag and Anand (2015), Brzozowska et al. (2016), Mercier et al. (2017), Refrigeration Industry (2017), UTIKAD (2017), Yu et al. (2018),Raut et al.(2019).		

***Storage Specifications and Loading Capacity (C2)*:** Cold store where is a special facility store many various perishable product groups in safe conditions, is equipped with refrigerated rooms and refrigerating equipments. The structure of cold store varies according to the layout of the shelving and the size of the room.

***Refrigeration Systems (C3)*:** Refrigeration systems (cooling systems) including, pre-cooling, refrigeration units, cold and freezer rooms, refrigerators and cold boxes is a necessity for bringing perishable cargo to the appropriate temperature throughout processing, storage and transportation. Failure to ensure the suitability of refrigeration systems because of mis-grading of advanced digital data logger, timing failures in refrigerating equipments or improper pre-cooling tends to increase the safety risk and decrease food quality.

Table 11. Refrigeration Systems with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
3	**Refrigeration Systems**	Inefficient and improper pre-cooling **(RS1)**. Mis-grading of data loggers **(RS2)**. Timing failures in refrigerated equipments **(RS3)**.
Author		
Pelletier et al. (2011), Nunes et al. (2014), Mercier et al. (2017), Onursal et al. (2018), Raut et al. (2019).		

Table 12. Handling Operations with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
4	**Handling Issues and Inventory Rotation**	Inappropriate handling practices **(HIIR1)**. Misplacement of different types of good in refrigerated warehouses/vehicles **(HIIR2)**. Poor inventory rotation **(HIIR3)**.
Author		
Redlingshöfer and Soyeux (2012), Verghese et al. (2013), Nunes et al. (2014), Brzozowska et al. (2016), Mercier et al. (2017),Onursal et al. (2018), Raut et al. (2019).		

***Handling Issues and Inventory Rotation (C4)*:** Material handling practices refer to short-distance movement from a transportation vehicle to a warehouse or warehouse to transportation vehicle and right placement of materials in shelves and vehicles. The efficient and suitable material handling operations with right handling equipments tend to reduce the maximum amount of food losses along cold supply chain.

***Transportation (C5)*:** Cold chain transportation moves to perishable products along from production sites to the final users by using refrigerated vehicles equipped with refrigeration units and insulated walls. A variation of more than one or two degrees ruins to the integrity of entire shipment can result in spoilage and deterioration which avoid the product usable. It is required that the cold shipping must be maintained at required temperature in order to guraantee human health, food quality and avoid food waste.

Table 13. Cold Transportation with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
5	**Cold Transportation**	Loading and unloading practices **(CT1)**. Pallet positions in refrigerated vehicles **(CT2)**. Special technical vehicle selection **(CT3)**. Travelling distance **(CT4)**.
Author		
Foster et al. (2003), Derens et al. (2006), Raab et al. (2009), Abad et al. (2009), Amador et al. (2009),Carullo et al. (2009), Koutsoumanis et al.(2010), Landfeld et al. (2011),Margeirsson et al. (2012), Mckellar et al. (2012),Verghese et al. (2013), Nunes et al. (2014), Mckellar et al. (2014), Gogou et al. (2015), Derens et al. (2015), Surendhar et al. (2015), Hoang et al. (2015), TIBA(2015),Defraeye et al.(2016),Brzozowska et al. (2016), Mercier et al. (2017), Ali et al. (2017), Raut et al. (2019).		

Table 14. Delivery Delays with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
6	**Delivery Delays**	Poor coordination/collaboration among cold chain partners **(DD1)**. Unexpected road conditions **(DD2)**.
Author		
Redlingshöfe and Soyeux (2012), Verghese et al. (2013), Ali et al.(2017), Onursal et al.(2018), Raut et al. (2019).		

***Delivery Delays (C6)*:** Delivery delays can be occurred by inconveniences and unexpected situations on road, including congestion in traffic, accidents and disasters, roadblock or vehicle breakdown.

***Traceability (C7)*:** The refrigeration equipments which are used for storage have to be equipped with temperature monitoring devices for monitoring the temperature variation and food applications at everywhere, anytime of year. All of which has automatic alarm system, is allowed to alert to staff the temperature of foods is out of the safe limits. Hence, the potential source of a problem of food poisoning at early stage is identified and provided a chance to businesses and food providers. The food quality management certifications enhance better control the occurrence of harmful foods by implementing corrective actions.

Table 15. Traceability with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
7	**Traceability**	Temperature monitoring/controlling technologies **(T1)**. Food safety business certifications **(T2)**.
Author		
Akyildiz et al. (2002), Frederiksen et al. (2002), Srivastava, B. (2004), Grönman et al. (2013), Regattieri et al. (2007), Kelepouris et al. (2007), Qu et al. (2007), Abad et al. (2009), Jedermann et al.(2009), Surak, J.(2009), Carullo et al. (2009), Ruiz et al. (2009), Ruiz and Lunadei (2010), Kraısıntu and Zhang (2011),Verghese et al. (2013), Turi et al. (2014), Li et al. (2015),Thakur and Forås (2015), Brzozowska et al. (2016), Mercier et al. (2017) Ndraha et al. (2018), Yu et al. (2018),Onursal et al. (2018), Raut et al. (2019),Yarali (2019).		

Table 16. Staff with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
8	**Staff**	Lack of technical ability of the staff and negligence **(S1)**. Personnel hygiene requirements **(S2)**. Lack of trained staff involved in cold chain management **(S3).**
Author		
Verghese et al. (2013),Brzozowska et al.(2016), Ali et al. (2017),Onursal et al. (2018).		

***Staff (C8)*:** The qualified and trained staff regarding the understanding the system requirements and hygiene requirements is the most critical condition for efficient cold chain process. The lack of technical ability of the staff involved cold chain management and negligence can result in temperature abuses and physical food damage.

***Technical Issues (9)*:** Technical issues involves local heat sources in refrigerated vehicles or warehouses, heterogeneity of the air flow, on-off cycles of refrigeration unit, interruptions of the refrigeration function and lack of technology and research and development (R&D) implementations.

Table 17. Technical Issues with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
9	**Technical Issues**	Lack of technology and R&D **(TI1)**. Temperature fluctuations caused by on–off cycles of the refrigeration unit **(TI2)**. Interruptions of the refrigeration function **(TI3)**.
Author		
Carullo et al.(2009), Nunes et al. (2014),Mercier et al. (2017), Onursal et al. (2018).		

Table 18. Households Consumption with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
10	**Consumption (at home)**	Poor household knowledge and hygiene requirements **(C1)**. Unsuitable purchasing portions **(C2)**. Frequency opening of the domestic refrigerator **(C3)**.
Author		
Redlingshöfe and Soyeux (2012), Verghese et al. (2013), Mercier et al. (2017).		

***Consumption (at home) (C10)*:** Consumers who are the final part of cold supply chain generate the large amount of food waste. Some of which do not consider importance of recommended storage temperature range into. Some do not prefer to use a cooling bag or an insulated box because of short transportation time from supermarket to their home or perishable foods may not often be put quickly in the fridge when households arrived at home.

***Hygiene Requirements of Physical Conditions (C11)*:** The walls and floors should be cleaned in accordance with sanitary hygiene requirements and pest control implemented periodically and regulary.

Table 19. Hygiene Requirements with sub-criteria in Cold Chain

C.No	Criteria	Sub-Criteria
11	**Hygiene Requirements of Physical Locations**	Inappropriate cleaning requirements in walls and floors **(HRPL1)**. Pest Control **(HRPL2)**.
Author		
Brzozowska et al. (2016) FSA (2017), UTIKAD (2017), Gunders,D. (2017).		

Table 20. Other Criteria in Cold Chain

C.No	Criteria	Sub-Criteria
12	**Others**	Weather condition **(O1)**. Heat sources in trucks or warehouses **(O2)**. Absence of legal regulations and regulatory requirements of the organizations **(O3)**.
Author		
Brzozowska et al. (2016), Mercier et al. (2017), Ndraha et al. (2018).		

Others (C12): Seasonal impacts, weather conditions and legal regulations and regulatory requirements of businesses are other notable factors may be shortened or endargers food safety.

From the perspective of holistic view and system approach, it can be said that, criteria under different suggestions can be related to each other. So, in order to understand the structure and propose managerial implications for organizations for a cold chain system, it is necessary to analyze causal relationships between these criteria by using fuzzy Dematel.

CHAPTER 5: METHODOLOGY

5.1. Fuzzy DEMATEL

The management structure of organizations has been evolving with increasing competition and changing and growing the economy. It is a hard job to make a decision where main target is determined by many parameters and the alternatives to be evaluated have different advantages. For such reasons, many different methods have so far created to overcome such a challenge. Decision Making Trial and Evaluation Laboratory (DEMATEL) is the most preferred method because of many important advantages and capabilities.

In this study, DEMATEL is selected because it is a useful way to develop an understanding of complicated system problem in many different areas and an identifying of viable solution in a hierarchical structure. Dematel has abilility to plan and solve the problems by dividing specified criteria into cause and effect groups, allowing ensure a better understanding of causal relations between criteria of a system. As a type of structural modelling approach, this method is not only converts the relationships into a cause and effect group but also explain the critical factors of a complex structure system by using visual graph diagram.

DEMATEL is one of the multi-criteria decision methods which was originally developed by the Science and Human Affairs Program (SHAP) of the Battelle Memorial Institute of Geneva Research Center between 1972 and 1976 (Gabus and Fontela, 1972; Fontela and Gabus, 1976) DEMATEL is a suitable way to examine direct and indirect relations among complicated and embranged factors with certain scores by using matrix operation. It is based on the basis of graph theory that divides selected factors into cause and effect groups by constructing a strategic map to decision-makers for a better understanding and interpreting of the causal interrelationship between selected factors, which is one of the most significant characteristics of the method.

The DEMATEL proceducers can be explained in the following steps;

Step 1. Define the Evaluation Scale

There are a group of m experts and decision-makers for solving the difficult and intertwined problem sets $E=\{ E_1, E_2, \dots , E_m \}$ and there are n criteria $F = \{ F_1, F_2, \dots , F_n \}$ to be considered. The binary relationships among selected factors and the degree of

influence of criteria i to criteria j are determined based on pair-wise comparison scale by expert evaluations. The pair-wise comparison scale may be designated five scales, where the integer scores of 0, 1, 2, 3 and 4 represent ‘‘No Influence’’ , ‘‘Very Low Influence’’ , ‘‘Low Influence’’ , ‘‘High Influence’’ , ‘‘Very High Influence’’ respectively.

Table 21. Comparison Scale of DEMATEL Method

Numerical Value	Linguistic Terms
0	No Influence
1	Very Low Influence
2	Low Influence
3	High Influence
4	Very High Influence

Step 2. Generate an Initial Direct-relation Matrix, *Z*

The initial direct-relation matrix Z is a $n \times n$ matrix is occured by pair-wise comparisons among factors by evaluators, Z= $[z_{ij}]_{n \times n}$. Z_{ij} is denoted as the degree to which the criterion i affects criterion j. When i=j in the matrix, diagonal values are identified as 0.

The direct matrix, *Z* is shown as follows;

$$Z = \begin{bmatrix} 0 & z_{1,2} & \cdots & z_{1,n} \\ z_{2,1} & 0 & \cdots & z_{2,n} \\ z_{n,1} & z_{n,2} & \cdots & 0 \end{bmatrix} \quad (1)$$

Step 3. Establish the Normalized Direct-relation Matrix, *X*

The normalized direct relation matrix X is denoted as X= $[X_{ij}]_{n \times n}$ and $0 \leq x_{ij} \leq 1$is acquired by using the formulas (2) and (3).

$$X = Z/k \quad (2)$$

$$\frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^{n} z_{ij}} ; i, j = 1,2 \ldots, n \quad (3)$$

where *k* indicates the highest value among all elements in the sum of rows and columns of direct-relation matrix *Z*.

Step 4. Obtain the Total-relation Matrix, T

The total-relation matrix T can be acquired by using the formula (4) and where the I is denoted as the identity matrix and the t_{ij} indicates the comprehensive degree to which the criterion i affects the criterion j.

$$T = \left(t_{ij}\right)_{n \times n} = X.(I - X)^{-1} \quad (4)$$

Step 5. The sums of rows and the sums of columns within the total relation matrix, T are respectively represented as D and R. *i.e.,* $D = [d_i]_{n \times 1}$ and $R = [r_i]_{n \times 1}$, is defined by the following formulas (5) and (6).

$$D = \sum_{j=1}^{n} t_{ij} \quad , \quad (5)$$

$$R = \sum_{i=1}^{n} t_{ij} \quad , \quad (6)$$

D indicates the sum of the directly or indirectly effects of criteria/factor i on other criteria, which is called as the influence degree of criteria i. R defines the sum of the directly or indirectly effects of all the other factors on criteria i, called the affected degree of criteria i.

Step 6. (D + R) and (D – R) are identified based on D and R value, where the horizontal axis (D + R) named " Prominence " illustrates the strength of influences given and received, which is calculated by adding D to R and the vertical axis (D – R) named " Relation " is made by subtracting D to R. In addition to these, the horizontal axis (D + R) plays a center role in the problem and shows how much importance the factors have. When the (D – R) > 0, criterion i is affecting other factors and is often grouped into net cause group. When the (D - R) < 0 , criterion i is being influenced by other factors in a system and may be grouped into net effect groups.

Step 7. Determine a Threshold Value (a) and Drawing Cause and Effect Diagram

A common threshold value is determined by decision-makers. All the factors which is greater than a in matrix T is selected and placed on the causal diagram. The causal diagrams can visualize the complicated causal relationships between factors by using graphical diagrams and gather information to decision-makers for solving a problem and making better decision by identifying the difference between cause and effect factors.

Crisp numbers are sometimes inadequate in decision-making process because it is a tough job to be expressed causal relationships among complicated factors by using certain numbers. So, DEMATEL method was extended to the Fuzzy DEMATEL method. This combination is generally preferred for subjective nature of human judgments. Interval sets are used rather than real numbers in a fuzzy environment thereby, linguistics terms are converted to fuzzy numbers.

The Fuzzy DEMATEL method procedures can be summarized as follows;

Step 1. Identifying the decision goal and forming a expert committee who have knowledge and experience to solve the problem.

Step 2. Developing the evaluation criteria.

Step 3. Designing the fuzzy linguistic scale.

The pair-wise comparison scale may be expressed by five linguistic levels; " No Influence (No) ", "Very Low Influence (VL) " , " Low Influence (L) " , " High Influence (H) " , " Very High Influence (VH)". The positive triangular fuzzy numbers, $(l_{ij,}\, m_{ij,}\, r_{ij})$ for these linguistic levels represent " Minimum Level ", " Intermediate Level " and " Maximum Level " respectively.

Table 22. The Fuzzy Linguistic Scale

Linguistic terms	Triangular fuzzy numbers
No influence	**(0, 0, 0.25)**
Very low influence	**(0, 0.25, 0.5)**
Low influence	**(0.25, 0.5, 0.75)**
High influence	**(0.5, 0.75, 1)**
Very high influence	**(0.75, 1, 1)**

Step 4. Obtain an Initial Fuzzy Direct-relation Matrix, Z^k

The initial fuzzy direct-relation matrix is described as $Z^k = [z_{ij}^k]_{n \times n}$ where Z is a $n \times n$ positive matrix is produced by evaluators , k is the numbers of experts, z_{ij} is denoted direct or indirect effects of criterion i affects on criterion j and when i=j, diagonal values are identified as 0.

$z_{ij}^k = (l_{ij}^k,\, m_{ij,}^k \mathrm{r_{ij}^k})$

$$Z^k = \begin{bmatrix} 0,0 & z_{1,2}^k & \cdots & z_{1,n}^k \\ z_{2,1}^k & 0,0 & \cdots & z_{2,n}^k \\ z_{n,1}^k & z_{n,2}^k & \cdots & \vdots \\ & & & 0,0 \end{bmatrix} \quad (7)$$

Step 5. Generate the Normalized Fuzzy Direct-relation Matrix, *D*

Normalized fuzzy direct-relation matrix namely "*D*" is achieved by the formula (8).

$$\frac{Z^k}{\max_{1\le i\le n}\sum_{j=1}^{n} z_{ij}} ; i,j = 1,2 \ldots, n \quad (8)$$

Step 6. Compute the Total-relation Matrix, *T*

Total-relation matrix, *T* is calculated by using expression (9), where I represents $n \times n$ identity matrix.

$$T = D\,(I - D)^{-1} \quad (9)$$

where $T = D + D^2 + D^3 \ldots + = \sum_{i=1}^{\infty} D^i$

Step 7. Determine row (r_i) and column (c_j) sums for each row i and column j from the *T* matrix respectively through following equations (10), (11) and (12).

$$\mathrm{T} = \left[t_{ij}\right]_{n \times n} \qquad i,j = 1,2,3 \ldots n \quad (10)$$

$$r_i = \sum_{1\le j\le n}^{n} t_{ij} \qquad \forall i \quad (11)$$

$$c_j = \sum_{1\le i\le n}^{n} t_{ij} \qquad \forall j \quad (12)$$

where r_i is refered to the influence level of criteria *i* on other criteria and c_j is indicated the relation level of of each criteria on criteria *i*.

Step 8. Establishing and Analyzing the Causal Diagram

The causal diagram is constructed with the horizontal axis ($r_i + c_j$) is known as the " Prominence " is calculated by adding r_i to c_j and the vertical axis ($r_i - c_j$) named " Relation " is determined by subtracting c_j from r_i. The vertical axis may divide criteria into cause group and effect group such as when the ($r_i - c_j$) axis is positive, the factor is in the cause group and it has a higher priority for long-term strategic decisions. When the ($r_i - c_j$) is negative, the factors belongs to the effect groups. Causal diagram can visual representation the complex causal relationships between

factors through a graphical diagram and helps to decision-makers for easily understanding structural model, providing awareness for problem solutions and indicating improvement stages.

CHAPTER 6: IMPLEMENTATION OF THE STUDY

In this study, an excel sheet on the basis of 12 main criteria and 35 sub-criteria was designed and conducted with the participation of 6 experts who have at least 5 years of experience via electronic mail (e-mail). Our participants who are currently working on cold supply chain in the Aegean Region (Turkey) especially in food industry. Participants expressed its own opinions and knowledge and skills on excel sheet by using fuzzy linguistic scale in Table 22. All the formulas and scoring of participants were entered into Microsoft Excel in order to solve the equations of fuzzy DEMATEL. The characteristics and demographic features of experts and evaluation criteria in our study are shown in Table 23 and Table 24 respectively. As a example, one of expert's evaluation is given in Table 25 and Table 26.

Table 23. Respondents Interviewed

Respondents	Department	Experience (Years)	Job Title
1	Logistics	10	Warehouse Logistic Operation Manager
2	Warehouse	10	Airfreight Operations Responsible
3	Production	7	Producer
4	Warehouse	11	Supervisor
5	Logistics	8	Expert Veterinary Surgeon
6	Production	12	Producer

Table 24. Selected Evaluation Criteria

C.No	Criteria
C1	Packaging
C2	Storage Specifications and Loading Capacity
C3	Refrigeration Systems
C4	Handling Issues and Inventory Rotation
C5	Cold Transportation
C6	Delivery Delays
C7	Traceability
C8	Staff
C9	Technical Issues
C10	Consumption (at home)
C11	Hygiene Requirements of Physical Conditions
C12	Others

Table 25. Linguistic Assessment of Expert 1 for first 6 criteria.

1	C1			C2			C3			C4			C5			C6		
C1	0	0	0,25	0,75	1	1	0,75	1	1	0,75	1	1	0,75	1	1	0,5	0,75	1
C2	0,5	0,75	1	0	0	0,25	0,5	0,75	1	0,5	0,75	1	0,5	0,75	1	0,5	0,75	1
C3	0,25	0,5	0,75	0,75	1	1	0	0	0,25	0	0,25	0,5	0,75	1	1	0,5	0,75	1
C4	0,5	0,75	1	0,75	1	1	0	0,25	0,5	0	0	0,25	0	0,25	0,5	0,25	0,5	0,75
C5	0,25	0,5	0,75	0,25	0,5	0,75	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0,5	0,75	1
C6	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5	0,75	1	1	0	0	0,25
C7	0,75	1	1	0,75	1	1	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0,25	0,5	0,75
C8	0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0,5	0,75	1	0,25	0,5	0,75
C9	0	0,25	0,5	0,25	0,5	0,75	0,75	1	1	0,25	0,5	0,75	0,75	1	1	0,5	0,75	1
C10	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5	0,5	0,75	1
C11	0,5	0,75	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5
C12	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5	0,5	0,75	1	0,75	1	1

Table 26. Linguistic Assessment of Expert 1 for last 6 criteria.

C7			C8			C9			C10			C11			C12		
0,75	1	1	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0	0,25	0,5
0,5	0,75	1	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5
0,5	0,75	1	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5	0,75	1	1	0	0,25	0,5
0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5
0,75	1	1	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5	0,25	0,5	0,75	0,5	0,75	1
0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5	0,75	1	1
0	0	0,25	0,75	1	1	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0,25	0,5	0,75
0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0,25	0,5	0,75
0,75	1	1	0,25	0,5	0,75	0	0	0,25	0	0,25	0,5	0,5	0,75	1	0	0,25	0,5
0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5	0	0	0,25	0	0,25	0,5	0	0,25	0,5
0,5	0,75	1	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5	0	0	0,25	0	0,25	0,5
0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5	0	0	0,25

Firstly, initial direct relation matrix (Z) produced by calculating arithmetic average of evaluation of 6 experts and maximum value determined by adding of rows and columns in Table 27.

Table 27. Initial Direct Relation Matrix

Z	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	Sum of Rows
C1	0,033	0,889	0,850	0,850	0,967	0,733	0,967	0,500	0,461	0,578	0,578	0,267	7,672
C2	0,656	0,033	0,578	0,850	0,344	0,656	0,889	0,733	0,422	0,578	0,578	0,267	6,583
C3	0,656	0,967	0,033	0,267	0,967	0,850	0,733	0,500	0,461	0,383	0,383	0,267	6,467
C4	0,617	0,967	0,267	0,033	0,850	0,733	0,500	0,500	0,422	0,500	0,500	0,267	6,156
C5	0,461	0,733	0,850	0,694	0,033	0,733	0,967	0,500	0,461	0,500	0,500	0,617	7,050
C6	0,461	0,267	0,500	0,267	0,656	0,033	0,578	0,500	0,422	0,267	0,267	0,733	4,950
C7	0,850	0,617	0,733	0,383	0,928	0,500	0,033	0,967	0,850	0,889	0,889	0,500	8,139
C8	0,889	0,772	0,889	0,928	0,928	0,500	0,889	0,033	0,850	0,850	0,850	0,500	8,878
C9	0,306	0,694	0,850	0,306	0,967	0,733	0,967	0,500	0,033	0,267	0,267	0,383	6,272
C10	0,772	0,150	0,111	0,267	0,111	0,189	0,539	0,500	0,111	0,072	0,072	0,383	3,278
C11	0,422	0,733	0,228	0,461	0,500	0,111	0,578	0,500	0,344	0,033	0,033	0,267	4,211
C12	0,500	0,422	0,267	0,267	0,733	0,539	0,500	0,733	0,656	0,539	0,539	0,033	5,728
Sum of Column	6,622	7,244	6,156	5,572	7,983	6,311	8,139	6,467	5,494	5,456	5,456	4,483	8,878

After that, by using Formula 8, normalized direct relation matrix (*X*) is created in Table 28. Normalized direct relation matrix indicates the overall evaluation of the experts.

Table 28. Normalized Direct Relation Matrix

X	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0,004	0,100	0,096	0,096	0,109	0,083	0,109	0,056	0,052	0,065	0,065	0,030
C2	0,074	0,004	0,065	0,096	0,039	0,074	0,100	0,083	0,048	0,065	0,065	0,030
C3	0,074	0,109	0,004	0,030	0,109	0,096	0,083	0,056	0,052	0,043	0,043	0,030
C4	0,069	0,109	0,030	0,004	0,096	0,083	0,056	0,056	0,048	0,056	0,056	0,030
C5	0,052	0,083	0,096	0,078	0,004	0,083	0,109	0,056	0,052	0,056	0,056	0,069
C6	0,052	0,030	0,056	0,030	0,074	0,004	0,065	0,056	0,048	0,030	0,030	0,083
C7	0,096	0,069	0,083	0,043	0,105	0,056	0,004	0,109	0,096	0,100	0,100	0,056
C8	0,100	0,087	0,100	0,105	0,105	0,056	0,100	0,004	0,096	0,096	0,096	0,056
C9	0,034	0,078	0,096	0,109	0,109	0,083	0,109	0,056	0,004	0,030	0,030	0,043
C10	0,087	0,017	0,013	0,030	0,013	0,021	0,061	0,056	0,013	0,008	0,008	0,043
C11	0,048	0,083	0,026	0,052	0,056	0,013	0,065	0,056	0,039	0,004	0,004	0,030
C12	0,056	0,048	0,030	0,030	0,083	0,061	0,056	0,083	0,074	0,061	0,061	0,004

Next, total relation matrix is created and presented by using Formula 9 in Table 29.

Table 29. Total Relation Matrix

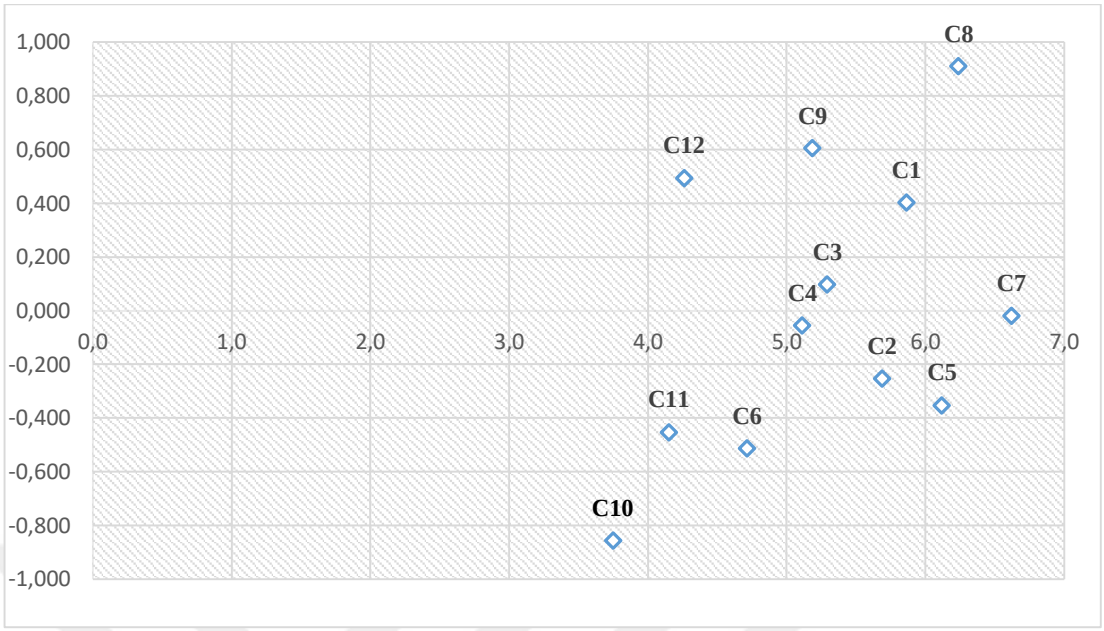
T	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0,206	0,313	0,281	0,278	0,338	0,271	0,345	0,250	0,218	0,232	0,232	0,169
C2	0,246	0,195	0,227	0,254	0,246	0,236	0,303	0,248	0,193	0,210	0,210	0,150
C3	0,242	0,288	0,172	0,195	0,304	0,256	0,290	0,223	0,195	0,189	0,189	0,151
C4	0,227	0,276	0,186	0,159	0,278	0,233	0,252	0,212	0,181	0,191	0,191	0,142
C5	0,236	0,278	0,264	0,246	0,224	0,255	0,324	0,236	0,206	0,211	0,211	0,193
C6	0,184	0,176	0,184	0,156	0,231	0,134	0,225	0,186	0,161	0,145	0,145	0,172
C7	0,300	0,296	0,281	0,245	0,346	0,255	0,263	0,305	0,266	0,271	0,271	0,199
C8	0,322	0,333	0,311	0,314	0,368	0,274	0,372	0,227	0,280	0,282	0,282	0,210
C9	0,220	0,278	0,268	0,276	0,323	0,259	0,326	0,236	0,161	0,188	0,188	0,171
C10	0,176	0,118	0,103	0,118	0,125	0,110	0,170	0,145	0,093	0,090	0,090	0,105
C11	0,165	0,209	0,142	0,166	0,195	0,129	0,207	0,171	0,139	0,108	0,108	0,110
C12	0,206	0,210	0,177	0,176	0,257	0,202	0,240	0,226	0,198	0,186	0,186	0,110

Finally, R+C and R-C values are calculated by using Formula 11 and Formula 12 and presented in Table 30. These value is used to draw the causal diagram in Figure 7.

Table 30. R+C and R-C Dataset

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
R+C	5,861	5,686	5,291	5,111	6,118	4,712	6,616	6,237	5,185	3,747	4,150	4,260
R-C	0,402	-0,254	0,097	-0,055	-0,353	-0,514	-0,019	0,909	0,604	-0,857	-0,453	0,493

Figure 7. Causal Diagram



CHAPTER 7. RESULTS AND MANAGERIAL IMPLICATIONS

According to the Fuzzy DEMATEL results, 5 cause groups and 7 effect groups is determined. The cause groups are packaging (C1), refrigeration systems (C3), staff (C8), technical issues (C9) and other criteria (C12), including weather conditions, legal regulations and regulatory requirements of the organizations, while effect groups are storage specifications and loading capacity (C2), handling issues and inventory rotation (C4), cold transportation (C5), delivery delays (C6), traceability (C7), households consumption (C10) and hygiene requirements of physical conditions (C11). Furthermore, the most importance criteria is traceability (C7). The importance order of evaluation criteria with cause and effect groups is seen in Table 31 respectively.

Table 31. Summary of Numerical Results

Importance Order	Cause Group	Effect Group
Traceability **(C7)**		**x**
Staff **(C8)**	**x**	
Cold Transportation **(C5)**		**x**
Packaging **(C1)**	**x**	
Storage Specifications and Loading Capacity **(C2)**		**x**
Refrigeration Systems **(C3)**	**x**	
Technical Issues **(C9)**	**x**	
Handling Issues and Inventory Rotation **(C4)**		**x**
Delivery Delays **(C6)**		**x**
Others **(C12)**	**x**	
Hygiene Requirements of Physical Conditions **(C11)**		**x**
Consumption (at home) **(C10)**		**x**

Below, the relationship between cause groups and effect groups are explained respectively;

***(C1 to C2)*:** Many different product categories are stored in a cold storage area for future delivery. Different product groups only can be stored together when the product is packed with appropriate and enclosed packaging material as well as match the temperature. Dirty packaging and worn packaging can not be received. Store foods in appropriate packaging without hole is essential.

***(C1 to C4)*:** Packages should be designed with good quality packaging material to prevent to any food damage or biological damage, especially in handling operations. For instance, when packaging material has sufficient stacking strength, it can withstand injuries caused by highly or improper humid environment and low temperatures in container or boxes.

***(C1 to C5)*:** Sub-standard packaging material is accepted as one of the major sources in terms of consignment failure and food damage in transit, especially products are shipped by truck. When packaging units have inadequate protection towards contamination, spoilage or physical damage, these must be transported with sealed container.

***(C1 to C6)*:** Thermal insulation packaging help to protect temperature inside a package when a delay occurred due to breakdown of vehicle.

***(C1 to C7)*:** Package is a useful material for monitoring and controlling the availability of suitable humidity environment and temperature. Temperature range collects regulary through the use of a intelligent tag or sensor attached on a package.

***(C1 to C10)*:** Many various information about products and detailed storage advice, including expired date, where to store the food and required temperature to store in domestic refrigerator before cooking are provided by packaging. Packages are divided into smaller portions to customers so that they can purchase only what they need.

***(C1 to C11)*:** Packages are stored and transported in a steriel atmosphere. A sealed package guards against pests and chemicals caused by hygiene materials, such as detergent.

(C3 to C2): Highly sophisticated refrigeration system, involving refrigeration equipments (e.g. chiller and refrigerated chamber) and facility to maintain appropriate temperature to store perishable foods and efficient air movement and ventilation are essential for a cold storage facility.

(C3 to C4): A cold storage facility needs cold dock space and blower to maintain internal temperature control during preparing, moving and receiving perishable cargo.

(C3 to C5): Proper refrigeration equipment is absolutely essential for a cold chain transportation system. Precooling before shipping helps to minimize loss and spoilage.

(C3 to C6)**:** Refrigeration units and insulated doors, floors and walls in a refrigerated vehicle are guarded temperature when a delay occured.

(C3 to C7)**:** Refrigeration equipments are continuously monitored and controlled in terms of air, temperature and humidity level in real-time mode. When the temperature is outside allowed range, temperature and humidity monitoring systems signal.

(C3 to C10)**:** Perishable foods are stored at acceptable temperature and humidity range in drawer of a domestic refrigerator, such as raw meats should be stored at the bottom of fridge to prevent cross contamination.

(C3 to C11)**:** Refrigeration facilities and equipments should be clean by appropriate sanitary requirements in regular periods.

***(C8 to C2)*:** Staff make efficient temperature adjustment of cold storage rooms and refrigeration equipments in a cold storage facility.

***(C8 to C4)*:** Staff is responsible for carrying and putting pallet units the shelves in the same direction and uniform placing to prevent loss. Some perishable products should be stored seperately from each other to prevent possible contamination.

***(C8 to C5)*:** Operator should make temperature adjustment according to range of required temperature when different product categories transported at one vehicle and avoid to spend redundant time and to negligentia, especially in transit.

***(C8 to C6)*:** Poor collaboration between workers and management will clearly result in delivery delay. Trained operators tend to reduce the risk of consignment failure at the same time.

***(C8 to C7)*:** Monitoring and controlling suitable temperature and humidity status in a cold storage facility and checking whether the refrigeration systems work accurately and maintenance time of them are main tasks of workers.

***(C8 to C10)*:** A qualified and skilled worker associated with cold chain procedures enhance 'customer confidence' in the quality of materials.

***(C8 to C11)*:** Pallet units should put in a clean and sanitized location to protect the food hygiene and a cold storage facility is regulary cleaned with appropriate detergent materials as well.

***(C9 to C2, C4, C5, C7)*:** These relations are clearly interrelated in terms of utilizing the food quality and its safety. Implications of technology and R&D will enhance to produce all the functional and specific requirements across cold chains. A malfunction or interruption of refrigeration systems will cause to increase the risk of consignment failure and food safety as well.

For storage specifications and loading capacity;

- Appropriate refrigeration equipment to maintain suitable temperature to store products, e.g. refrigeration units, refrigerated chamber.
- Adequate equipment to store products, e.g. shelves.

For material handling systems;

- Adequate material handling equipment for carrying products, e.g. pallets or coli.
- Appropriate and enough material handling system, e.g. forklift, hand-lift or reach truck.

For cold transport;

- Adequate and functional vehicle for transporting of products, e.g. refrigerated truck or container.

For traceability;

- Adequate and needed device to monitor and control suitable temperature, e.g. datalogger.
- Appropriate innovative solutions to monitor and control both suitable internal and external conditions of packed product, e.g. tag or sensor.

***(C9 to C6)*:** Car breakdown and absence of tracking technologies to safety road can affect to delivery on time.

***(C9 to C10)*:** An interruption of a domestic refrigerator may cause to food spoilage.

***(C9 to C11)*:** A technical problem may affect both lighting and availability of pest control device in a cold storage facility.

(C12 to C2, C4, C5, C6, C11) **:** Legal obligations and regulatory requirements of the organizations will clearly cause inefficient harvesting, storage, transportation and processing.

***(C12 to C7)*:** HACCP should be adopted to ensure food safety and traceability of operations along a cold chain by organizations. HACCP is not only affect cold chain performance but other food safety certification as well.

***(C12 to C10)*:** Weather condition is one of the important threat to safely ensure temperature control for perishables. Customers should not store perishable foods where sun light is intensive, especially on a balcony or patio.

In the overall evaluation of the results of the study, some important suggestions for managerial implications to organizations are given as follow;

Staff need to be trained to manage, observe and control dealing with cold goods and storage in order to achieve efficient cold chain management and reduce spoilage.

Training modules dealing with occupational health and safety and personnel hygiene requirements, involving gloves and safety shoes should be established for both management and workers.

A hand washing location, including liquid soap, alcohol, hand sanitizer, hand dryer and single-use paper towel should be designed in a cold storage facility.

Training certification should be adopted in order to enhance the food safety and reduce the amount of food waste.

Using appropriate and enough management information systems and mobile technologies suited to all the specific requirements across cold chains should be encouraged.

- Temperature sensors located at many various space in a cold storage facility.
- Collecting and storing temperature data by manual or thermometer.

Electric-powered material handling vehicles should be preferred in order to prevent food safety caused by some dangerous gas, including carbonmonoxide.

A reliable electric system should be conducted in a cold storage facility. For instance, a storage generator is used both provide power to refrigeration units and avoid potential loss when power interruption is.

Refrigerated vehicles should be designed with different refrigeration units for different range of required temperature products to avoid temperature abuses and possible contamination.

Regular meetings among supply chain partners should be organized to avoid poor collaboration and continuous improvement.

Approved sanitation programs should be applied to ensure quality and safety requirements.

Technological and innovative developments should be followed and innovative solutions are involved in cold chain process.

Selection of true partnerships will achieve quick and long-term improvements for a sustainable cold chain process.

CONCLUSION

This study aims to determine performance criteria in a cold supply chain by using comprehensive literature review and to explain causal interrelationship between criteria, additionally to importance order. The proposed conceptual framework, including 12 main criteria with 35 sub-criteria is presented in order to identify evaluation criteria and a simple-structured excel sheet conducted. Fuzzy DEMATEL is applied because it is an useful way to solve complicated problems by insight into causal relationships and to assess importance order between criteria.

Significant drivers identified both influence group and importance order and some managerial suggestions for organizations proposed. The most important criteria is the 'traceability' as one of the results of fuzzy Dematel. It is usual because monitoring and controlling in food industry where cold chain logistics is important is essential to prevent food-related disease and to development of a cold chain performance. Personnel is both the most strongest cause criteria and second importance criteria. It is an unavoidable outcome since personnel is an integral part of a cold chain management. Personnel who well-informed and well-trained will be more useful within the cold chain. Trained person will lead to achieve higher customer satisfaction and increase profits. In deed, personnel is responsible for all processes of cold chain, like installation and controlling of refrigeration systems, distribution of products at safe conditions, usage of appropriate packaging material or appropriately holding and handling of packages. Supervise to them regulary is essential.

To choose a helpful tool like HACCP is very important in order to ensure the realibility of the cold chain. Food safety certifications are a missing subject in relevant literature. ISO 9001 Quality Management System has been commonly pointed. HACCP shall be applied to analyze the processes of cold chain, discover the potential risk area for each operations and ensure the safety and quality of the cold chain by solving them.

The main contribution of the study is to propose meaningful suggestions for managerial implications about sustainable cold chain in food industry for businesses and to examine causal relations between criteria and to rank criteria in descending importance order.

To build availability of temperature-controlled storage facility and vehicles equipped with appropriate and adequate refrigeration systems is high capital and operating costs. This is an important barrier for food providers and businesses in order to successful and long term improvement of cold chain. Future research should aim to provide clear and detailed assessment related to barriers of the cold chain. Second one is proposed methodology can be conducted in other industry and even comparative studies applied, such as between food industry and medical industry. Finally, evaluation criteria may be extended and analyzed by using different MCDM methods.

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APPENDIXES

Table 32. DEMATEL Survey

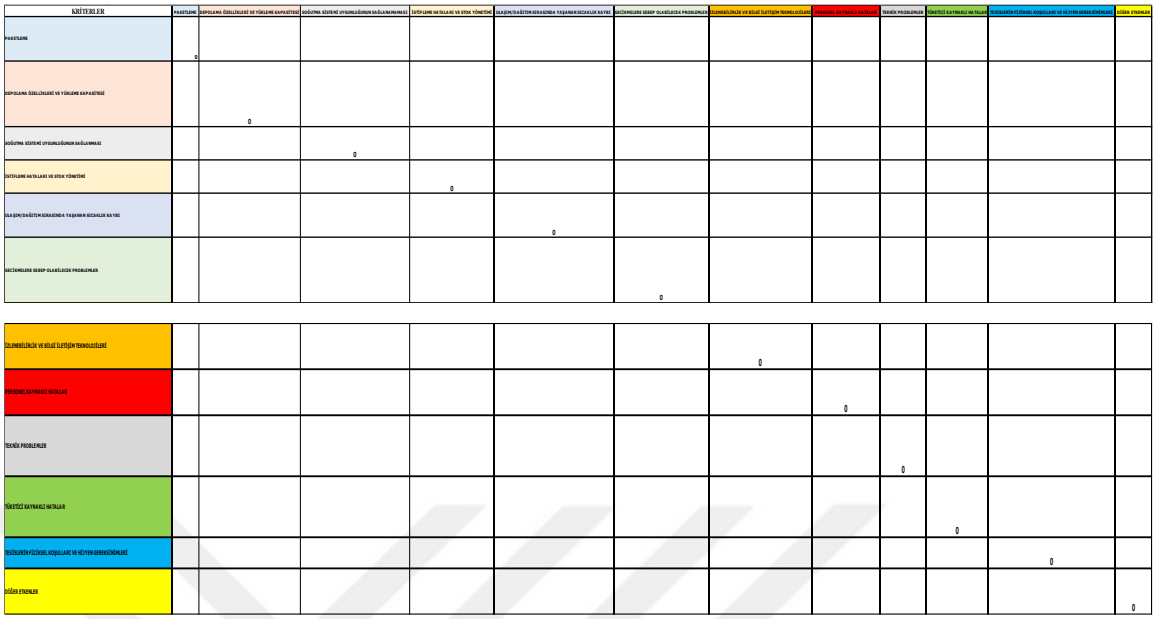

Table 33. Linguistic Assessment of Expert 2

2	C1			C2			C3			C4			C5			C6			C7			C8			C9			C10			C11			C12		
C1	0	0	0,25	0,75	1	1	0,75	1	1	0,75	1	1	0,75	1	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0	0,25	0,5
C2	0,5	0,75	1	0	0	0,25	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0	0,25	0,5	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5
C3	0,75	1	1	0,75	1	1	0	0	0,25	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0,5	0,75	1	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5
C4	0,5	0,75	1	0,75	1	1	0	0,25	0,5	0	0	0,25	0,75	1	1	0	0,25	0,5	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5
C5	0,25	0,5	0,75	0,25	0,5	0,75	0,75	1	1	0,5	0,75	1	0	0	0,25	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0,25	0,5	0,75	0,5	0,75	1
C6	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5	0,75	1	1	0	0	0,25	0,5	0,75	1	0,25	0,5	0,75	0	0,25	0,5	0,5	0,75	1	0	0,25	0,5	0,75	1	1
C7	0,75	1	1	0,75	1	1	0,75	1	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0,75	1	1	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0,25	0,5	0,75
C8	0,75	1	1	0,75	1	1	0,75	1	1	0,75	1	1	0,75	1	1	0,25	0,5	0,75	0,75	1	1	0	0	0,25	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0,25	0,5	0,75
C9	0	0,25	0,5	0,5	0,75	1	0,75	1	1	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0	0,25	0,5	0,5	0,75	1	0	0,25	0,5
C10	0,75	1	1	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75	0	0,25	0,5	0	0	0,25	0	0,25	0	0	0,25	0,5
C11	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0,25	0,5	0,75	0	0,25	0,5	0,5	0,75	1	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0	0,25	0	0,25	0,5
C12	0,5	0,75	1	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5	0,5	0,75	1	0	0,25	0,5	0,25	0,5	0,75	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0	0,25	0,5	0	0	0,25

Table 34. Linguistic Assessment of Expert 3

3	C1			C2			C3			C4			C5			C6			C7			C8			C9			C10			C11			C12		
C1	0	0	0,25	0,5	0,75	1	0,75	1	1	0,75	1	1	0,75	1	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0	0,25	0,5
C2	0,75	1	1	0	0	0,25	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0,75	1	1	0,5	0,75	1	0	0,25	0,5	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5
C3	0,75	1	1	0,75	1	1	0	0	0,25	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0,5	0,75	1	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5
C4	0,5	0,75	1	0,75	1	1	0	0,25	0,5	0	0	0,25	0,75	1	1	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5
C5	0,25	0,5	0,75	0,25	0,5	0,75	0,75	1	1	0,5	0,75	1	0	0	0,25	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0,25	0,5	0,75	0,5	0,75	1
C6	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0,5	0,75	1	0	0,25	0,5	0,75	1	1
C7	0,75	1	1	0,75	1	1	0,75	1	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0,75	1	1	0,5	0,75	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75
C8	0,75	1	1	0,75	1	1	0,75	1	1	0,75	1	1	0,75	1	1	0,25	0,5	0,75	0,75	1	1	0	0	0,25	0,75	1	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75
C9	0	0,25	0,5	0,5	0,75	1	0,75	1	1	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0	0,25	0,5	0,5	0,75	1	0	0,25	0,5
C10	0,75	1	1	0	0	0,25	0	0	0,25	0	0,25	0,5	0	0	0,25	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0	0	0,25	0	0	0,25	0	0	0,25	0	0	0,25
C11	0,5	0,75	1	0,5	0,75	1	0	0	0,25	0,5	0,75	1	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0	0,25	0	0,25	0,5
C12	0,5	0,75	1	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0,25	0,5	0,75	0	0	0,25

Table 35. Linguistic Assessment of Expert 4

4	C1			C2			C3			C4			C5			C6			C7			C8			C9			C10			C11			C12		
C1	0	0	0,25	0,75	1	1	0,5	0,75	1	0,5	0,75	1	0,75	1	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0,25	0,5	0,75	0,75	1	1	0	0,25	0,5	0	0,25	0,5
C2	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,75	1	1	0	0,25	0,5	0,5	0,75	1	0,75	1	1	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5
C3	0,25	0,5	0,75	0,75	1	1	0	0	0,25	0	0,25	0,5	0,75	1	1	0,75	1	1	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5
C4	0,25	0,5	0,75	0,75	1	1	0	0,25	0,5	0	0	0,25	0,75	1	1	0,75	1	1	0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5
C5	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0,5	0,75	1	0	0	0,25	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0,25	0,5	0,75
C6	0	0,25	0,5	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5	0,25	0,5	0,75
C7	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0,75	1	1	0,75	1	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75
C8	0,75	1	1	0,5	0,75	1	0,75	1	1	0,75	1	1	0,75	1	1	0,25	0,5	0,75	0,75	1	1	0	0	0,25	0,75	1	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75
C9	0	0,25	0,5	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0	0,25	0,5	0	0,25	0	0,25	0,5	0,75
C10	0,75	1	1	0	0	0,25	0	0	0,25	0	0,25	0,5	0	0	0,25	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0	0	0,25	0	0	0,25	0	0,25	0	0,25	0,5	0,75
C11	0	0	0,25	0,5	0,75	1	0	0	0,25	0	0,25	0,5	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0	0,25	0	0,25	0,5
C12	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0	0	0,25

Table 36. Linguistic Assessment of Expert 5

5	C1			C2			C3			C4			C5			C6			C7			C8			C9			C10			C11			C12		
C1	0	0	0,25	0,75	1	1	0,5	0,75	1	0,5	0,75	1	0,75	1	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0,25	0,5	0,75	0,75	1	1	0	0,25	0,5	0	0,25	0,5
C2	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,75	1	1	0	0,25	0,5	0,5	0,75	1	0,75	1	1	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5
C3	0,25	0,5	0,75	0,75	1	1	0	0	0,25	0	0,25	0,5	0,75	1	1	0,75	1	1	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5
C4	0,25	0,5	0,75	0,75	1	1	0	0,25	0,5	0	0	0,25	0,75	1	1	0,75	1	1	0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5
C5	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0,5	0,75	1	0	0	0,25	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0,25	0,5	0,75
C6	0	0,25	0,5	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5	0,25	0,5	0,75
C7	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0,75	1	1	0,75	1	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75
C8	0,75	1	1	0,5	0,75	1	0,75	1	1	0,75	1	1	0,75	1	1	0,25	0,5	0,75	0,75	1	1	0	0	0,25	0,75	1	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75
C9	0	0,25	0,5	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0	0,25	0,5	0	0,25	0	0,25	0,5	0,75
C10	0,75	1	1	0	0	0,25	0	0	0,25	0	0,25	0,5	0	0	0,25	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0	0	0,25	0	0	0,25	0	0,25	0	0,25	0,5	0,75
C11	0	0	0,25	0,5	0,75	1	0	0	0,25	0	0,25	0,5	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0	0,25	0	0,25	0,5
C12	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0	0	0,25

Table 37. Linguistic Assessment of Expert 6

6	C1			C2			C3			C4			C5			C6			C7			C8			C9			C10			C11			C12		
C1	0	0	0,25	0,5	0,75	1	0,5	0,75	1	0,5	0,75	1	0,75	1	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0,25	0,5	0,75	0,75	1	1	0,5	0,75	1	0	0,25	0,5
C2	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,75	1	1	0	0,25	0,5	0,5	0,75	1	0,75	1	1	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5
C3	0,25	0,5	0,75	0,75	1	1	0	0	0,25	0	0,25	0,5	0,75	1	1	0,75	1	1	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0,25	0,5
C4	0,25	0,5	0,75	0,75	1	1	0	0,25	0,5	0	0	0,25	0,75	1	1	0,75	1	1	0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5
C5	0,5	0,75	1	0,75	1	1	0,5	0,75	1	0,5	0,75	1	0	0	0,25	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0,25	0,5	0,75
C6	0,5	0,75	1	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0	0,25	0,5	0,25	0,5	0,75
C7	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0,75	1	1	0,75	1	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75
C8	0,75	1	1	0,5	0,75	1	0,75	1	1	0,75	1	1	0,75	1	1	0,25	0,5	0,75	0,75	1	1	0	0	0,25	0,75	1	1	0	0,25	0,5	0,75	1	1	0,25	0,5	0,75
C9	0	0,25	0,5	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0,75	1	1	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0	0	0,25	0	0,25	0,5	0	0,25	0	0,25	0,5	0,75
C10	0,75	1	1	0	0	0,25	0	0	0,25	0	0,25	0,5	0	0	0,25	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0	0	0,25	0	0	0,25	0	0,25	0	0,25	0,5	0,75
C11	0	0	0,25	0,5	0,75	1	0	0	0,25	0	0,25	0,5	0,25	0,5	0,75	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0	0	0,25	0	0,25	0,5
C12	0	0,25	0,5	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0,5	0,75	1	0	0	0,25

Table 38. Dematel Results of Expert 1

1	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0,033	0,967	0,967	0,967	0,967	0,733	0,967	0,500	0,733	0,733	0,733	0,267
C2	0,733	0,033	0,733	0,733	0,733	0,733	0,733	0,733	0,500	0,733	0,733	0,267
C3	0,500	0,967	0,033	0,267	0,967	0,733	0,733	0,500	0,733	0,967	0,967	0,267
C4	0,733	0,967	0,267	0,033	0,267	0,500	0,500	0,500	0,500	0,500	0,500	0,267
C5	0,500	0,500	0,967	0,500	0,033	0,733	0,967	0,500	0,733	0,500	0,500	0,733
C6	0,500	0,267	0,500	0,267	0,967	0,033	0,733	0,500	0,500	0,267	0,267	0,967
C7	0,967	0,967	0,267	0,967	0,733	0,500	0,033	0,967	0,733	0,733	0,733	0,500
C8	0,500	0,500	0,500	0,733	0,733	0,500	0,500	0,033	0,500	0,500	0,500	0,500
C9	0,267	0,500	0,967	0,500	0,967	0,733	0,967	0,500	0,033	0,733	0,733	0,267
C10	0,267	0,500	0,267	0,267	0,267	0,733	0,267	0,500	0,267	0,267	0,267	0,267
C11	0,733	0,733	0,967	0,500	0,500	0,267	0,733	0,500	0,733	0,033	0,033	0,267
C12	0,267	0,267	0,267	0,267	0,733	0,967	0,500	0,733	0,267	0,267	0,267	0,033

Table 39. Dematel Results of Expert 2

2	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0,033	0,967	0,967	0,967	0,967	0,733	0,967	0,500	0,267	0,733	0,733	0,267
C2	0,733	0,033	0,733	0,733	0,267	0,267	0,733	0,733	0,267	0,733	0,733	0,267
C3	0,967	0,967	0,033	0,267	0,967	0,733	0,733	0,500	0,267	0,267	0,267	0,267
C4	0,733	0,967	0,267	0,033	0,967	0,267	0,500	0,500	0,267	0,500	0,500	0,267
C5	0,500	0,500	0,967	0,733	0,033	0,733	0,967	0,500	0,267	0,500	0,500	0,733
C6	0,500	0,267	0,500	0,267	0,967	0,033	0,733	0,500	0,267	0,267	0,267	0,967
C7	0,967	0,967	0,967	0,267	0,967	0,500	0,033	0,967	0,733	0,733	0,733	0,500
C8	0,967	0,967	0,967	0,967	0,967	0,500	0,967	0,033	0,733	0,733	0,733	0,500
C9	0,267	0,733	0,967	0,267	0,967	0,733	0,967	0,500	0,033	0,733	0,733	0,267
C10	0,967	0,267	0,267	0,267	0,267	0,267	0,967	0,500	0,267	0,033	0,033	0,267
C11	0,733	0,733	0,267	0,733	0,500	0,267	0,733	0,500	0,267	0,033	0,033	0,267
C12	0,733	0,267	0,267	0,267	0,733	0,267	0,500	0,733	0,733	0,267	0,267	0,033

Table 40. Dematel Results of Expert 3

3	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0,033	0,733	0,967	0,967	0,967	0,733	0,967	0,500	0,267	0,733	0,733	0,267
C2	0,967	0,033	0,500	0,733	0,267	0,733	0,967	0,733	0,267	0,500	0,500	0,267
C3	0,967	0,967	0,033	0,267	0,967	0,733	0,733	0,500	0,267	0,267	0,267	0,267
C4	0,733	0,967	0,267	0,033	0,967	0,733	0,500	0,500	0,267	0,500	0,500	0,267
C5	0,500	0,500	0,967	0,733	0,033	0,733	0,967	0,500	0,267	0,500	0,500	0,733
C6	0,500	0,267	0,500	0,267	0,500	0,033	0,500	0,500	0,267	0,267	0,267	0,967
C7	0,967	0,967	0,967	0,267	0,967	0,500	0,033	0,967	0,733	0,967	0,967	0,500
C8	0,967	0,967	0,967	0,967	0,967	0,500	0,967	0,033	0,967	0,967	0,967	0,500
C9	0,267	0,733	0,967	0,267	0,967	0,733	0,967	0,500	0,033	0,033	0,033	0,267
C10	0,967	0,033	0,033	0,267	0,033	0,033	0,500	0,500	0,033	0,033	0,033	0,267
C11	0,733	0,733	0,033	0,733	0,500	0,033	0,500	0,500	0,267	0,033	0,033	0,267
C12	0,733	0,500	0,267	0,267	0,733	0,500	0,500	0,733	0,733	0,500	0,500	0,033

Table 41. Dematel Results of Expert 4

4	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0,033	0,967	0,733	0,733	0,967	0,733	0,967	0,500	0,500	0,267	0,267	0,267
C2	0,500	0,033	0,500	0,967	0,267	0,733	0,967	0,733	0,500	0,500	0,500	0,267
C3	0,500	0,967	0,033	0,267	0,967	0,967	0,733	0,500	0,500	0,267	0,267	0,267
C4	0,500	0,967	0,267	0,033	0,967	0,967	0,500	0,500	0,500	0,500	0,500	0,267
C5	0,267	0,967	0,733	0,733	0,033	0,733	0,967	0,500	0,500	0,500	0,500	0,500
C6	0,267	0,267	0,500	0,267	0,500	0,033	0,500	0,500	0,500	0,267	0,267	0,500
C7	0,733	0,267	0,733	0,267	0,967	0,500	0,033	0,967	0,967	0,967	0,967	0,500
C8	0,967	0,733	0,967	0,967	0,967	0,500	0,967	0,033	0,967	0,967	0,967	0,500
C9	0,267	0,733	0,733	0,267	0,967	0,733	0,967	0,500	0,033	0,033	0,033	0,500
C10	0,967	0,033	0,033	0,267	0,033	0,033	0,500	0,500	0,033	0,033	0,033	0,500
C11	0,033	0,733	0,033	0,267	0,500	0,033	0,500	0,500	0,267	0,033	0,033	0,267
C12	0,500	0,500	0,267	0,267	0,733	0,500	0,500	0,733	0,733	0,733	0,733	0,033

Table 42. Dematel Results of Expert 5

5	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0,033	0,967	0,733	0,733	0,967	0,733	0,967	0,500	0,500	0,267	0,267	0,267
C2	0,500	0,033	0,500	0,967	0,267	0,733	0,967	0,733	0,500	0,500	0,500	0,267
C3	0,500	0,967	0,033	0,267	0,967	0,967	0,733	0,500	0,500	0,267	0,267	0,267
C4	0,500	0,967	0,267	0,033	0,967	0,967	0,500	0,500	0,500	0,500	0,500	0,267
C5	0,267	0,967	0,733	0,733	0,033	0,733	0,967	0,500	0,500	0,500	0,500	0,500
C6	0,267	0,267	0,500	0,267	0,500	0,033	0,500	0,500	0,500	0,267	0,267	0,500
C7	0,733	0,267	0,733	0,267	0,967	0,500	0,033	0,967	0,967	0,967	0,967	0,500
C8	0,967	0,733	0,967	0,967	0,967	0,500	0,967	0,033	0,967	0,967	0,967	0,500
C9	0,267	0,733	0,733	0,267	0,967	0,733	0,967	0,500	0,033	0,033	0,033	0,500
C10	0,967	0,033	0,033	0,267	0,033	0,033	0,500	0,500	0,033	0,033	0,033	0,500
C11	0,033	0,733	0,033	0,267	0,500	0,033	0,500	0,500	0,267	0,033	0,033	0,267
C12	0,500	0,500	0,267	0,267	0,733	0,500	0,500	0,733	0,733	0,733	0,733	0,033

Table 43. Dematel Results of Expert 6

6	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0,033	0,733	0,733	0,733	0,967	0,733	0,967	0,500	0,500	0,733	0,733	0,267
C2	0,500	0,033	0,500	0,967	0,267	0,733	0,967	0,733	0,500	0,500	0,500	0,267
C3	0,500	0,967	0,033	0,267	0,967	0,967	0,733	0,500	0,500	0,267	0,267	0,267
C4	0,500	0,967	0,267	0,033	0,967	0,967	0,500	0,500	0,500	0,500	0,500	0,267
C5	0,733	0,967	0,733	0,733	0,033	0,733	0,967	0,500	0,500	0,500	0,500	0,500
C6	0,733	0,267	0,500	0,267	0,500	0,033	0,500	0,500	0,500	0,267	0,267	0,500
C7	0,733	0,267	0,733	0,267	0,967	0,500	0,033	0,967	0,967	0,967	0,967	0,500
C8	0,967	0,733	0,967	0,967	0,967	0,500	0,967	0,033	0,967	0,967	0,967	0,500
C9	0,500	0,733	0,733	0,267	0,967	0,733	0,967	0,500	0,033	0,033	0,033	0,500
C10	0,500	0,033	0,033	0,267	0,033	0,033	0,500	0,500	0,033	0,033	0,033	0,500
C11	0,267	0,733	0,033	0,267	0,500	0,033	0,500	0,500	0,267	0,033	0,033	0,267

C12	0,267	0,500	0,267	0,267	0,733	0,500	0,500	0,733	0,733	0,733	0,733	0,033

Figure 8. Pest Control

Figure 9. Portable Temperature Measuring Instrument

Figure 10. Datalogger

Source: Testo. Soğuk Zincir Zorunlu Gıdalar için İpuçları ve Püf Noktaları, p.7.

Figure 11. Temperature Measurement in a Delicatessen Cold Chamber

Figure 12. Real-time Temperature and Humidity Monitoring System

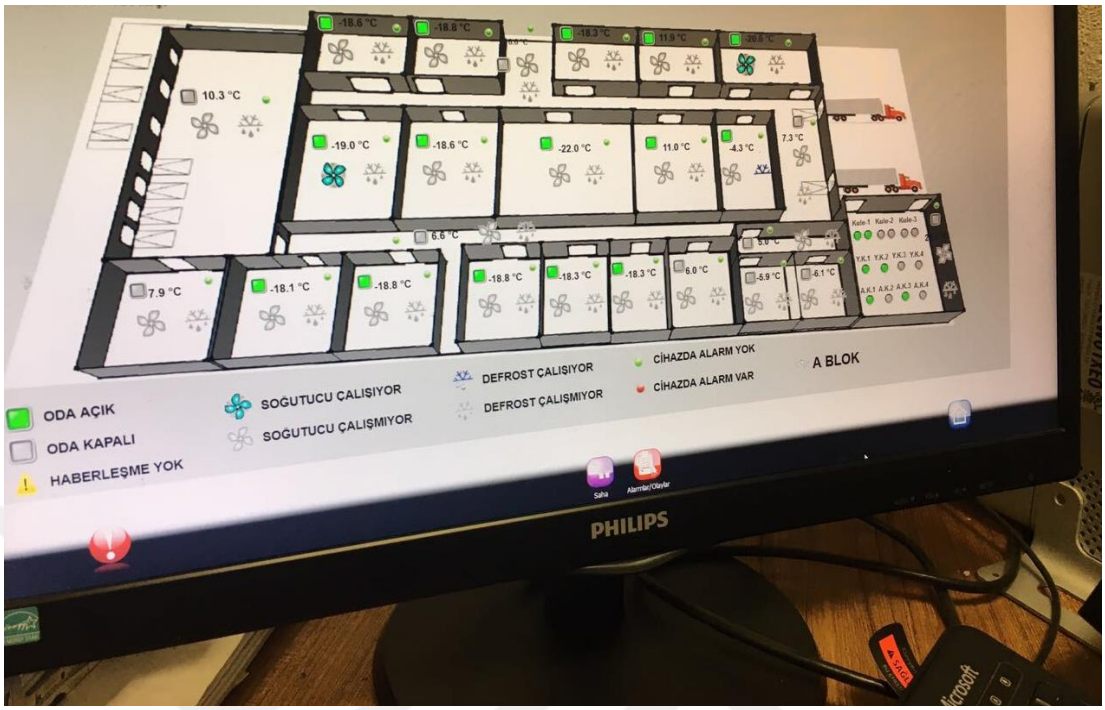

Figure 13. Blower System

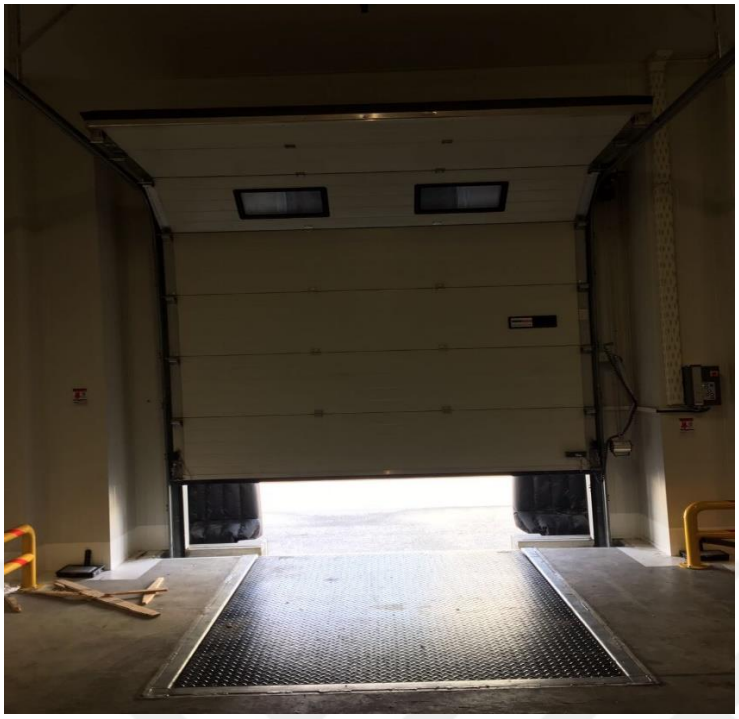

Figure 14. An Insulated Box Liner to Keep Cold during Shipment

Source: Quesnel (2017). Cold Chains: How Various Industries Keep Products Cold During Shipping.

Figure 15. Dry Ice

Source: Quesnel (2017). Cold Chains: How Various Industries Keep Products Cold During Shipping.