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A conceptual framework model for an effective cold food chain management in sustainability environment

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Abstract

Purpose – There is a large number of perishable foodstuffs produced, stored, distributed and delivered daily around the world. Almost all except for root vegetables are sensitive products to temperature. Thus, adopting uninterrupted and appropriate logistics activities with predetermined range of temperature from production site until end-user is critical for ensuring required quality and safety. If a mistake is made during either transport or storage, it not only becomes risky for human health, but also generates huge food waste for the environment and negative economic impact for food providers. Therefore, this study aims to identify all potential factors affecting the cold chain performance in the food industry and to design a framework that includes these factors. This framework is also a roadmap for managers, food providers and logistics parties for sustainable cold chain management.

Design/methodology/approach – Considering, tangible and intangible potential criteria, the ultimate goal of this study is to identify potential criteria affecting cold food chain performance and propose a conceptual framework including 12 main criteria. Next, the importance order of each criterion and the causal relationships between them are determined. In this study, this relationship among criteria is analyzed by using fuzzy Decision-making Trial and Evaluation Laboratory (DEMATEL) approach because of its ability to solve complex problems by ensuring causal relationship among factors, additionally to determine importance order. Finally, suggestions for administrative implications are presented.

Findings – Fuzzy DEMATEL was used to explain the causal link and importance order among identified drivers. The analysis shows that five criteria (C1, C3, C8, C9 and C12) belong to cause (influential) groups and remaining seven criteria belong to effect (influenced) groups. The highest influential criterion is staff (C8) and is followed by technical issues (C9) as the second most influential factor. Additionally, top three most important factors are traceability (C7), staff (C8) and cold transportation (C5). According to the numerical results of fuzzy DEMATEL implementations, suggestions for managerial implementations are presented.

Practical implications – 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.

Originality/value – To the best of the authors' knowledge, this is the first study that focuses on determining the potential criteria affecting cold supply chain performance both theoretically and empirically in the sustainability environment. What are the enablers that affect the cold food supply chain stages is the research question of this study.

Keywords Decision-making, Supply chain management, Cold chain, Food chain, Fuzzy DEMATEL

Paper type Research paper

1. Introduction

The cold chain food industry has been increasingly improving over the past years with increasing world population, significant growth of frozen foods and increasing customer

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requirements with increasing health consciousness (Lynch, 2016). Millions of tons of perishable foodstuffs are produced, stored, transported and distributed around the world every day. Customers have the right to want the food products they purchase to be of excellent quality and safety. In parallel with this purpose, safe temperature ranges depending on each food product categories should be adapted under specific series of logistics activities roof. If the proper temperature is not maintained or part of the supply chain is not taken into account, not only will the freshness of food products be reduced, but food may deteriorate and even the health of millions of people can be directly affected by dangerous bacteria.

Understanding every stage of the cold food supply chain is essential because of its important role in both human health and economics. A mistake made during either transport or storage causes the cold chain to break. Once thawed, the food product becomes unusable. The cold chain is a supply chain where refrigeration and freezing technology is necessary for transporting of perishable foods from supply until final consumption. Refrigeration, food safety and food waste are directly correlated. More specifically, proper refrigeration slows the growth of bacteria on foods, including pathogenic and spoilage bacteria. The pathogenic bacteria cause foodborne illness, while spoilage bacteria cause deterioration of foods and flavor, color and texture changes, weight loss, softening and excessive ripening. It is estimated that annual number of illnesses, hospitalizations and deaths in the USA because of foodborne pathogens are approximately 47.8 million, 127,839 and 3,037, respectively (CDC, 2016). But when the safety risk is discovered and reported at an earlier stage in cold chain, food will not be consumed and causes food waste, is a threat for the environment. Otherwise, the food goods probably can be consumed, which causes safety risk for human health (Mercier *et al.*, 2017). Briefly, cold chain is a strategic tool to achieve social (guarantee human health by preventing and controlling occurrence of harmful foods), economic (cost reduction) and ecological sustainability (waste reduction) (Singh and Shabani, 2016).

There are many studies on the economic and environmental effects of the traditional food supply chain. However, although the importance and awareness of the cold food chain increases with the change of lifestyles, there are very few studies on perishable foodstuffs. Most of these studies only track temperature fluctuations during cold transport (Derens-Bertheau *et al.*, 2015; Gogou *et al.*, 2015; Defraeye *et al.*, 2016). Other studies mostly examined in detail the production perspective. Calanche *et al.* (2013) evaluated the inherent quality issues of a company located in Spain. To achieve this, the cold chain process of this plant, dedicated to fresh fish processing, was explained through physical analysis (e.g. surface temperature of fishes and pH value), microbiological and sensory changes for two different kinds of fish, namely, sardine and *Salmo salar*. According to the numerical results of evaluation, the final value of pH for finished product of sardine depends on the quality of the raw material. Surface temperature in finished products is higher than material in both types. Microbiological findings were pleasurable both two fishes in respect of the specifications of European legislation and freshness rate of them was very high degree (about 90%), additionally to, the brightness of their skin. While cold plasma technology is used for sterilization of heat-sensitive packing materials, including polythene ethylene, as the temperature is low, over the past years, this technology is responsible for microbial inactivation while ensuring the quality of fresh produce in recent years and the effectiveness of cold plasma technology has already proven in relation to food decontamination and shelf-life extension (Thirumdas *et al.*, 2014). However, at least the production of cold foods, as well as transportation and storage conditions, are issues that should be examined by researchers. Briefly, a holistic approach that considers both economic conditions and human health is required for the cold food chain. To address this gap, this study focuses on identifying potential criteria that affect cold food chain performance and proposes a conceptual framework that includes these criteria. According to the results of our investigations in various studies, there is a need for a conceptual framework to guide food providers, logistics parties and managers to strive a holistic view for avoiding the danger of misleading managerial implications and preventing the food waste and safety concerns. Therefore, we designed a framework that covers main criteria within cold chain performance in the food industry because each step of cold chain has a significant impact on the final quality of the food goods. If foods are stored or transported at inadequate or too high temperature, bacteria can grow rapidly. Therefore, adopting and adapting procedures regarding these potential criteria in this framework are needed to minimize the risk of food safety hazard resulting in foodborne illness for consumers. To the best of our knowledge, this is the first study that focuses on determining the potential criteria affecting cold supply chain performance both theoretically and empirically in the sustainability environment. The research question of this study is: What are the enablers that affect the cold food supply chain stages? To answer this question, the study investigates the relationship between various enablers and determines the causal relationships and the relative importance of these enablers that are critical to the success of cold food supply chain performance and policymakers for implications.

To find answers to these questions, first, 12 main criteria were identified by using the combination of current literature review and expert's input. Second, a conceptual framework including these criteria was developed and a simple and structured Excel sheet was maintained. To understand the structure and propose managerial implications for an effective cold food chain management in sustainability environment, it is essential to analyze relationships between each criterion. Although there are many different multi-criteria decision-making (MCDM) techniques including presenting the causal relationships among factors and importance order with a holistic view, fuzzy Decision-making Trial and Evaluation Laboratory (DEMATEL), an MCDM method, is proposed to be used in this study.

The rest of the paper consists of six sections. Section 2 involves an overview of literature review of the cold supply chain. A conceptual framework model for cold chain is proposed in Section 3. Section 4 addresses the methodology of the proposed model. The implementation of the model is presented in Section 5. The results of the study and managerial suggestions for organizations are given in Section 6. This study is finalized with discussion of the main findings.

2. Literature review

Perishable products are temperature-sensitive items. "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). Perishables are divided into different food product categories: dairy products and eggs, fish and seafood products, meat and poultry, fruits and vegetables and all cooked foods and even leftovers. There are various temperature standards to suit them along storage and transport to ensure their freshness, marketability and desirability (Jedermann *et al.*, 2009).

Cold chain is a logistics process of transporting, handling and holding of perishable products throughout a supply chain within a desired low-temperature range (Bozorgi *et al.*, 2014). A basic cold chain infrastructure begins with supplier and ends with end-users like a traditional supply chain. One or multiple storage areas and distribution centers (DCs) depending on market demand may be required. DC is a critical plant for cold chain management regardless of industry because it provides sorting and arranging shipments received from many suppliers according to retailer demand, food arrival time and the quality of foods before being shipped to retailers (Mercier *et al.*, 2017). Cold chain is a very special supply chain with an uninterrupted series of logistics activities and temperature controlled at each steps in cold chain has a significant impact on the final quality of foods. Protecting of integrity of 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.

To extend, ensure and maintain the quality of the food products, the preservation of processing along the supply chain from harvesting is essential. Precooling (prompt cooling after harvesting) is the first critical stage for fruits and vegetables, and helps removing the pip heat of them gradually following the harvesting. 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, pathogens and bacteria. Otherwise, it has been shown to increase losses and render fruits and vegetables inedible. In this regard, 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 needful facilities, means and materials including, refrigerated transportation, refrigerated containers, cold warehouses and cold stores, which are needed to preserve the safety and freshness of foods in the suitable conditions. After harvesting or processing, perishable foods are departed to cold warehouses for storage and they stay there for a particular period of time. Good and proper storage conditions are main parts of warehouses in a well-functioning cold chain. Essential and adequate number of equipment in terms of functional helps in maintaining pre-determined temperature range of foods during storage. 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. It is also required that the appropriate and high capacity storage area (generally 80–120 tons) for the pallet units and storage shelves should be characterized by appropriate distance, strength and stable construction (Brzozowska *et al.*, 2016).

Refrigerated transportation (or reefer freight) is an absolute necessity for moving perishable products safely, and is done by land, air or sea. During the shipment, required cold transportation requirements should be maintained (including, insulation capabilities, insulated containers [or cooler], insulating barrier materials and temperature monitoring and recording device). Travelled distance between origin and final destination, the type, size and weight of shipments as well as needed exterior temperature environment may be important parameters in relation to how to select the most suitable transportation mode for each product categories. In general, land transportation by cars or trucks is preferred for short-distance trips and perishable foods with longer shelf-life, while a container ship and airplane are more suitable for longer distances. Given the travelled long distance, maintaining of acceptable temperature range during transportation looks like a hard job, the processing of cold chain has gone as planned. Derens-Bertheau *et al.* (2015) tracked the temperature range of pre-packed meat and yoghurt from production site to retailer by using electronic temperature monitoring device, approximately for 1,000 km. Gogou *et al.* (2015) controlled the temperature fluctuations of meat products during commercial transportation in Greece. In both two cases, expected average temperature range has been provided during transportation. However, sometimes, temperature has exceeded than acceptable range throughout cold transportation. Raab *et al.* (2009) observed average temperature range of chicken breasts from manufacturer to DC at two different positions of pallet units throughout cold transport and recorded differences in temperature of up to 10°C between the air near the refrigeration units and the air near the doors of the truck. Abad *et al.* (2009) reported the temperature flows throughout three days in fish logistics chain and observed temperature increases of 2°C during loading of fish boxes and of 3°C during unloading operations. Koutsoumanis *et al.* (2010) measured the time and temperature conditions of pasteurized milk throughout the entire cold chain in Greece and reported that the average temperature during road transport exceeded 6°C.

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 found temperature abuses because of unloading and loading operations and absence of appropriate storage conditions at the airports. Mckellar *et al.* (2012) observed the temperature range of 27 packed lettuces in winter months (January and February) in Canada. In 2014, the study was carried out during summer months (July and August) by Mckellar *et al.* When we looked at the results among these two studies, the winter performance is satisfactory because of protecting frozen conditions. During summer months, higher temperature ranges were observed (approximately by 6.3°C for July and 5.9°C for August) during loading and unloading operations with increasing sunlight. Nunes *et al.* (2014) investigated the real-time temperature fluctuations of blackberries inside pallets placed at different positions from Mexico to California by using time–temperature indicators and observed significant heterogeneity of the temperature of up to 4°C–5°C among pallets. Amador *et al.* (2009) monitored the temperature of pineapples throughout three days from Costa Rica to Florida (USA) by using temperature sensors and smart tags that were placed at three different points in the pallets: upper corner, middle point from bottom to up and lower corner. Defraeye *et al.* (2016) investigated temperature fluctuations of oranges in refrigerated container in sea transportation during 21 days (from 2 July to 23 July). Both the studies reported that the temperature close to the bottom of pallets is lower than close to the top of pallets because of vertical air-flow in refrigerated containers. Nicomento *et al.* (2014) investigated the real-time temperature fluctuations of blackberries inside pallet units that were placed at different positions from Mexico to California and observed significant heterogeneity of the temperature of up to 4°C–5°C among pallet units.

Recently, many advanced innovative solutions (including, temperature data loggers, thermometers and temperature monitoring devices) for monitoring, checking and recording the acceptable temperature in real-time have become very important especially in food industry where safety risk is intensive. Monitoring and controlling of product temperature in refrigerated vehicles, storage areas and loading or unloading points help to ensure the human health at the highest level as far as possible. As one of the sub-criteria of quality management, traceability slows contamination, pathogens and spoilage microorganisms by tracking the processing of storage and distribution and avoids potential hazards at earlier stage of supply chain. As we pointed out above, the cold chain is a science, technology and a series of specific logistics activities (Rodrigue and Notteboom, 2014). Proper and uninterrupted logistics activities, understanding of all customer requirements and biological and chemical processes correlated with perishable foods are factors affecting the cold food chain performance. A good quality in the supply chain, supported with innovations and information and communication technologies, would 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.

As pointed out above, keeping at constant temperature until perishables are put in domestic refrigerator by consumer is essential to ensure the quality of food goods and prolong their shelf-life. Maintaining of specific temperature and tolerances depends on storage and transportation conditions. Thus, many researchers have studied the time–temperature conditions of different food product categories at different stages of the cold chain including, precooling, storage and transportation. However, it has always been neglected to examine other stages in the cold food supply chain from a holistic perspective. Therefore, the main aim of this study is to define potential criteria that affect cold food chain performance, using existing literature review and sectoral inferences, and develop a conceptual framework that includes these criteria with a holistic approach.

3. Conceptual framework model

Because of its significant role in both human health and economic perspective, it is very important to understand each stage of the cold food supply chain. A mistake made during either transportation or storage causes the cold chain to break. Once defrosted, the food product becomes unusable again. Therefore, it is essential to identify all the potential factors affecting the food quality and food safety within cold food chain industry and it is a roadmap to managers, food providers and logistics parties in terms of successful cold chain management.

Based on the detailed literature review and current practices, 12 main criteria are determined. To verify these criteria, a Delphi study was conducted by the participation of experts, who also attended to the implementation of the study that is explained in the following sections. The following 12 major criteria and their sub-criteria have been identified to affect the food quality and food safety within food cold chain industry.

Packaging (C1): Packaging has the ability to protect biological damage and contamination which will meet the requirements of the perishable products. Material selection (Verghese *et al.*, 2015; Brzozowska *et al.*, 2016; Ali *et al.*, 2018), inadequate packaging (Mercier *et al.*, 2017; Yildirim *et al.*, 2018; Rodrigue and Notteboom, 2014), inappropriate packaging (Onursal *et al.*, 2018) and dirty packaging are the sub-criteria of the packaging (Raut *et al.*, 2019).

Storage specifications and storage capacity (C2): Perishable products must be stored within an acceptable temperature range to maintain the required quality and quantity of foods. A special technical (or functional) facility is required, which is equipped with appropriate cooling units that allow the proper management of this storage area and the insulation of the walls. Inadequate cold storage capacity and unstable construction (Mercier *et al.*, 2017), non-functional refrigeration equipment and lack of temperature variability-controlling facilities/providers (Refrigeration Industry, 2017) and insulation of walls are the sub-criteria of storage specification (Zhang *et al.*, 2018; Raut *et al.*, 2019).

Failures in refrigeration systems (C3): Refrigeration systems, including a needful facility, means and materials, are capable of maintaining appropriate temperature range and relative humidity conditions along the processing, storage and transportation. Inefficient and improper pre-cooling (Pelletier *et al.*, 2011; Nunes *et al.*, 2014; Mercier *et al.*, 2017), mis-grading of data loggers and timing failures in refrigerated equipment (Onursal *et al.*, 2018; Raut *et al.*, 2019) are the sub-criteria.

Handling issues and inventory rotation (C4): It refers to short-distance movement from a transportation vehicle to DC or DC to transportation vehicle and to right placement of products in shelves and vehicles. This feature consist of three sub-criteria: inappropriate handling practices (Mercier *et al.*, 2017), misplacement of different types of good in refrigerated warehouses/vehicles (Onursal *et al.*, 2018) and poor inventory rotation

(Raut *et al.*, 2019). The shelf-life is defined as "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). In general, "First to expire, first out" inventory strategy should be applied for fresh food products because of their perishable nature. For the continuity of products, inventory should be checked periodically and expired products should be removed immediately.

Cold transportation (C5): Refrigerated transportation is equipped with refrigeration units that allows pre-determined range of temperature for protecting the freshness of perishable products. This feature consists of four sub-criteria: loading and unloading practices (Carullo *et al.*, 2008; Koutsoumanis *et al.*, 2010), pallet positions in refrigerated vehicles (Landfeld *et al.*, 2011), special technical vehicle selection (Margeirsson *et al.*, 2012; Mckellar *et al.*, 2012; Verghese *et al.*, 2013) and travelling distance (Brzozowska *et al.*, 2016; Mercier *et al.*, 2017; Ali *et al.*, 2018; Raut *et al.*, 2019).

Delivery delay (C6): Delivery delay may be occurred because of inconveniences and unexpected situations on road. This feature consists of two sub-criteria: poor coordination/collaboration among cold chain partners (Verghese *et al.*, 2013; Ali *et al.*, 2018) and unexpected road conditions (Raut *et al.*, 2019).

Traceability (C7): Traceability is a crucial point because it slows contamination, pathogens and spoilage microorganisms by tracking and controlling the potential hazards as well as operationalizing standards by increasing transparency across cold supply chain. This feature consists of two sub-criteria: temperature monitoring/controlling technologies (Li *et al.*, 2015; Thakur and Forås, 2015; Brzozowska *et al.*, 2016) and food safety business certifications (Ruiz-Garcia and Lunadei, 2010; Zhang and Kraisintu, 2011; Ndraha *et al.*, 2018).

Staff (C8): A well-trained and qualified staff regarding the understanding of system requirements and hygiene requirements for successful cold chain process is essential. Lack of technical ability of the staff and negligence (Brzozowska *et al.*, 2016), personnel hygiene requirements (Ali *et al.*, 2018) and lack of trained staff involved in cold chain management (Onursal *et al.*, 2018) are the sub-criteria.

Technical issues (C9): Technical issues directly affect cold chain performance. Lack of technology and research and development (R&D) (Carullo *et al.*, 2008), temperature fluctuations caused by on–off cycles of the refrigeration unit (Nunes *et al.*, 2014) and interruptions of the refrigeration function (Carullo *et al.*, 2008) are the sub-criteria.

Consumption (at home) (C10): Consumers who are the final part of cold supply chain generate the large amount of food waste because of lack of knowledge or negligence. Poor household knowledge and hygiene requirements (Redlingshofer and Soyeux, 2012), unsuitable purchasing portions (Verghese *et al.*, 2013) and frequency of opening of the domestic refrigerator (Mercier *et al.*, 2017) are the sub-criteria.

Hygiene requirements of physical conditions (C11): The walls, floors and shelves should be cleaned in accordance with sanitary hygiene requirements as well as pest control should be implemented in regular periods. This feature consists of two sub-criteria: inappropriate cleaning requirements in walls and floors (Gunders, 2017) and pest control (Brzozowska *et al.*, 2016).

Others (C12): Some external factors are notable and may shorten or endanger food safety. This feature consists of three sub-criteria: weather condition, heat sources in trucks or warehouses and absence of legal regulations and regulatory requirements of the organizations (Ndraha *et al.*, 2018) (Table 1).

Criteria	Author(s)
Packaging	Redlingshofer and Soyeux (2012), Realini and Marcos (2014); Bag and Anand (2015), Cakilci and Ozturkoglu (2020)
Storage specifications and loading capacity	Carullo *et al.* (2008), Ismail *et al.* (2011); Bag and Anand (2015), Brzozowska *et al.* (2016)
Refrigeration systems	Pelletier *et al.* (2011); (Nunes *et al.*, 2014); Mercier *et al.* (2017), Onursal *et al.* (2018); Raut *et al.* (2019)
Handling issues and inventory rotation	Redlingshofer and Soyeux (2012), Verghese *et al.* (2013); (Nunes *et al.*, 2014); Brzozowska *et al.* (2016)
Cold transportation	Foster *et al.* (2003), Derens-Bertheau *et al.* (2015); Raab *et al.* (2009), Abad *et al.* (2009); Amador *et al.* (2009), Moslemi *et al.* (2017); Kolat *et al.* (2019)
Delivery delay	Redlingshofer and Soyeux (2012), Verghese *et al.* (2013); Ali *et al.* (2018), Onursal *et al.* (2018)
Traceability	Akyildiz *et al.* (2002), Frederiksen *et al.* (2002); Srivastava (2004); Grönman *et al.* (2013)
Staff	Verghese *et al.* (2013), Brzozowska *et al.* (2016); Ali *et al.* (2018), Onursal *et al.* (2018)
Technical issues	Carullo *et al.* (2008); (Nunes *et al.*, 2014); Mercier *et al.* (2017), Onursal *et al.* (2018)
Consumption	Redlingshofer and Soyeux (2012), Verghese *et al.* (2015); Mercier *et al.* (2017)
Hygiene requirements of physical conditions	Brzozowska *et al.* (2016), FSA (2017); UTIKAD (2017), Gunders (2017)
Others	Brzozowska *et al.* (2016), Mercier *et al.* (2017); Ndraha *et al.* (2018), Ozbekler and Ozturkoglu (2020)

Table 1.
Main criteria for cold chain

From the perspective of holistic view and system approach, it can be said that criteria under different suggestions can be related to each other. Therefore, to propose suggestions about managerial implications for a cold chain system and understand the structure, it is necessary to analyze causal relationships between selected criteria by using fuzzy DEMATEL. In the following section, fuzzy DEMATEL method is presented.

4. Methodology: fuzzy Decision-making Trial and Evaluation Laboratory

The DEMATEL is one of the multi-criteria decision methods, which was originally developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva Research Center between 1972 and 1976 (Aktas *et al.*, 2015). DEMATEL is a suitable way to examine direct and indirect relations among complicated and embrangled criteria with certain scores by using matrix operation (Lin *et al.*, 2018). It is based on the basis of graph theory that divides selected criteria into cause and effect groups by constructing a strategic map to decision-makers for a better understanding and interpreting of the causal interrelationship between criteria, which is one of the most significant characteristics of the method.

The DEMATEL procedures can be explained in the following steps:

- Step 1. The pair-wise comparison scale can be designated with five scales, where the integer scores of 0, 1, 2, 3 and 4 represent no influence (NO), very low influence (VL), low influence (L), high influence (H) and very high influence (VH), respectively.
- Step 2. The initial direct relation matrix Z is a $n \times n$ matrix and is occurred by pair-wise comparisons among criteria by evaluators, $Z = [z_{ij}]_{n \times n}$. Z_{ij} is denoted as the degree to which the criterion i affects criterion j. When $i = j$, diagonal values are identified as 0.

- Step 3. 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 formulas (1) and (2):

$$\mathrm{X} = \mathrm{Z}/k \tag{1}$$

$$k = \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^{n} Z_{ij}} \quad i,j = 1,2\ldots,n \tag{2}$$

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

- Step 4. T is the total relation matrix and is produced by using below formula, where I refers to the identity matrix:

$$\mathrm{T} = X.\ (I - X)^{-1} \tag{3}$$

- Step 5. The sums of rows and the sums of columns within the total relation matrix T are, respectively, represented as D and R values, i.e. $D = [d_i]_{n\times 1}$ and $R = [r_i]_{n\times 1}$, and are calculated by using formulas (4) and (5):

$$D = \sum_{j=1}^{n} t_{ij}, \tag{4}$$

$$R = \sum_{i=1}^{n} t_{ij} \tag{5}$$

D indicates the sum of effects of criteria i on other criteria, which is called as the influence degree of criteria i. R indicates the sum of the effects of all the other criteria on criteria i, called the affected degree of criteria i.

Crisp numbers are sometimes inadequate in decision-making process because it is hard to express causal relationships among complicated criteria by using certain numbers. Therefore, DEMATEL method was extended to the fuzzy DEMATEL method. This combination is generally preferred for subjective nature of human judgments (Kirkire and Rane, 2017). Interval sets are used rather than real numbers in a fuzzy environment thereby linguistics terms are converted to fuzzy numbers (Tan *et al.*, 2010; Malekzadeh *et al.*, 2016). In this study, fuzzy DEMATEL approach is used instead of traditional DEMATEL method because DEMATEL is not well-equipped to solve the uncertainty data in evaluation. Sometimes, the fuzzy DEMATEL method procedures can be summarized as follows:

- Step 1. Identifying the decision goal and forming an expert committee which has knowledge and experience to solve the problem.
- Step 2. Defining the evaluation criteria.
- Step 3. Designing the fuzzy linguistic scale.

- Step 4. Obtaining and collecting the evaluation of experts.
- Step 5. Identifying the structural model (Table 2).

The causal diagram is the final step of fuzzy DEMATEL method; a causal diagram is created based on D and R values, where the horizontal axis (D + R) named the "Prominence" is calculated by adding D to R. It plays a central role in a problem because it shows the importance of degree between selected criteria; the vertical axis (D − R) named the "Relation" is calculated by subtracting D to R and it divides criteria into cause and effect groups. When the (D − R) > 0, criterion *i* affects other criteria and is often grouped into net cause group. Otherwise, the criteria belong to the effect groups, criterion *i* is being influenced by other criteria. The causal diagram can visualize the complicated causal relationships between cause and effect groups by using graphical diagram and gathering information for decision-makers for solving a problem and making better decision by identifying the difference between cause and effect groups.

5. Implementation of the study

This section describes the application of the fuzzy DEMATEL to the comprehensive variables listed in Table 1. The criteria have been identified based on the discussions on the relationship between cold food supply chain stages in the previous section. A survey on the basis of 12 main criteria was designed and conducted with the participation of 6 experts who have at least 5 years of experience via e-mail. The experts to be surveyed were determined by judgmental sampling method. The purpose of this sampling is to identify companies, which include both marketing and production part of the cold food management strategies in their processes. Experts who are currently working at logistics department of cold chain in Turkey in the manager position were selected. In this study, while creating an expert group, people who have sectoral knowledge on the subject and who can contribute to the study with their experience are chosen. The specifications of the experts are given in Table 3.

Participants expressed their own opinions, knowledge and skills on Excel sheet by using fuzzy linguistic scale in Table 2. All the formulas and scoring of participants were entered into Microsoft Excel to solve the equations of fuzzy DEMATEL. The methodology was

Table 2.
Fuzzy linguistic scale

Linguistic terms	Triangular fuzzy numbers
No influence (NO)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.5)
Low influence (L)	(0.25, 0.5, 0.75)
High influence (H)	(0.5, 0.75, 1.0)
Very high influence (VH)	(0.75, 1.0, 1.0)

Table 3.
The specifications of the experts

Experts	Departments	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

explained in detail in the previous section. As an example, one of the expert's evaluation is shown in Table 4.

After initial direct relation matrix is produced by calculating arithmetic average of evaluation of six experts and maximum value determined by adding of rows and columns, the normalized direct relation matrix is created by using formula (2) and is presented in Table 5.

Next, the total relation matrix is produced by using formula (3) and is shown in Table 6.

As a final step, D + R and D − R values are calculated by using formulas (4) and (5) to show structural model (Table 7). These values are used to draw the causal diagram in Figure 1.

6. Results and managerial implications

The numerical result of fuzzy DEMATEL analysis provided the importance order of each criterion and is divided into two groups, namely, cause and effect groups. Importance order of criteria measured on the basis of (D + R) value. The importance order of criteria from upper value to lower value are ranked (C7), (C8), (C5), (C1), (C2), (C3), (C9), (C4), (C6), (C12), (C11) and (C10), respectively. Through calculation of (D − R) values, cause and effect groups are classified. The cause group contains five factors, namely, (C1), (C3), (C8), (C9) and (C12). Similarly, the effect group involves remaining seven factors, namely, (C2), (C4), (C5), (C6), (C7), (C10) and (C11).

1	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	NO	VH	VH	VH	VH	H	VH	L	H	VL	H	VL
C2	H	NO	H	H	H	H	H	H	L	L	H	VL
C3	L	VH	NO	VL	VH	H	H	L	H	VL	VH	VL
C4	H	VH	VL	NO	VL	L	L	L	L	VL	L	VL
C5	L	L	VH	L	NO	H	VH	L	H	VL	L	H
C6	L	VL	L	VL	VH	NO	H	L	L	H	VL	VH
C7	VH	VH	VL	VH	H	L	NO	VH	H	VL	H	L
C8	L	L	L	H	H	L	L	NO	L	VL	L	L
C9	VL	L	VH	L	VH	H	VH	L	NO	VL	H	VL
C10	VL	L	VL	VL	VL	H	VL	L	VL	NO	VL	VL
C11	H	H	VH	L	L	VL	H	L	H	VL	NO	VL
C12	VL	VL	VL	VL	H	VH	L	H	VL	VL	VL	NO

Table 4. Linguistic assessment of expert 1

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

Table 5. Normalized direct relation matrix

Table 6.
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

Table 7.
D + R and D − R data set

Prominence and relation value	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
D + R	5.861	5.686	5.291	5.111	6.118	4.712	6.616	6.237	5.185	3.747	4.150	4.260
D − R	0.402	−0.254	0.097	−0.055	−0.353	−0.514	−0.019	0.909	0.604	−0.857	−0.453	0.493

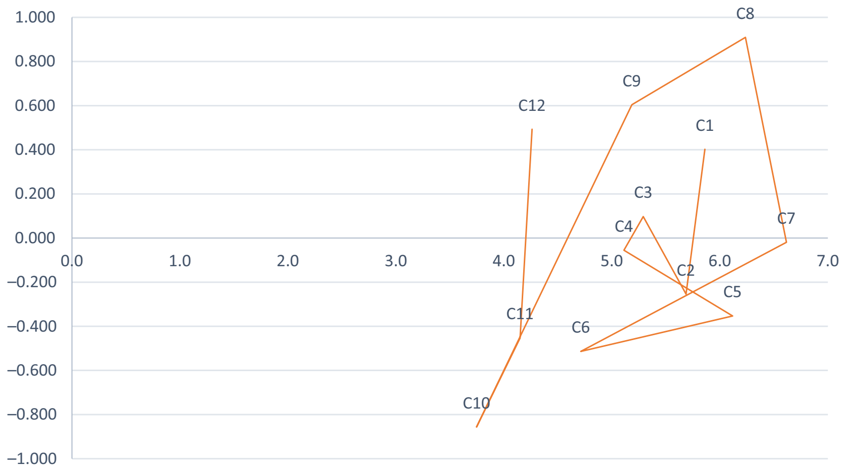

Figure 1.
Cause–effect relationship diagram

The detail numerical results of analysis are presented in Table 8.

Five cause criteria are identified as significantly important toward effective implementation of cold food supply chain performance. Additionally, the improvement in the cause criteria brings the improvement in the effect groups. Therefore, we need to focus on influential criteria:

- The highest "D − R" score is staff (C8) should understand the effect of temperature on foods and receive comprehensive training regarding correct loading and unloading practices, proper storage and handling practices, quality assurance and a general knowledge of refrigeration system. There should be an adequate number of qualified

Importance order	Cause group	Effect group
Traceability (C7)	0	x
Staff (C8)	x	0
Cold transportation (C5)	0	x
Packaging (C1)	x	0
Storage specifications and loading capacity (C2)	0	x
Refrigeration systems (C3)	x	0
Technical issues (C9)	x	0
Handling issues and inventory rotation (C4)	0	x
Delivery delays (C6)	0	x
Others (C12)	x	0
Hygiene requirements of physical conditions (C11)	0	x
Consumption (at home) (C10)	0	x

Table 8. Summary of numerical results

and skilled staff at each plant of supply chain and they should take necessary precautions including hygiene requirements and protective clothes in cold warehouses.

- The second most influential criterion among the identified criteria is technical issues (C9); implications of technology and R&D will enhance to produce all the functional and specific requirements toward cold chain. A malfunction or interruption of refrigeration system will cause to increase the risk of consignment failure and food safety as well.
- The third influential driver is others (C12). Legal obligations and various regulatory requirements of the organizations will clearly cause efficient harvesting, storage, transportation and processing. Weather condition is also one of the important threats for food quality. Perishables should not be stored where sun light is intensive such as a balcony or patio.
- The fourth influential criterion is packaging (C1). Proper, adequate and good quality packaging materials are accepted as one of the major logistics activities in terms of contamination, spoilage, hygiene and freshness of food products. Proper insulated container with strong and durable external surface material helps to maintain the specified range of temperature of food products along the transport and shipment of them. When packaging material has sufficient stacking strength, it can withstand injuries and losses caused by highly or improper humid environment and low temperatures in container or boxes. Throughout a cold chain transportation link, adequate number of dry ice should be correctly placed inside the insulated container. In terms of household consumption, detailed storage advice including expiry date, where and which temperature range to store in domestic refrigerator before cooking are provided. Consumers should adopt these advices on pack and should purchase only what they need to prevent the food waste.
- The last influential criterion is failures in refrigeration system (C3). Refrigeration system including refrigeration equipment (e.g. chiller and refrigerated chamber) for ensuring the food quality and precooling for prolonging the shelf-life of fruits and vegetables is critical. Failure to ensure the suitability of refrigeration systems led to high food waste and reduces the quality of foods.

Seven effect groups are identified. The cause group criteria affect these effect group criteria so the improvement of effect group criteria depends on the improvement in the cause groups.

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

- Staff need to be trained to manage, observe and control dealing with cold goods and storage 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 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.
- Electric-powered material handling vehicles should be preferred to prevent food safety caused by some dangerous gas, including carbon monoxide.
- A reliable electric system should be used in a cold storage facility. For instance, a storage generator is used both to provide power to refrigeration units and avoid potential loss when power is interrupted.
- 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 should be involved in cold chain process.
- Selection of true partnerships will achieve quick and long-term improvements for a sustainable cold chain process.

7. Conclusion

This study aims to evaluate the causal interrelationships among potential criteria, additionally to their importance order and design a conceptual framework regarding these criteria is a roadmap for managers, logistics parties and food providers in their making decision. The combination of comprehensive literature review and experts' input is used for determining 12 main criteria affecting the cold chain performance in the food industry and a simple and structured Excel sheet is maintained. Although there are many MCDM techniques, fuzzy DEMATEL is used for this study because it has the ability to deal with complicated problems by insight into causal relations and asses importance order among criteria. Fuzzy DEMATEL divides the criteria into two groups (based on the $D - R$ value), namely, cause group and effect group. This analysis shows five criteria (C1, C3, C8, C9 and C12) belong to cause groups and remaining seven criteria belong to effect groups. On the basis of increasing $(D + R)$ values, the importance order of criteria is ranked. According to the findings of the study, staff is the most influential factor. The most important criterion is traceability. It is an expected outcome for this study because continuous temperature monitoring in real-time is critical point in terms of safety, quality and shelf-life of food products and staff are integral part of cold chain and knowledge and skill of staff led to achieve higher customer satisfaction and increase profits. Furthermore, based on the overall evaluation of the research, meaningful suggestions for managerial implications for organizations are proposed.

Having of temperature-controlled storage facility and refrigerated vehicles involve high capital. It is a very important barrier for food providers and businesses for long-term improvement of cold chain. Future research should aim to provide clear and detailed assessment related to barriers of the cold chain. Secondly, proposed evaluation criteria can be conducted in other industry or comparative studies applied between food industry and pharmaceutical industry. Finally, evaluation criteria can be extended and evaluated by using different MCDM methods.

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