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# Prioritising Factors Affecting Cold Chain Logistics Performance and Their Implication for Sustainability

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## Abstract

A significant portion of agricultural and healthcare products share the feature of being perishable. If not properly handled from the point of production to their use or consumption, using cold chain logistics (CCL) systems, their quality deteriorates causing economic, social, and environmental consequences. The focus must extend beyond boosting agricultural productivity and investing in procuring pharmaceuticals to include robust CCL practices that reduce perishable product losses during grading, sorting, packing, storage, processing, and transportation considering sustainability. The CCL in developing countries lags behind, is in the nascent stage, is not much explored, and faces challenges; there is paucity of previous studies addressing issues of sustainability. This study aims to prioritise factors affecting perishable products' CCL performance and their implication for sustainability. After conducting a comprehensive literature review, and consulting experts and practitioners, the study employed thematic analysis to generate factors affecting perishable products' CCL performance. The study employed the decision-making trial and evaluation laboratory (DEMATEL) technique to identify and categorise CCL performance-related factors into cause and effect groups. Subsequently, total interpretive structural modelling (TISM) and cross-impact matrix multiplication applied to classification (MICMAC) were employed to establish interrelationships among the factors. The study identified and prioritised factors affecting perishable products' CCL performance and their implication for sustainability. The findings of this study will guide perishable products' supply chain leaders and government officials what to focus on for reducing losses and improving sustainability.

**Keywords:** Perishable, Cold Chain Logistics, Sustainability, Thematic Analysis, DEMATEL Analysis

## Introduction

Access to affordable and safe food, whether perishable or nonperishable, is a fundamental human need. Similarly, ensuring the accessibility and affordability of vaccines and essential medicines is a key focus of the 2030 Sustainable Development Goals (SDGs), which aim to achieve universal health coverage (CEPAL, N., 2019). There is a growing body of evidence that places the issue of access to quality and affordable essential medicines in the framework of the human right to health, and of the achievement of universal health coverage (Singh et al., 2013; Gyansa-Lutterodt et al., 2017). Perishable goods, including food, medicine, flowers, and chemicals, are characterised by their tendency to deteriorate over time, particularly during their journey from point of production to consumption. As Razzaq et al. (2024) note, the food system, encompassing both production and consumption, is a global network with significant effect on the environment, human health, and economy.

About one-third of the global food products intended for human consumption is lost along the food value chain (FAO, 2017) when more that 26% of the world population lives under moderate and severe food insecurity (FAO, 2019). While urbanisation and population continue growing, particularly in less developed countries, projections reveal that about 582 million people will be chronically undernourished in 2030 globally (FAO, 2024).

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Food loss and undernourishment can definitely lead to reduced labour productivity. Food loss also contributes to about 8% of the total global emissions of greenhouse gases (GHGs) (Shaikh, 2019), and hence, its current practice is not sustainable (Razzaq et al., 2024). Unhealthy diet may also imply an increased demand for medication that in turn requires more health commodities. According to the World Food Programme's report (https://www.wfp.org/ending-hunger), two people per 10,000 die from starvation or disease and malnutrition; 20% of households face extreme food shortages; and 30% of children suffer from acute malnutrition at mid-2025.

The health sector represents a major consumer of national resources. Historically, agriculture has been a cornerstone of Ethiopia's economy and it remains one of the country's five priority sectors despite its ongoing challenges in feeding a growing population. Both fresh agricultural products and health commodities share the characteristic of being perishable. For a country such as Ethiopia, transforming agriculture is essential not only for economic growth and poverty reduction but also for guaranteeing food security. As Xu (2021) points out, this transformation requires equal attention to logistics, particularly cold chain logistics (CCL). Inefficiencies in CCL practices, such as packaging, transport, and storage, are major contributors to food loss, a problem that is particularly acute in developing countries (Pajic et al., 2024).

Health commodities, including medicines and vaccines, along with fresh agricultural products such as fruits, vegetables, dairy products, poultry, flowers, and meat (Zhang & Mohammad, 2024; Mercier et al., 2017; Ndraha et al., 2018), are susceptible to quality deterioration and spoilage during transit to point of consumption. There is huge loss (over EUR300 million) of health commodities (Tumwine et al., 2023) and food commodities worth about USD1 trillion (Ishangulyyev et al., 2019; UNEP, 2024) every year due to improper storage or distribution globally. In Ethiopia vaccines lose their potency during storage at the centres and the majority of facilities have registered poor vaccine management practices (Bogale et al., 2019; Erassa et al., 2023).

Estimates suggest that major food and cash crop losses amount to more than 25% of Ethiopia's export earnings (30% to 40% for cereals, fruits, and vegetables) that could feed millions of food-insecure individuals. Beyond their loss or becoming waste, these commodities pose environmental concerns causing infectious diseases (Wassie et al., 2022) and contributing to global GHG emissions (Shaikh, 2019; Razzaq et al., 2024). Food waste, for instance, generates 8–10% of global GHG emissions and drives biodiversity loss (United Nations Environment Programme [UNEP], 2024).

Han et al. (2021) noted well-functioning CCL plays a crucial role in maintaining quality of temperature-sensitive and perishable products – both healthcare and agricultural. The importance of the cold chain is apparent to governments and key stakeholders within the health sector all over the world (Tumwine et al., 2023). Product loss can occur during storage, transport, handling, or processing (Delgado et al., 2021). Among the various strategies, investing in CCL for reducing food loss will save more than the annual increase in production that would feed millions of people (Dou et al., 2016).

Inefficiently operating CCL exposes the inventory items in storage and in transit, causing product quality loss, resulting in high operational expenses, which impede the attainment of value generated by CCL. The significance of CCL has escalated in tandem with the global demand for fresh and safe food products, pharmaceuticals, and other temperature-sensitive items (Shi et al., 2024; Ren et al., 2022). CCL is receiving more and more attention, both in practice and in scientific literature (Ndraha et al., 2018).

Thus, optimising the CCL of fresh produce has now become the main focus of research (Han et al., 2021) with emphasis on aspects such as, improved efficiency (Duan et al., 2020; Han et al., 2018a), ensuring the integrity of the cold chain and its precise control (Bouzembrak et al., 2019), and promoting the ecological and sustainable development of the cold chain (Wu et al., 2019).

There are studies conducted in the area of CCL with a focus on its practice (Tumwine et al., 2023; *Ogboghodo et al., 2017*) – cold chain transportation decision (Lin et al., 2020), establishing a comprehensive framework for temperature monitoring within CCL focusing on transportation and warehousing aspects (Pajic et al., 2024), and an in-depth exploration of CCL and joint distribution (Shi et al., 2024). Studies show that the efficiency of the CCL is often less than ideal (Mercier et al., 2017). In addition, the CCL faces several major challenges that undermine its performance (Mustafa et al., 2024). The challenges are related to packaging, handling, customs clearance, contamination, and rising transportation costs (Mohamed & Emel, 2025); infrastructural deficiencies (Dou et al., 2016; Linh, 2018; Han et al., 2021; Chen et al., 2023; Loi et al., 2024), the institutional and legal framework regulating logistics activities; the quality of human resources in the logistics industry; and the effectiveness of the processes, procedures, capacity of logistics service providers (Linh, 2018), poor control resulting from a lack of appropriate logistics infrastructure and of knowledge of how to handle perishables (Han et al., 2021); among others. Focusing efforts to improve CCL performance is a more practical approach than trying to address all challenges at once, especially for countries with limited resources and access to latest technologies in the area. Hence, prioritising the factors is crucial.

However, there is paucity of literature prioritising the factors that affect CCL performance while establishing cause and effect relationship. Mohamed and Emel (2025) identified about 14 factors that affect the cut flower CCL sector in Kenya. They tried to prioritise these factors using the Improved Fuzzy Stepwise Weight Assessment Ratio Analysis (IMF-SWARA) methodology based on interview data from five experts. The influence of factors such as natural disasters (for example, heavy rain), level of knowledge and information sharing, perishability and loss, service quality level and reliability, and responsiveness of the demand on CCL seems questionable.

Chermala et al. (2025) found in their recent study that distribution, warehouse inventory storage, quality, demand, and technology affect the CCL's performance, although they did not prioritise the factors. Even the factors are not exhaustive. Kumar and Krithika (2025), in a study on challenges faced by the cold chain service providers with reference to frozen food products, tried to prioritise five challenges using descriptive statistics that does not seem strong enough to show the casualty. Studies relating the factors to sustainability are also limited. This study aims to prioritise the major factors affecting CCL and further tried to examine their implication for sustainability. The study tried to address the following research questions:

- Which factor is the most influential in the context of CCL performance?
- What does the cause and effect relationship between the factors look like?
- To what extent do the factors affecting CCL performance imply sustainability?

The study employs a pragmatic or interpretivist approach, often utilising a qualitative-dominant mixed approach. The pragmatic paradigm is considered because decision-making trial and evaluation laboratory (DEMATEL) is a problem-solving methodology that focuses on understanding complex relationships. Since DEMATEL relies on expert opinions and subjective assessments to establish cause and effect relationships between factors affecting CCL performance, an interpretivist lens is found relevant.

This paper is structured in five sections. Section two reviews existing literature on CCL and relevant sustainability concepts. Section three outlines the research methodology used. Section four presents the analysis and key findings. Finally, section five summarises the conclusions and discusses managerial implications derived from the research.

## Literature Review

### CCL

CCL plays a critical role in preserving the integrity and quality of perishable agricultural and health commodities. CCL is a critical component of the supply chain that ensures the preservation of perishable goods from the point of origin to the consumer (Shi et al., 2024). CCL is defined in various ways in existing literature (Chermala et al., 2025). Mallik et al. (2011) defined CCL as the continuous process of managing processes, equipment, and resources to retain the necessary temperature for storing and distributing perishable goods. Doing so helps organisations preserve the freshness of commodities and products. Fan et al. (2021) defined CCL as a system that must deal with the requirements of product quality, temperature controls, cost efficiency, timeliness, and environmental impacts, as well as the technical issues in handling the possibility of processed meat products. CCL of fresh agricultural products refers to the food supply logistics chain that uses refrigeration technology to continuously maintain a suitable temperature and humidity environment for perishable products such as fruits, vegetables, dairy, meats, and fish (Han et al., 2021).

Prakash et al. (2022) note that beyond food products there is a growing demand for CCL for pharmaceuticals. The use of CCL for storing temperature-sensitive materials, such as expensive vaccines, is now considered a critical driver for effective value-delivery systems across the pharmaceutical industry.

There are countless factors that may affect CCL performance. Search terms such as 'factors', 'determinants', and 'challenges' were used to identify potential factors affecting the CCL performance. Breakdown of refrigerators and freezers, delays during transportation, inappropriate refrigerators, long duration of storage at the health unit, improper use of refrigerators, power interruptions, and lack of trained personnel capable of managing the cold chain (Tumwine et al., 2023; Lin et al., 2020), nonuniformity in storage temperature instructions on the label, user education, and lack of awareness about cold chain management (Ringo et al., 2017) were some of the factors identified. Mustafa, Namasivayam, and Demirovic (2024) mention critical shortcomings in areas such as the initial cooling of products, operations on the ground during transit, maintaining appropriate conditions during product display, and practices in commercial management as major challenges considering food cold chains. From the literature review carried out, 12 factors were selected based on their relevance: packaging, functionality of cold storage equipment, capacity of storage facility, handling and inventory rotation, cold transportation, delivery delay, traceability, staff competence, technical factors, consumer factors, hygiene factors, and government policies and regulations.

Packaging is a crucial component of CCL performance, as it contains and protects the products throughout their journey from origin to end-user (Ren et al., 2022; Pajic et al., 2024). Its influence is higher when inadequate, inappropriate, unclean, nonreusable materials that do not allow ventilation and temperature control are used.

It is not about availability alone. A functional cold storage equipment can prevent the product from quality or safety deterioration (Ren et al., 2022). The availability of functional cold storage equipment enables to maintain the product at a top condition suitable for consumption. Nonfunctional refrigeration equipment, insufficient temperature variability-controlling facilities, poor insulation, insecure data loggers, timing failures, and inappropriate weather compromise the integrity of CCL.

An effective cold chain relies on three main elements – well-trained staff; reliable storage, distribution, and temperature monitoring equipment; as well as accurate inventory management (Chukwu & Adibe, 2022; Shashi et al., 2021). Since production and consumption occur at different places and times, establishing cold storage facilities possessing the required capacity at strategic locations was a vital component for both fresh product import and export operations (Prakash et al., 2022). Inadequate cold storage capacity and unstable construction used for cold chain storage facility pose a danger (Shashi et al., 2021). Handling and inventory rotation challenges refer to inappropriate loading/unloading practices, misplacement of different types of goods in refrigerated warehouses or vehicles, and poor inventory rotation.

Cold transportation-related challenges include incorrect loading and unloading practices, wrongly positioned pallet in refrigerated vehicles, and inappropriate vehicle selection (Xu, 2021; Shashi et al., 2021). Delivery delay occurs due to poor co-ordination/collaboration among cold chain partners, and unexpected road conditions (Shashi et al., 2021; Zhang 2023). Traceability-related challenges occur due to lack of temperature monitoring/controlling technologies and food safety business certifications (Wang et al., 2024).

Staff competence-based challenges happen due to lack of technical ability of the staff and negligence, personnel hygiene requirements, and lack of trained staff (Simpah et al., 2022). Technical factors are lack of technology and research and development, temperature fluctuations caused by on-off cycles of the refrigeration unit, and interruptions of the refrigeration function (Bogale et al., 2019). Consumer factors are poor household knowledge and hygiene requirements, unsuitable purchasing portions, and frequency of opening of the domestic refrigerator (Lim et al., 2021).

Hygiene factors refer to inappropriate cleaning requirements in walls and floors, and pest control. The availability of conducive standards and policies formulated by government agencies to make safe delivery of items such as medicine, vaccines, and food items is vital (Prakash et al., 2022). Adherence to such policies and regulations will help avoid the dangers of decay, contamination, or loss of potency because of temperature variations, inappropriate handling, or exposure to external factors. On the other hand, lack of conducive government policies and regulations; duplication of regulatory agencies with similar responsibilities; lack of transparency in the way the rules, legislation, and policies are formulated; and lack of incentive policies for those investing in the cold chain facilities may act as major challenges.

### Sustainability Implication of CCL

The CCL industry consumes approximately 30% of the world's energy to maintain product quality, extend shelf life, and reduce food loss (Han et al., 2021). Of this, refrigeration accounts for 8% of the industry's total electrical energy use (Han, Zhao et al., 2018). Hence, minimising food loss and unnecessary energy consumption during all phases of the CCL will improve the overall sustainability and help reduce fossil fuel consumption, thereby alleviating some of the associated environmental problems (Azmi et al., 2017; Surucu-Balci & Tuna, 2021) such as GHG emissions.

## Research Methods

The study employed both descriptive and explanatory designs. Descriptive design was employed to describe the study participants' response to the factors affecting CCL performance. Explanatory design was employed to establish the cause and effect relationship among the 12 factors related to CCL. The study approach is mixed as the study used both quantitative and qualitative data. Expert opinion obtained through survey data collected using five-point Likert scale questionnaire was used in the study.

The study population is deliberately geared towards those who have logistical background, including academicians (PhD candidates and master's students), those who are in the logistics job, and those directly working on CCL activities, horticulture sector, agriculture sector, and pharmaceutical area. The final version of the instrument was thoroughly reviewed by experts to ensure its content validity. It was being assessed for online accessibility and comprehension by a cohort of logistics professionals and experienced researchers. Its content, clarity, and length were subsequently adjusted as necessary. The snowball sampling technique was employed to recruit research participants familiar with CCL. This sampling method is useful for studying a population that is difficult to reach through conventional means (Shooshtarian et al., 2024). Central to snowballing sampling are the characteristics of networking and referral (Parker et al., 2019). Email communication with the extended networks of participants was the main means to recruit the research participants.

Totally, 285 questionnaires were distributed of which 204 usable questionnaires were returned and employed in the analysis. Both a drop and collect approach and online platforms were employed. Ten experts participated in gathering expert opinion.

The study adopted the DEMATEL method. The DEMATEL method was initially developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976 to study and resolve the complicated and intertwined problem group (Tzeng et al., 2010; Wu, 2008; Shieh et al., 2014; Ogrodnik, 2018; Kashyap et al., 2022). The DEMATEL method could improve understanding of the specific problem, the cluster of intertwined problems, and contribute to identification of workable solutions by a hierarchical structure (Chen-Y et al., 2007; Tsai & Chou, 2009; Tzeng et al., 2010; Ogrodnik, 2018; Kashyap et al., 2022). DEMATEL is chosen above the analytic hierarchy process (AHP), total interpretive structural modelling (TISM), interpretive structural modelling (ISM), and other multicriteria decision making (MCDM) approaches because it categorises difficulties into groups based on causes (that is, higher priority factors that overall have a greater effect) and effects (that is, lower priority factors that are overall influenced by others), and also shows the gravity of those impacts (Kashyap et al., 2022; Hsieh et al., 2024).

Unlike the traditional techniques such as AHP with the assumption that elements are independent, this method, one of the structural modelling techniques, can identify the interdependence among the elements of a system through a causal diagram (Kim Yong Hun, 2006; Tzeng et al., 2010; Wu & Lee, 2007; Ogrodnik, 2018; Kashyap et al., 2022). The causal diagram uses digraphs rather than directionless graphs to portray contextual relationships and the strengths of influence among the elements (Wu, 2008; Kashyap et al., 2022). The steps in the DEMATEL method are summarised as follows (Tzeng et al., 2010; Wu, 2008; Shieh et al., 2014; Ogrodnik, 2018: Kashyap et al., 2022):

- *Step 1:* Compute the average matrix. Each respondent was asked to evaluate the direct influence between any two factors by an integer score ranging from 0, 1, 2, 3, to 4, representing 'no influence', 'very low influence', 'low influence', 'high influence', and 'very high influence', respectively. The notation of $x_{ij}$ indicates the degree to which the respondent believes factor i affects factor j. For i = j, the diagonal elements are set to zero. An n x n nonnegative matrix can be established for each respondent as $X^k = [x^k_{ij}]$, where k is the number of respondents with $1 \leq k \leq H$, and n is the number of factors. Thus, $X^1$, $X^2$, $X^3$, ..., $X^H$ are the matrices from H respondents. To incorporate all opinions from H respondents, the average matrix A = [aij] can be constructed as follows:

$$aij = 1/H \sum_{k=1}^{H} X_{ij}^{k} \quad (1)$$

- *Step 2:* Calculate the normalised initial direct-relation matrix. Normalise initial direct-relation matrix D by D = A x S, where

$$S = \frac{1}{max_{1 \leq i \leq n} \sum_{j=1}^{n} a_{ij}} \quad (2)$$

Each element in matrix D fails between zero and one.

- *Step 3:* Calculate the total relation matrix. The total relation matrix T is $T = D(I - D)^{-1}$, where I is the identity matrix. Define r and c as n x 1 and 1 x n vectors representing the sum of rows and sum of columns of the total relation matrix T, respectively. Suppose $r_i$ is the sum of ith row in matrix T, then $r_i$ summarises both direct and indirect effects given by factor i to the other factors. If $c_j$ denotes the sum of jth column in matrix T, then $c_j$ shows both direct and indirect effects by factor j from the other factors. When j = i, the sum $(r_i + c_j)$ shows the total effects given and received by factor i. That is, $(r_i + c_j)$ indicates the degree of importance that factor i plays in the entire system. On the contrary, the difference $(r_i - c_j)$ depicts the net effect that factor i contributes to the system. Specifically, if $(r_i - c_j)$ is positive, factor i is a net cause, while factor i is a net receiver or result if $(r_i - c_j)$ is negative (Lee et al., 2013; Liou et al., 2007).
- *Step 4:* Set up a threshold value to obtain the digraph. Since matrix T provides information on how one factor affects another, it is necessary for a decision maker to set up a threshold value to filter out some negligible effects. In doing so, only the effects greater than the threshold value would be chosen and shown in digraph. In this study, the threshold value is set up by computing the average of the elements in matrix T. The digraph can be acquired by mapping the dataset of (r + c, r − c).

## Results and Analysis

**Table 1: Demographic Data**

| Work Experience | | | | | |
|---|---|---|---|---|---|
| | | Frequency | % | Valid% | Cumulative% |
| Valid | .00 | 6 | 2.9 | 4.0 | 4.0 |
| | 1.00 | 18 | 8.8 | 12.0 | 16.0 |
| | 3.00 | 42 | 20.6 | 28.0 | 44.0 |
| | 4.00 | 6 | 2.9 | 4.0 | 48.0 |
| | 5.00 | 6 | 2.9 | 4.0 | 52.0 |
| | 6.00 | 6 | 2.9 | 4.0 | 56.0 |
| | 7.00 | 6 | 2.9 | 4.0 | 60.0 |
| | 8.00 | 6 | 2.9 | 4.0 | 64.0 |
| | 10.00 | 12 | 5.9 | 8.0 | 72.0 |
| | 13.00 | 18 | 8.8 | 12.0 | 84.0 |
| | 15.00 | 24 | 11.8 | 16.0 | 100.0 |
| | Total | 150 | 73.5 | 100.0 | |
| Missing | System | 54 | 26.5 | | |
| Total | | 204 | 100.0 | | |

The above table shows the respondents have work experience ranging from one year to above 15 years; a majority of them have three years or more. This implies they have knowledge in the area that adds to the quality of their responses.

After collecting the experts' opinion, the average direct-relation matrix is prepared as shown in Table 2.

**Table 2: Average Matrix**

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F1 | 0 | 2.6667 | 2.9333 | 3.4667 | 3.4 | 2.1667 | 2.7333 | 2.1333 | 2.4 | 2.5667 | 3.1 | 2.9667 |
| F2 | 2.4 | 0 | 3 | 3.2 | 3.3333 | 3 | 2.3 | 2.6333 | 3.4333 | 2.5333 | 2.4667 | 2.4667 |
| F3 | 2.9667 | 2.9333 | 0 | 3.4667 | 3.0333 | 2.9333 | 1.9 | 2.1667 | 2.6667 | 2.3 | 2.5 | 2.4667 |
| F4 | 3.2 | 3 | 3.1667 | 0 | 3.1667 | 2.6667 | 2.5 | 3.0333 | 3.0333 | 2.2 | 2.6333 | 2.4 |
| F5 | 3 | 3.3667 | 3.0667 | 3 | 0 | 3.4667 | 2.7667 | 2.7333 | 3.1333 | 2.4 | 2.8 | 2.5 |
| F6 | 2 | 2.5667 | 2.8 | 2.4667 | 2.8 | 0 | 2.3667 | 2.8667 | 2.4333 | 2.5 | 1.9333 | 2.4 |
| F7 | 2.6 | 2.6667 | 2.2333 | 2.6667 | 2.9 | 2.8667 | 0 | 2.9667 | 3.0667 | 2.3667 | 1.9667 | 2.6667 |
| F8 | 2.6 | 3.1 | 2.3667 | 3.3667 | 3 | 3.0333 | 3.1 | 0 | 3 | 2.6333 | 2.7 | 2.8 |
| F9 | 2.8 | 3.4667 | 2.8 | 2.9667 | 3.1 | 2.6 | 2.9333 | 2.9 | 0 | 2.2667 | 2.3667 | 3.0667 |
| F10 | 2.6 | 2.4 | 2.0667 | 2.1 | 2.2 | 2.2333 | 2.1333 | 2.1667 | 2.4333 | 0 | 2.9333 | 2.6 |
| F11 | 2.7333 | 2.7333 | 2.8 | 2.9 | 2.6667 | 1.8333 | 2.3333 | 2.6667 | 2.6667 | 3.0667 | 0 | 2.7333 |
| F12 | 3.56 | 2.6 | 2.76 | 2.56 | 2.96 | 2.64 | 2.6 | 2.56 | 2.76 | 2.56 | 3 | 0 |

Step 2 is to calculate the normalised initial direct-relation matrix (D), depicted below is the formula: $D = A \times \frac{1}{max_{1\leq i\leq 9}\sum_{j=1}^{9} a_{ij}}$

**Table 3: Normalised Matrix**

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F1 | 0 | 0.08190 | 0.09009 | 0.10647 | 0.10442 | 0.06654 | 0.08395 | 0.06552 | 0.07371 | 0.07883 | 0.09521 | 0.09111 |
| F2 | 0.07371 | 0.00000 | 0.09214 | 0.09828 | 0.10238 | 0.09214 | 0.07064 | 0.08088 | 0.10545 | 0.07781 | 0.07576 | 0.07576 |
| F3 | 0.09111 | 0.09009 | 0.00000 | 0.10647 | 0.09316 | 0.09009 | 0.05835 | 0.06654 | 0.08190 | 0.07064 | 0.07678 | 0.07576 |
| F4 | 0.09828 | 0.09214 | 0.09726 | 0.00000 | 0.09726 | 0.08190 | 0.07678 | 0.09316 | 0.09316 | 0.06757 | 0.08088 | 0.07371 |
| F5 | 0.09214 | 0.10340 | 0.09419 | 0.09214 | 0.00000 | 0.10647 | 0.08497 | 0.08395 | 0.09623 | 0.07371 | 0.08600 | 0.07678 |
| F6 | 0.06143 | 0.07883 | 0.08600 | 0.07576 | 0.08600 | 0.00000 | 0.07269 | 0.08804 | 0.07473 | 0.07678 | 0.05938 | 0.07371 |
| F7 | 0.07985 | 0.08190 | 0.06859 | 0.08190 | 0.08907 | 0.08804 | 0.00000 | 0.09111 | 0.09419 | 0.07269 | 0.06040 | 0.08190 |
| F8 | 0.07985 | 0.09521 | 0.07269 | 0.10340 | 0.09214 | 0.09316 | 0.09521 | 0.00000 | 0.09214 | 0.08088 | 0.08292 | 0.08600 |
| F9 | 0.08600 | 0.10647 | 0.08600 | 0.09111 | 0.09521 | 0.07985 | 0.09009 | 0.08907 | 0.00000 | 0.06962 | 0.07269 | 0.09419 |
| F10 | 0.07985 | 0.07371 | 0.06347 | 0.06450 | 0.06757 | 0.06859 | 0.06552 | 0.06654 | 0.07473 | 0.00000 | 0.09009 | 0.07985 |
| F11 | 0.08395 | 0.08395 | 0.08600 | 0.08907 | 0.08190 | 0.05631 | 0.07166 | 0.08190 | 0.08190 | 0.09419 | 0.00000 | 0.08395 |
| F12 | 0.10934 | 0.07985 | 0.08477 | 0.07862 | 0.09091 | 0.08108 | 0.07985 | 0.07862 | 0.08477 | 0.07862 | 0.09214 | 0.00000 |

In Step 3, we calculate the total relation matrix (T) using the following formula:

$T = D(I - D)^{-1}$, where D is the normalised direct-relation matrix (Given in Table 4).

The total relation matrix is the product of the two matrices, the normalised direct-relation matrix and the inverse of the difference matrix obtained using the formula $T = D(I - D)^{-1}$.

**Table 4: Total Relation Matrix**

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F1 | 0.9140 | 1.0195 | 0.9866 | 1.0581 | 1.0675 | 0.9493 | 0.9124 | 0.9295 | 0.9985 | 0.8979 | 0.9427 | 0.9558 |
| F2 | 0.9884 | 0.9512 | 0.9947 | 1.0582 | 1.0728 | 0.9781 | 0.9074 | 0.9491 | 1.0321 | 0.9026 | 0.9315 | 0.9491 |
| F3 | 0.9637 | 0.9924 | 0.8716 | 1.0235 | 1.0230 | 0.9373 | 0.8603 | 0.8989 | 0.9716 | 0.8608 | 0.8957 | 0.9110 |
| F4 | 1.0171 | 1.0435 | 1.0068 | 0.9777 | 1.0772 | 0.9768 | 0.9200 | 0.9666 | 1.0297 | 0.9012 | 0.9436 | 0.9551 |
| F5 | 1.0421 | 1.0844 | 1.0346 | 1.0938 | 1.0211 | 1.0273 | 0.9547 | 0.9882 | 1.0634 | 0.9342 | 0.9761 | 0.9869 |
| F6 | 0.8758 | 0.9184 | 0.8880 | 0.9316 | 0.9501 | 0.7949 | 0.8157 | 0.8580 | 0.9022 | 0.8097 | 0.8220 | 0.8498 |
| F7 | 0.9439 | 0.9753 | 0.9252 | 0.9919 | 1.0088 | 0.9265 | 0.7965 | 0.9107 | 0.9721 | 0.8535 | 0.8720 | 0.9072 |
| F8 | 1.0181 | 1.0630 | 1.0022 | 1.0880 | 1.0903 | 1.0025 | 0.9510 | 0.8979 | 1.0460 | 0.9277 | 0.9606 | 0.9814 |
| F9 | 1.014 | 1.063 | 1.0044 | 1.0684 | 1.0833 | 0.9825 | 0.9380 | 0.9704 | 0.9523 | 0.9095 | 0.9433 | 0.9793 |
| F10 | 0.854 | 0.875 | 0.832 | 0.882 | 0.895 | 0.821 | 0.775 | 0.804 | 0.864 | 0.705 | 0.814 | 0.820 |
| F11 | 0.951 | 0.980 | 0.943 | 1.001 | 1.005 | 0.901 | 0.865 | 0.905 | 0.964 | 0.875 | 0.818 | 0.912 |
| F12 | 1.011 | 1.017 | 0.981 | 1.034 | 1.055 | 0.960 | 0.908 | 0.939 | 1.006 | 0.897 | 0.939 | 0.872 |

Table 5 gives the sum of influences given and received among these nine factors or dimensions.

**Table 5: Cause and Effect**

| Factors | Ri | Ci | Ri_Ci | Ri-Ci | Identify |
|---|---|---|---|---|---|
| Packaging (F1) | 11.6318 | 11.5952 | 23.227 | 0.0366 | Cause |
| Functionality of cold storage equipment (F2) | 11.7151 | 11.9834 | 23.6985 | -0.2683 | Effect |
| Capacity of storage facility (F3) | 11.2097 | 11.4708 | 22.6805 | -0.2611 | Effect |
| Handling and inventory rotation (F4) | 11.8152 | 12.2099 | 24.0251 | -0.3947 | Effect |
| Cold transportation (F5) | 12.2068 | 12.3506 | 24.5574 | -0.1438 | Effect |
| Delivery delay (F6) | 10.4162 | 11.2594 | 21.6756 | -0.8432 | Effect |
| Traceability (F7) | 11.0836 | 10.6062 | 21.6898 | 0.4774 | Cause |
| Staff competence (F8) | 12.0288 | 11.0185 | 23.0473 | 1.0103 | Cause |
| Technical factors (F9) | 11.9086 | 11.8038 | 23.7124 | 0.1048 | Cause |
| Consumer factors (F10) | 9.9467 | 10.4758 | 20.4225 | -0.5291 | Effect |
| Hygiene factors (F11) | 11.1251 | 10.8601 | 21.9852 | 0.265 | Cause |
| Government policies and regulations (F12) | 11.6266 | 11.0804 | 22.707 | 0.5462 | Cause |

The highest Ri + Ci coefficients of 24.55, 24.03, and 23.71 imply that cold transportation, handling and inventory rotation, and technical factors are the top three factors influencing CCL performance, respectively. The result also shows six factors in the cause group (challenges that influence other clusters of challenges) and six in the effect group (those affected by other challenges). The observations from this study can be very helpful in developing the framework for prioritising factors affecting CCL from a developing economy context.

*Step 4:* Set up a threshold value to obtain the digraph.

**Table 6: Threshold Value**

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F1 | 0.9140 | 1.0195 | 0.9866 | 1.0581 | 1.0675 | 0.9493 | 0.9124 | 0.9295 | 0.9985 | 0.8979 | 0.9427 | 0.9558 |
| F2 | 0.9884 | 0.9512 | 0.9947 | 1.0582 | 1.0728 | 0.9781 | 0.9074 | 0.9491 | 1.0321 | 0.9026 | 0.9315 | 0.9491 |
| F3 | 0.9637 | 0.9924 | 0.8716 | 1.0235 | 1.0230 | 0.9373 | 0.8603 | 0.8989 | 0.9716 | 0.8608 | 0.8957 | 0.9110 |
| F4 | 1.0171 | 1.0435 | 1.0068 | 0.9777 | 1.0772 | 0.9768 | 0.9200 | 0.9666 | 1.0297 | 0.9012 | 0.9436 | 0.9551 |
| F5 | 1.0421 | 1.0844 | 1.0346 | 1.0938 | 1.0211 | 1.0273 | 0.9547 | 0.9882 | 1.0634 | 0.9342 | 0.9761 | 0.9869 |

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F6 | 0.8758 | 0.9184 | 0.8880 | 0.9316 | 0.9501 | 0.7949 | 0.8157 | 0.8580 | 0.9022 | 0.8097 | 0.8220 | 0.8498 |
| F7 | 0.9439 | 0.9753 | 0.9252 | 0.9919 | 1.0088 | 0.9265 | 0.7965 | 0.9107 | 0.9721 | 0.8535 | 0.8720 | 0.9072 |
| F8 | 1.0181 | 1.0630 | 1.0022 | 1.0880 | 1.0903 | 1.0025 | 0.9510 | 0.8979 | 1.0460 | 0.9277 | 0.9606 | 0.9814 |
| F9 | 1.0142 | 1.0630 | 1.0044 | 1.0684 | 1.0833 | 0.9825 | 0.9380 | 0.9704 | 0.9523 | 0.9095 | 0.9433 | 0.9793 |
| F10 | 0.8548 | 0.8754 | 0.8323 | 0.8829 | 0.8950 | 0.8217 | 0.7758 | 0.8043 | 0.8641 | 0.7058 | 0.8144 | 0.8203 |
| F11 | 0.9513 | 0.9801 | 0.9431 | 1.0016 | 1.0059 | 0.9016 | 0.8656 | 0.9052 | 0.9648 | 0.8752 | 0.8186 | 0.9121 |
| F12 | 1.0118 | 1.0172 | 0.9813 | 1.0344 | 1.0557 | 0.9608 | 0.9089 | 0.9398 | 1.0069 | 0.8976 | 0.9397 | 0.8724 |
| **Threshold (alpha) value** = 0.949403 | | | | | | | | | | | | |

**Table 7: Inner Relation Matrix**

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F1 | | 1.0195 | 0.9866 | 1.0581 | 1.0675 | | | | 0.9985 | | | 0.9558 |
| F2 | 0.9884 | 0.9512 | 0.9947 | 1.0582 | 1.0728 | 0.9781 | | | 1.0321 | | | |
| F3 | 0.9637 | 0.9924 | | 1.0235 | 1.0230 | | | | 0.9716 | | | |
| F4 | 1.0171 | 1.0435 | 1.0068 | 0.9777 | 1.0772 | 0.9768 | | 0.9666 | 1.0297 | | | 0.9551 |
| F5 | 1.0421 | 1.0844 | 1.0346 | 1.0938 | 1.0211 | 1.0273 | 0.9547 | 0.9882 | 1.0634 | | 0.9761 | 0.9869 |
| F6 | | | | | 0.9501 | | | | | | | |
| F7 | | 0.9753 | | 0.9919 | 1.0088 | | | | 0.9721 | | | |
| F8 | 1.0181 | 1.0630 | 1.0022 | 1.0880 | 1.0903 | 1.0025 | 0.9510 | | 1.0460 | | 0.9606 | 0.9814 |
| F9 | 1.0142 | 1.0630 | 1.0044 | 1.0684 | 1.0833 | 0.9825 | | 0.9704 | 0.9523 | | | 0.9793 |
| F10 | | | | | | | | | | | | |
| F11 | 0.9513 | 0.9801 | | 1.0016 | 1.0059 | | | | 0.9648 | | | |
| F12 | 1.0118 | 1.0172 | 0.9813 | 1.0344 | 1.0557 | 0.9608 | | | 1.0069 | | | |

Following the formation of the total relation matrix, an inner relation matrix is also formed as shown in Table 7. An inner relation matrix is formed by eliminating all the values from the total relation matrix that are less than the threshold value. Basically, the inner relation matrix signifies the rate of correlation among different factors. Only factor F5 has the influence on almost all the other factors as shown in Table 7. Consumer related factors (F10) has no effect on the other factors. Cause and effect Diagram is given in Fig. 1 and 2.

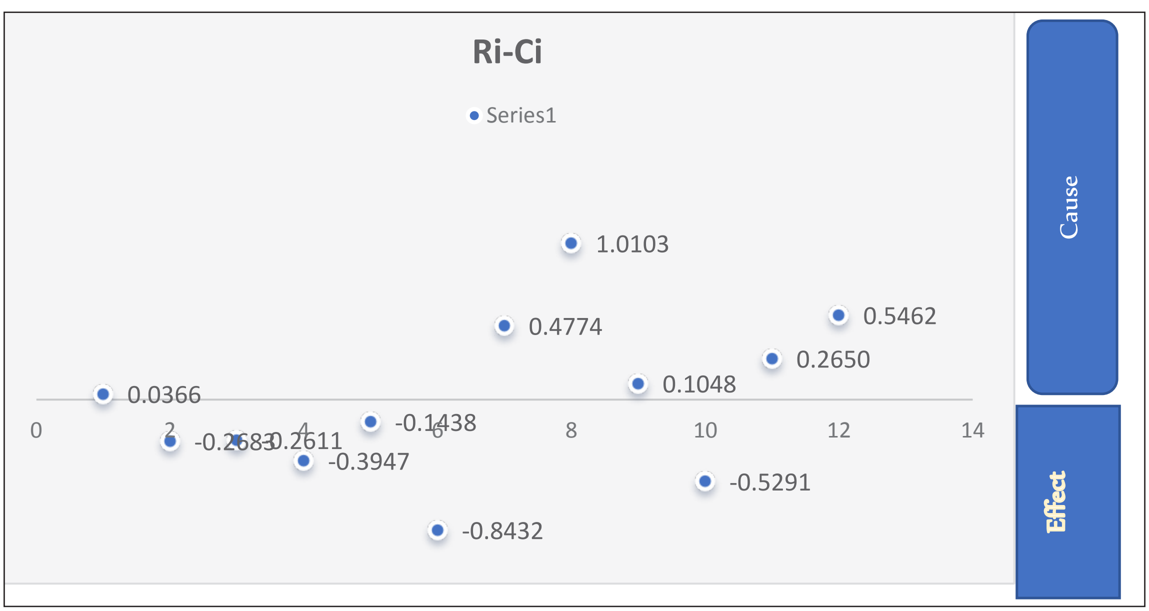


**Fig. 1: Cause and Effect Diagram**

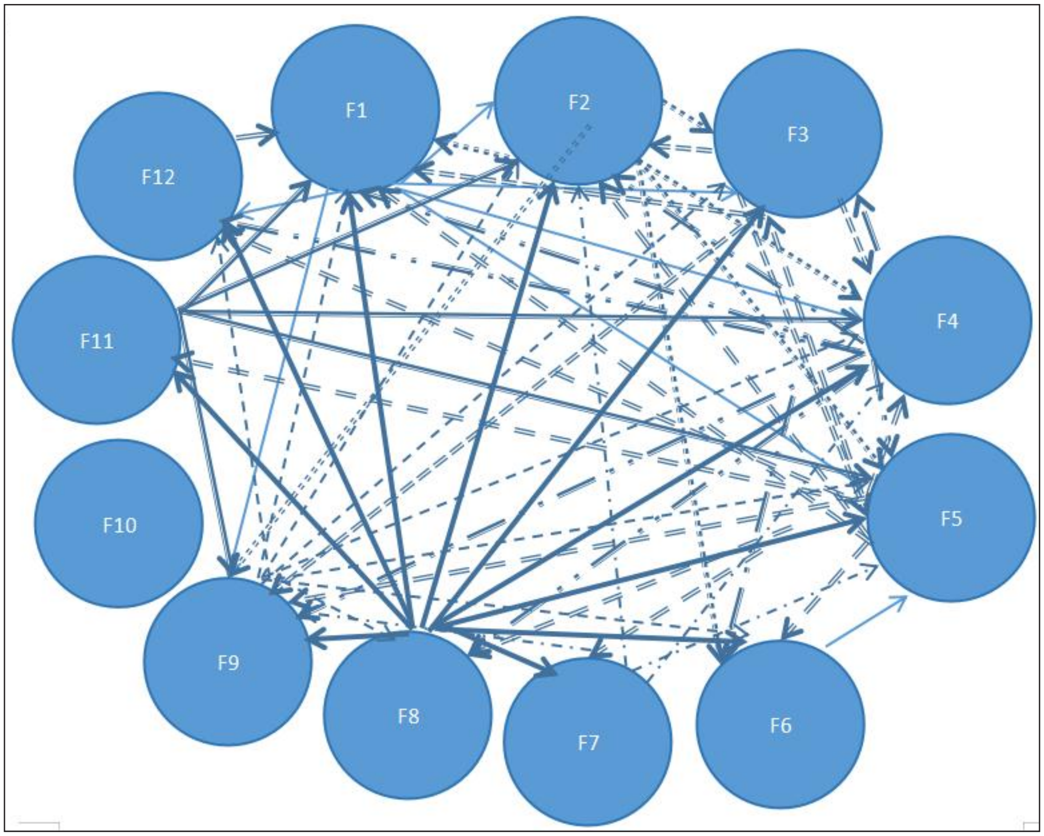


**Fig. 2: Interrelationship Diagram**

## Managerial Implications, Conclusions, and Limitations

The changing consumer behaviour due to technological advancements such as e-commerce has significantly contributed to the rising demand for temperature-sensitive products. CCL, a critical component of the larger supply chain, is exposed to inefficiency and it is subject to sustainability issues. There are countless factors affecting CCL performance leading to increased product waste and loss. Addressing all these challenges at once do not seem practical, especially from a developing country's perspective. To remain competitive, businesses dealing with perishable products have to follow a focused approach by prioritising factors affecting CCL to enhance its performance and hence reduce product waste and loss particularly in economies where millions suffer from food and medical supply shortages. Prioritising such factors will have significant implications for a manager's strategic decisions, resource allocation, and overall business success.

There is no single solution that fits all situations. For instance, addressing the challenges related to packaging alone is not enough if a mechanism to ensure traceability is not in place. Ensuring the sustainability of CCL is paramount as the global population continues increasing given the present-day global warming and climate changes. This study focused on prioritising key factors affecting CCL to achieve sustainability. The DEMATEL method was utilised to assess the relative importance of selected factors. The findings aim to guide partners in developing focused solutions. The stakeholders to perishable products, both pharmaceuticals and agricultural, play a pivotal role in fostering sustainability by investing in infrastructure, implementing supportive policies, and promoting environmentally friendly behaviours among consumers.

The researcher offers the following valuable contributions and recommendations to the CCL sector:

- With regard to cold transportation, improving loading/unloading practices, properly positioning pallets used in refrigerated vehicles, and carefully selecting vehicle and minimising travelling distance as much as possible.

- With regard to handling issues and inventory rotation, reducing inappropriate handling practices, avoiding misplacement of goods in refrigerated warehouses or vehicles, and reducing poor inventory rotation will pay a lot.

The study's findings and recommendations are based on data collected from a single metropolitan city and its surroundings in a developing country, which might be considered as a limitation. Future studies may consider data from multiple countries that will help in filling such a limitation.

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