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## Article

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# Improvement in the food losses in fruits and vegetable supply chain - a perspective of cold third-party logistics approach

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## ABSTRACT

The maximum amount of food losses in the fruits and vegetable supply chain due to quality and mismatch between supply and demand. As per the Global Agenda Council on Logistics and Supply Chains indicated that fruits and vegetables food losses due to improper handling and lack of proper cold transportation such as cold-logistics facilities/providers or inadequate infrastructure. In this article, a unique fuzzy Multi-Criteria Decision Making approach is proposed for improving the food losses through cold-third party logistics providers (CTPLs) evaluation and selection process. Through a literature survey and expert opinion, five criteria and thirty sub-criteria were identified for reducing the food losses in fruits and vegetable supply chain. The proposed tool use of fuzzy-Decision making trial and evaluation laboratory tool for selection and evaluation the priority weights of the factors and fuzzy-analytical hierarchy process tool assessing the best CTPLs according to factors. The result shows that 'Refrigerator and loading capacity' and 'Knowledge and Information technology management' were most significant in the selection of CTPLs. The findings of this paper are anticipated to guide managers of the food industry, CTPLs, and government agencies in formulating of strategies for the practical food supply chain. Future scope includes extending the study for other developing countries, validating the proposed methodology, and improving the reliability of the model.

## 1. Introduction

India produces sufficient food to fulfil the demand of its entire nation's population; however, it is not able to feed billions of them. India is the 2nd highest grower of fruits and vegetable, and at the other hand twenty-five to thirty per cent of it is food losses and damages due to insufficient transportation and distribution facilities such as cold storage, dedicated fleet, cold trucks, etc. ([www.asianage.com](http://www.asianage.com); [www.downtoearth.org.in](http://www.downtoearth.org.in)). Principato et al. [112] mentioned that food loss and wastage maximum at the consumption side. FAO [40]; NRDC [107] mentioned in the report published by United Nations, estimated that every year approximately one-third of all food items/products for society is lost and its value nearby dollar 8.3 billion. As per the Global Hunger Index (GHI), survey 2017 report mentioned that India was the 119 ranked in the world.

The maximum amount of food loss and waste is a mismatch between supply and demand [40,142]. Van Donselaar et al. [152] argued the mismatch between supply and demand depends on internal and

external factors (such as government policy, lack of storage facilities, awareness, and transportation facilities, etc.). Mercier et al. [97]; Kader [73] presented that every year, almost one-third part of all food produced for human being consumption is wasted. FAO [40]; NRDC [107] indicated that all types of food waste account for approximately 40 per cent of creation. Young [167]; (ReFED [114]; FUSION [48] explained the food waste regarding economic impact. According to these studies, the yearly economic impact of food waste is calculated at \$218 billion in the United States, \$143 billion in European countries, and \$27 billion in Canada. World forum organisation's founder and the chief executive officer said, in 2050, the world's population will increase up to 9.1 billion. It is necessary to increase food production by 70 per cent to meet the food demand of people's needs ([www.weforum.org](http://www.weforum.org)).

As per the Global Agenda Council on Logistics and Supply Chains indicated that fruits and vegetables food losses due to improper handling and lack of proper cold transportation such as cold-logistics facilities or inadequate infrastructure ([www.weforum.org](http://www.weforum.org)). Fonseca and Vergara [45] stated that an excellent logistics facility and logistics

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management is one of the essential and active processes to improve food losses within supply chain management. Singh et al. [134] presented that in the Asian developing nations such as India, an estimated 20–30 per cent fruits and vegetable food losses due to lack of cold logistics infrastructure available. The fruits and vegetable food losses reduction is possible by improving the efficiency of cold supply chain management (CSCM) that are correctly used to maintain perishable/fruits and vegetable food in the controlled temperature range is monitored to as the cold-logistics [97,134].

To maintain the flow supply chain management for the various items or products such as fruits and vegetables, medicines, milk, meat, etc. is a difficult task for the industry in the current competitive and agile business environment. In most of the cases, the supply chain is not in a position to maintain their business performance due to high losses and the additional price is occurring at various levels [20,93,134]. Singh et al. [134] identified that different demographic region of consumers and their uncertain needs as well as changing shelf product lifecycle has greater difficulty in cold supply chain management (CSCM). CSCM is accountable for the transportation and distribution of fruits and vegetable in the right temperature value to gentle organic deterioration process and transports the right and good quality products to customers [97].

In CSCM processes two issues which are more important, i.e., safety and security. If safety and security risk is unidentified, the products may be consumed and cause food poisoning, which has a significant social and financial loss. It is necessary to have a refrigeration facility to provide safety to the products from biological degradation and food losses. Similarly, Kader [73]; Mercier et al. [97] mentioned in the article, that food loss and wastage may be reduced by providing sufficient infrastructure and transportation facilities. In CSCM processes involves the activities such as production planning, operation, and managing the flow of material, information, and packing of fruits and vegetables, related to sales and services in order to improve consumer value and to ensure minimum cost [18,43].

The CSCM or cold logistics management are mainly classified into three categories: precooling (chilling and cooling), storage system, and transportation [84,134]. Significant losses in the perishable food supply chain because of not maintaining the products at a standard of food transport safety regulations (temperature violations) by the transportation industry or CTPLs providers ([www.loaddelivered.com](http://www.loaddelivered.com)). Three essential structures of a CSCM system needs to be focused on reducing the perishable food losses and improving the quality of the food from farm to fork such as *i)* A considerable amount of financial investment for the development of a rigid and complicated system. *ii)* Appropriateness required for collaboration of different industry and sectors. *iii)* Last and most important is an adequate amount of price or sufficient amount of finance [134]. The CTPLs or CSCM has become an internal process of supply chain management for the storage and transportation of refrigerated food. At the same time, it has become difficult for the industry to act or execute such type of logistics process efficiently with their nuclear capabilities of production/manufacturing; they incline to subcontract these operations to third-party logistics ([87,134]; [www.fnbnew.com](http://www.fnbnew.com); [www.weforum.org](http://www.weforum.org)).

The selection of 3PL issue has brought the attention of many organisations and academicians across the world. Logistics outsourcing or 3PL can offer greater competitiveness. They have specific logistics core competencies, which make them capable of managing the logistics activities more effectively and efficiently than their partners. Most of the firms prefer to do logistics outsourcing, and due to this, the total profit margin of the organisations have increased [79].

Extended distance shipping is unavoidable in maximum fruits and vegetable supply chains due to the demographic distribution of the farm to fork. The capability of long-distance transportation with the required chilling facility allows the third-party logistics provider to add an improvement over other means of shipping [26]. The CSCM organisation in India is mainly imbalanced/unstructured, disorganised area

([www.asianage.com](http://www.asianage.com); [www.downtoearth.org.in](http://www.downtoearth.org.in); [40,107,134]). This area weak regarding lack of cold infrastructure, lack of ground operations procedures during logistics, lack of storage systems, lack of loading and unloading procedures, lack of cold chains, and lack of modern cold chain practices. This part is not well discussed in the Indian CTPLs supply chain or CCL. This article has attempted to address issues related to selection and evaluation of CTPLs providers by using integrated multi-criteria decision making (MCDM) approach such as Fuzzy-Decision making trial and evaluation laboratory (FDEMATEL) and Fuzzy Analytical Hierarchy Process (FAHP). The firms are dealing with perishable items as well as fruit and vegetable supply chain items are targeted firms. The study scope is the CTPLs providers' of the firms that provide the services from farm to fork as well as which will help to reduce the food losses during transportation. The focused group for the study on Government of India runs the cooperatives societies and private sectors supermarkets chains which offer the quality and hygiene fruits and vegetables under the same umbrella. Research objectives (ROs) of the study are as follows:

**RO1:** To explore the critical factors and sub-factors to cold-third party logistics providers (CTPLs) in the Indian context.

**RO2:** To identify the influencing criteria and understand the cause-effect relationship amongst criteria.

**RO3:** To identify the ranks of the sub-criteria.

**RO4:** To evaluate and select cold-third party logistics providers (CTPLs).

The remaining part of the paper has organised as a literature review in Section 2, theoretical grounds of Fuzzy DEMATEL and Fuzzy AHP method in Section 3. Section 4 elaborates the method of analysis, followed by results and discussion in Section 5. The last section has a conclusion, managerial implications and future scope of the study.

## 2. Literature review

### 2.1. Cold supply chain management (CSCM)

The term cold supply chain is a particular supply chain whose processes and activities ensure control of temperature for the perishable food products [129]. A typical CSCM consists of freezing/chilling, packaging, cold store, transport to holding store, transport to the distribution centre, transport to retail outlet, and consumer handling [8]. CSCM or cold chain logistics (CCL) has become critical as there is huge demand rise in temperature controlled products, especially fruits and vegetable [77]. Even though the growth trend in CSCM is high, maintaining food safety and quality is a primary concern for service providers in order to get a competitive advantage [156].

CSCM is accountable for the conservation, shipping, and distribution of fruits and vegetables in the controlled temperature limits to slow biodegradation processes and on-time deliver the right product and good-quality foods to customers ([97]; Singh et al. 2017). The CSCM is a physical system that controls the supply chain logistics activities of a specific foods item [14,123]. CSCM could be classified into three levels that are planning, execution, and distribution of efficient and effective movement of perishable foods and fulfilment of customer's orders at the right time by reducing the food losses [86,151]. The complete time of the CSCM is mostly dependent on the particular food item and the precise market, with some cold chains being as small hours too long hours/ months/years especially for frozen food products [52,93,97]. Most of the authors have been discussed about different problems of CCL or CSCM on various stages of fruits and vegetable supply chain such as from farm to fork (includes farmer; producer; processor; distributor; retailer; and customers) [17,71,72,122].

Lupien et al. (2005) estimated that thirty-three per cent of foods losses due to transportation, shipments, and some other reasons. The other reasons are; high amount of pesticide, high level of contamination

with insects, etc. to maintain the life of fruits and vegetables for an extended period. Lebersorger and Schneider [88]; Halloran et al. [60] concluded in the research article, a high level of coordination and information sharing system within the food supply chain mainly in distribution and transportation areas for reducing the losses. Watkins [158] discussed in the research, lack of packing equipment, lack of refrigeration facility, lack of transportation, delay in the cooling process, and other internal and external factors are responsible for perishable food losses. Estrada-Flores et al. [38] done the research and concluded that some precautions that could help reducing food losses during the transportation stage. According to Sargent et al. [126], most of the time, substantial food losses occurs during transportation and shipment within the supply chain. Estrada-Flores et al. [38] mentioned that there is variation in the refrigerating system or temperature controlling system during transportation stage are main, causing food losses. Edwards-Jones et al. [35] summarised that the objective of the investment in the food logistics supply chain should be focused at efficient on-time delivery as well as to maintain the food quality with minimum food losses. The CSCM is required for good health, health and fruit food, improve the quality of life by avoiding infections and the rate of losses [33].

The industrialisation has managed to improve many industries expanding and trading fruits and vegetable products/food supply chain. The amount of global trading business of food items due to the open market has built much pressure for the betterment of the cold logistics sector [134]. As per Taoukis et al. [141]; Omta et al. [109]; Van Der Vorst [150] mentioned in the research article that temperature monitoring of food items from start to end of the distribution and transportation system is more important to maintain the food quality and reduces the losses within the supply chain. The reliability of the cold supply chain must be well-maintained from the being of the production process, through each level of activities within the chain, i.e., loading, unloading, material handling, storage, transportation and distribution of fresh food at the customer end [123].

As per the Sadiq and Saad Al-Abdali [119] due to the industrialisation of businesses and economic and environmental pressures, industries are facing massive problem to maintain or fulfil the supply and demand of food items all over the globe safely, fresh, and on-time delivery. The efficiency and effectiveness of the supply chain are dependent on two factors, i.e., low price, and on-time delivery [133,134]. A significant problem in the cold chain is to maintain the different temperature requirement of different perishable food item categories at each stage of the supply chain [97]. Temperature controlling and data management tracking system are two essential activities of the cold chain system and to manage these two activities in the real field is the major challenge [101].

Every day the new technology is coming, sustainability, and customer satisfaction level is the critical challenges in the cold supply chain management or cold chain logistics [134]. The importance of technology in CSCM is particular method or technical approach to adopt for controlling, and monitoring the range of temperature to maintain the quality of particular perishable food items [94]. In the literature, many authors discussed the success and unreliability of Radio frequency identification (RFID) in the real-time scenario [83,97,134]. The success regarding tracing reduces the number of recollections, which incomes as a profit for the industry. However, on the other hand, the unreliability of RFID such as measuring and monitoring the range of reading precision in the real-time scenario. Innovative ideas and proper use of technology for tracing, material handling, packaging, etc. would give the detail information for items and avoids the mismatching of items within the warehouse, distribution, and transportation stages. It directly affects the efficiency of the CSCM or CCL system. It has been discussed in the literature about the customer's expectation and satisfaction level has become increased, and to maintain these two parts in the real-time supply chain for a company become challenging.

According to Trienekens and Zuurbier [148] to maintain the customer's service-satisfaction level, fresh food products or right quality products should be delivered to the customers, and in the coming years, this will govern the production process, distribution, and transportation systems or quality logistics system in food supply chain [117,151]. The degradation of food quality products depends on processing, packaging, storage, and transportation facilities [85]. In the past recent years, sustainability is one of the challenges in the supply chain by introducing the term "sustainable supply chain (SSC)" [61]. The SSC is depended on three pillars, i.e., environmental, economic, and social. In the area of the food supply chain, sustainability focuses on the waste reduction or minimise food losses. The maximum amount of food losses in the food supply chain due to a quality issue (Van Donselaar et al. 2006). The concept called 'farm to fork.' means a large amount of distance (in kilometres) a food item has to travel before it reaches the customers' fork or table and because of this CO<sub>2</sub> (carbon emissions) affects the nature (carbon footprint). Investment in the logistics infrastructure such as cooling, cold storage, refrigerated trucks, better information sharing process, and tracking system, etc. has not only improved the logistics performance but reduces the food losses as well as prevent the environment [150]. Salin and Nayga Jr. [123] presented the results of the CSCM for potatoes. The data were collected from the Philippines and Thailand nations' of an international and smaller restaurant. The outcome of the research mentioned that price policy for CSCM is tangibly associated with the quality of the items and maybe affect the availability of subcontracted CSCM activities.

Ali et al. [4] proposed a resilience model for CCL of perishable food products. The study concludes that resilience affects the negative relationship between performance and CCL risks. Post-harvest food losses in India is on a higher side. Chaudhuri et al. [29] emphasised on the importance of real-time data analysis for minimisation of waste by effective decision making. Interconnection of critical dimensions of CSCM such as information technology, equipment, infrastructure, and regulatory aspects must be present for perishable food products [22]. To understand CSCM performance, Cerchione et al. [27] considered infrastructure, stakeholders' interest, integration, partners' performance, and value addition. For multi-temperature vegetable and cold fruit chain, Hsiao et al. [64] considered vehicle routing, quality to the customer, temperature setting, and fleet size. Bhatnagar et al. [16] considered requirements for relative humidity, temperature, ethylene production, and odour for agro-based CSCM. To investigate the high cost, Negi and Anand [106] carried out an exploratory study for the mango supply chain in India. The author found resources, infrastructure, poor ambience, and operational issues as significant factors.

## 2.2. Third-party logistics evaluation criteria

Third-party logistics (3PL) service provider is an evolving area in the volatile and competitive market environment. The critical assistance of outsourcing logistics providers allows organisations to focus on their core activities. To increase the operational and functional efficiency, to earn higher flexibility, to enjoy improved customer service, to reduce the transportation cost, to enhance and restructure the supply chains, and to establish marketplace legitimacy [55,59,121]. 3PL provider for perishable products benefits farmers and distributors both in terms of cost and quality [26,117].

In this section of the paper, the criteria used for the selection of the 3PL by the various author(s) are detailed. The international markets are affected by the volatility in many driving economies, fluctuating fuel prices, increased regulations of global markets, and economic downturn. Fawcett and Smith [41] proposed five criteria to evaluate third-party logistics performance, i.e., flexibility, cost, quality, delivery, and innovation in services. Morash et al. [102] surveyed sixty-five US organisations in the furniture industry. The authors proposed that logistics performance may be evaluated by pre-sale and post-sale customer service, delivery speed, delivery reliability, and responsiveness to target

market and supply capabilities (i.e., distribution coverage, selective distribution coverage, and low total cost distribution). Nakandala et al. [105] proposed cost model for perishable food transportation and quality. The proposed model was demonstrated using simulated annealing (SA), genetic algorithm (GA), and fuzzy genetic algorithm (FGA). Results show that FGA had better performance compared to SA and GA. Yan [164] proposed an E-commerce platform for 3PL based fruit cold chain in China. Fruit product logistics characteristics considered were diversity, timeliness, and high risk (social, economical, time, functional, privacy, and psychological). Sun et al. [138] categorised 3PL financial risk for CCL as commodity supervision risk, improper control of stock, and poor warehouse management.

Stank and Maltz [137] surveyed by on 3PL in domestic versus international logistics market and they recommended six critical criteria be uncertainty/volatility, service capability, long-term cooperation, organisational characteristics, learning capability, and asset investment. Anderson and Norman [6] proposed that 3PL selection and evaluation criteria entirely depend on the organisation activity, processes, and product. The more important aspects of this process are the organisation which focused on outsourcing the execution of the inbound logistics or outbound logistics services. Yeung [166] studied an empirical survey in Hong Kong and came up with four essential criteria to evaluate the 3PL performance, i.e., price, quality of delivery, timeliness of services, and customised supplementary services.

Mortensen and Lemoine [103] presented that selection of 3PL is mainly dependent on the quality and reliability of the transport, market coverage, especially at the international level, and most important is price competences. Briggs et al. [23] conducted the exploratory research with 109 experts of the Council of Supply Chain Management and proposed four critical criteria, i.e., reliability, the speed of service, service availability, and information accessibility.

Aghazadeh [1] highlighted that 3PL successful relationship mainly depends on customers and service providers' need. The author proposed the five essential criteria, namely- information technology system, trust, mutual respect, similar value and objectives, and shared willingness to make a better relationship. Senthil et al. [128] presented a plastic industry case study for the vendor selection of third-party reverse logistics services. The author proposed nine main criteria namely- organisational performance, reverse logistics process functions, the organisational role of reverse logistics, resources capacity, quality of service, enterprise alliance, location, experience, and communication systems. Miller et al. [98] proposed a decision-support system (DSS) for the effective utilisation of the storage capacity as well as meet the customer's demand, which impacts on firms' performance and operational capability. Logistics firms' performance depended on availability, flexibility, and operational performance capability [19]. Organisation's effectiveness, i.e., the internal environment and external environment, plays a critical role in the selection of third-party logistics process [95,96]. McGinnis et al. [95] done the study of 3PL selection for the USA firms' and considered 8 critical factors for 3PL selection process, the 8 factors were as on-time shipment and delivery, cost, availability of top management, responsiveness error rates, creative management, financial stability, and ability to deliver as promised. The same work carried out by Menon et al. [96]. Sangam [125] further illustrated the findings of these two authors, author recommended that the 3PL selection process more factors should take into consideration such as cost, volumes, financial stability, growth forecast, IT support system and used, quality standards, capacity, manufactured product lines, and compliance, and the value-added services. Montanari [101] concluded that the reliable IT support for the CSCM because tracking/traceability is more critical not for food quality but also food safety [44,72,115,116]. Spencer et al. [136] done the work for the 3PL selection process, used six factors, namely as regarding services, on-time delivery, quality, speed, reliability, communication, and flexibility. Moberg and Speh [99] concluded that service requirements, the capability to provide value-added services, quality of management, and previous ethical track record are

more important factors for the 3PL selection process. Fearne and Hughes [42] discussed the UK recent producer firm case and determined two more crucial critical success factors such as improvement in the cost and innovations. Bogataj et al. [18] done the work in CCL and broadly discussed the stability of perishable items in CCL, which improves the quality and hygiene of perishable items. Excellent quality and hygiene of perishable items or fruits and vegetable items require a sufficient amount of efficient equipment, proper quality certificates, suitable standard operating procedures, and proper information system, which helps to reduce the food losses and wastage [72,92]. Montanari [101] mentioned that quality and safety issues of perishable items from start to end of the CCL would entirely depend upon the selection of critical success factors.

### 2.3. Tools and techniques used in the evaluation and selection 3PL

In the area of 3PL selection, AHP is the most widely used tool among the researchers. It may be noted that along with AHP other multi-criteria decision-making tools (VIKOR, TOPSIS, and IRP) were also used for improving the robustness of the developed model. Some of the papers published in the past using various tools/techniques for the selection and evaluation purpose are detailed below-

Senthil et al. [128] applied a mixed MCDM approach (AHP and fuzzy TOPSIS) for the evaluation and selection of third-party reverse logistics service provider (3PLSP). The AHP approach was selected to assign the weights to the selection factors, and fuzzy TOPSIS was engaged for the final classification. Peng [111] developed a model for the evaluation and selection of the 3PL for the Chinese frozen food sector by employing AHP. Ravi (2012) employed AHP and TOPSIS methodology for the selection of 3PL for a computer hardware manufacturing industry. Falsini et al. [39] employed an integrated approach consisting of AHP, DEA, and LP for the 3PL selection. For validation of the model, three Italian sectors, namely consumer goods, perishable goods, and defence, were considered. Ho et al. [63] proposed a hybrid QFD and fuzzy-AHP methodology for the 3PL selection. Büyükoçkan et al. [24] developed an integrated model of fuzzy AHP-TOPSIS for the selection of 3PL. Göl and Çatay [53] applied the AHP methodology for the best 3PL service provider in the Turkish automotive industry. So et al. [135] employed AHP tool for the service quality evaluation of four 3PL in Korea. Zhang et al. (2006) used AHP for evaluating the subjective opinions and DEA for analysing the quantitative data for the 3PL. Korpela and Tuominen [80] used AHP to identify the best third-party logistics provider in the processing industry.

Aguezoul [3] has classified the performance measurement tools and techniques of 3PL into five categories: multi-criteria decision-making (MCDM) techniques, statistical approaches, artificial intelligence, mathematical programming, and hybrid methods. Efeendigil et al. [36] proposed a hybrid approach for 3PL in the presence of vagueness by using the artificial neural network and fuzzy analytical hierarchy process. Shi et al. [131] proposed empirical research of 3PL by using structural equation modelling. Visani et al. [155] proposed a data envelopment analysis based tool for approximation the total cost of ownership of analysing suppliers' performance, rationalising and reducing the supplier base. Momeni et al. [100] applied the network DEA approach for the evaluation and the selection of the eligible reverse logistics service providers. Venkatesh et al. [153] selected DEA approach using the platform STATA for analysing the performance of the 3PL for the apparel industries. Chandraprakash and Suebpongakorn [28] evaluated the operation performances of 55 logistics companies of Thailand using DEA along with a Malmquist productivity index (MPI). Saen [120] proposed a framework for the selection of third-party reverse logistics service provider, taking into consideration the imprecise data and dual factors. Azadi and Saen [11] proposed a new chance-constrained data envelopment analysis approach to assist the decision maker in identifying the best possible third-party reverse logistics service provider in dual-role factors and stochastic data. Ting

and Fang [145] identified the key performance indicators of a distribution centre and evaluated their performances using DEA and MPI. It was found that the main reason behind the inefficient DMUs was the scale inefficiency.

Sureeyatanapas et al. [139] evaluated ranking order of green logistic activities and results indicate rank as eco-driving, alternative energy, modal shift, and vehicle routing. Li et al. [90] selected 3PRLP in China by using Cumulative prospect theory and hybrid information MCDM. Kannan [75] proposed a three-phase methodology by using ISM, ANP, and COPRAS-G for the sustainable supplier selection. Allaoui et al. [5] proposed a hybrid MCDM based on AHP and Ordered weighted averaging for sustainable food SCM. Banaeian et al. [12] compared the results of fuzzy GRA, fuzzy VIKOR, and fuzzy TOPSIS for food supplier selection. Sureeyatanapas et al. [140] used extended TOPSIS method for supplier selection in unavailable and uncertain information situation. Kozarević and Puška [81] employed fuzzy TOPSIS and Fuzzy entropy method to understand the food supply chain performance. Yadavalli et al. [163] used fuzzy TOPSIS with Z number in order to evaluate and select the green supplier. Fuzzy GRA involves less computational complexity compared to fuzzy VIKOR, and fuzzy TOPSIS [12].

### 2.4. Research gaps

In recent years, worldwide retail supermarkets are the focus area of trade where supplier and consumers managed the industry in fruits and vegetable items [104]. In fruits and vegetables business industry, the more critical challenges are managing the quality and safety, and enlarge the speed of food items through the distribution and transportation processes [104].

In the developing nations, the amount of food losses in fruits and vegetables supply chain is very high; on the other hand, logistics and transportation cost is also very high. In the agricultural sector, India's production outcome has a significant impact on global food security. Artiuch and Kornstein [7] agricultural sector in India creates the revenue or contributes approximately 20 per cent of the country's gross domestic product (GDP). A survey was done by the World Economy forum in 2011 among the 142 countries in the world for positioning infrastructure reliability and adequacy. The result of the study showed that India position 89 ranks of 142 countries ([www.weforum.org](http://www.weforum.org)). The overall production and distribution system depends on the nation's infrastructure to transport and stock billions of tons of food every year. The primary problem behind this is not well organised CSCM or cold logistics management. The lack of logistics infrastructure (such as production, processes, handling, distribution, and transportation) has affected India's agricultural business especially fruits and vegetable sector [7,104]. The assumption of factors and their significance depend on the requirements and financial position/growth of the purchaser/customer organisation. Hence, in the real and practical cases the objectives and opportunities of a cold third-party plan will permit a firm to determine its factors for 3PL selection and evaluation, which will their business target and arrange or provide the excellent transportation facility to the customers' organization [125,134]. Therefore this research will attempt to propose a tool for the selection and evaluation process of CTPLs providers in the fruits and vegetable supply chain by a broad outline. From the above review discussion, the factors identified for a CTPLs selection procedure in this article case are Knowledge and Information technology management; Budget and Government approvals; Safety, security, comfort, convenience, and aesthetics view; Maintenance Management; Refrigerator and loading capacity. The details are given in Table 1.

To the authors' best knowledge, the goal of reduction of post-harvest losses in the food supply chain - towards a cold third-party logistics provider was not discussed before. This paper discussed the CTPLs evaluation and selection problem is modelled and solved by using a hybrid tool, i.e., Fuzzy-DEMATEL and fuzzy-AHP. There are many more

logistics providers available in the dynamic market, and there is a cut to the struggle between the providers. Therefore, it is very crucial for the strategy team/decision makers to decide on logistics operations. The application of the proposed integrated tool, along with the tool execution steps is discussed in the following sections.

## 3. Theoretical grounds of fuzzy DEMATEL and fuzzy AHP method

Multi-criteria decision making (MCDM) consists of various hierarchical constructions. At present hierarchies among the factors echelons and effects the factors in the same echelons. This article assumed the interactions and hierarchies between the factors. Fuzzy-DEMATEL and Fuzzy-AHP tool are applied in to study the factors/criteria interactions within the factors and factors hierarchies in the proposed methodology ([34]; Baykasoglu et al. 2013; [10,76]).

### 3.1. Fuzzy theory

The classical set theory allows membership of an element in a set of binary terms 1 or 0 (True/False). Fuzzy logic is developed by Zadeh to deal with vagueness and uncertainty in the system [168]. A fuzzy set is a superset of a classical set, which allows a real unit interval between 0 and 1. These intermediate values are often termed as the degree of membership, which allows continuous assessment of membership of element. Fuzzy logic is used to mimic human reasoning and deciding according to various inputs and type of membership function [168]. Out of various membership functions like triangular, trapezoidal, sigmoid, etc., the triangular membership function is more popular amongst researchers.

A triangular fuzzy number N is represented as a TRIFN (l, m, n), and  $\mu(N)$ , the, i.e. membership function for real numbers l, m, and n is defined as:

$$\mu(N) = \begin{cases} 0, & x \leq l \\ \frac{x-l}{l-m}, & l \leq x \leq m \\ \frac{n-x}{n-m}, & m \leq x \leq n \\ 0, & x \geq n, \end{cases} \quad (1)$$

With the constraint of  $l \leq m \leq n$ . Fig. 1 shows a triangular membership function corresponding to Eq. (1).

### 3.2. DEMATEL model

DEMATEL stands for Decision Making and Trial Evaluation Laboratory. Bastille National Laboratory of USA had proposed DEMATEL in 1971 and popular to visualise logically complex causal relationships [9,49,50,76]. In comparison with directionless graphs, a directed graph (often termed as digraph) is more useful as it depicts a contextual relationship. The DEMATEL method is based on digraph, which gives a structural model to portray a cause-effect relationship between factors. Author refined the version used by Fontela and Gabus [46] for steps used in DEMATEL as follows:

Step 1: The pair-wise scale of comparison may be labelled in four levels, where the scores of 3, 2, 1, and 0 represent "Very high influence", "High influence", "Low influence", and "No influence" respectively.

Step 2: The initial direct-relation matrix M is a square matrix of size 'n' and found by pair-wise judgments (influences, directions) between criteria, in which  $m_{ij}$  is denoted as  $M = [m_{ij}]_{n \times n}$ , which represents the degree of criterion i' affects the j<sup>th</sup> criterion.

Step 3: The normalized direct relation matrix (N) can be acquired by the following Eqs. (1) and (2)

$$N = s^*M, \quad (2)$$

**Table 1**  
List of selected criteria and sub-criteria.

S. no.	Criteria	Brief description	Sub-criteria	Author
1	Knowledge and Information technology management(KITM)	Knowledge management is a function of information generation and dissemination, sharing information, and filtering to store valuable knowledge. Quality of knowledge and information management plays a crucial role in global competition. Technological developments in RFID and communication have made knowledge management more reliable.	KITM1- Inbuilt Radio frequency identification device (RFID) system KITM2- Security system KITM3- a Communication facility KITM4- Parking and sensor facility KITM5- Customization competencies KITM6- Reliable technology for roads conditions	Gunasekaran et al. (2002), Irani et al. [70], Heydari et al. [62]
2	Budget and Government approvals (BGA)	Increase in budgetary requirements due to increase in fuel prices and the cost of consumable parts is a standard parameter in CSCM. In India, the Ministry of Food Processing Industries (MoFPI) is taking all essential steps to increase investments in the food industry by easing government approval process. However, finance availability and minimising total cost are the primary concern.	BGA1- Low fuel consumption BGA2- Easily and readily available the spare parts with minimum cost BGA3- Best price in the second-hand market/ resale market BGA4- Low-cost consumable parts BGA5- Easily finance availability BGA6- Government clearance and approvals	Singh et al. [134], Agrawal et al. [2], Singh and Sharma [133], Baykasog'lu et al. [13], Kumar and Singh [82], Fu and Yin [47], Choy et al. [32] Zhu et al. (2017), Jabbour and Jabbour (2016)
3	Safety, security, comfort, convenience, and aesthetics view (SSCA)	Safe steps must be followed while handling the food as one cannot smell, see or taste dangerous bacteria. Safety norms need to be followed rigorously at all stages of the supply chain. Driver comfort can be ensured through proper AC facility, proper cabin space, and aesthetics.	SSCA1- Comfortable cabin space SSCA2- Smooth and comfort driving SSCA3- Air-conditioned facility inside the cabin SSCA4- Interior and aesthetics view SSCA5- Perishable food and safety norms SSCA6- Safety and Security features for accidents	Singh et al. [132], Agrawal et al. [2], Thakker et al. [143], Ho et al. [63], Elhedhli et al. [37]
4	Maintenance Management(MAM)	Maintenance management brings focus on various facets of the supply chain, capacity facilities, and service station. Maintenance cost should be minimised by increasing service locations, on-time delivery, and other necessary measures.	MAM1- Large numbers of the service station and capacity facilities MAM2- Low maintenance cost MAM3- Free service for a maximum period or extended period facility MAM4- Maximum guarantee and warranty period MAM5- After sales and service support MAM6- On-time delivery after sales and service	Singh et al. [132], Singh and Sharma [133], Miller et al. [98], Kumar and Singh [82]
5	Refrigerator and loading capacity (RELC)	In CSCM, various products require different temperature, which makes temperature control more crucial. Trucks must have flexible adjustments for different loading requirements as per ISO requirements. Advanced digital data logger to measure temperature and loading has become popular these days.	RELC1- Efficient precooling and temperature variability-controlling equipment facility RELC2- Electronic Data Logging Monitor RELC3- Easy Installation and modification facility in the truck RELC4- Quality and ISO certificates (such as 9000; 16000; 14000; etc.) RELC5- Standard operating policy and procedures as per Govt. policy RELC6- Temperature and loading display facility	Singh et al. [132], Agrawal et al. [2], Baykasog'lu et al. [13], Thakker et al. [143], Ho et al. [63], Singh and Sharma [133], Gunasekaran and Negi [57],

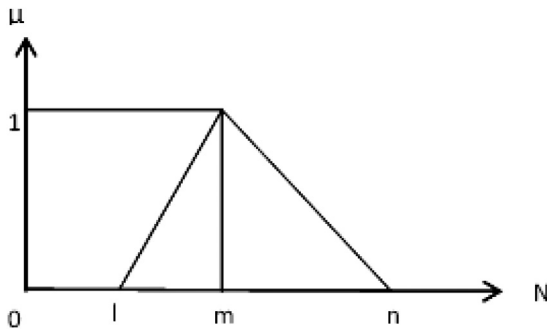


Fig. 1. Triangular membership function.

$$s = \frac{1}{\max \sum mij}, \quad i, j = 1, 2, \dots, n \tag{3}$$

Step 4: The total- relation matrix TR can be calculated using Eq. (4)

$$TR = N(I - N)^{-1} \tag{4}$$

where I is an identity matrix of size 'n.'

Step 5: The sum of rows (R) and the sum of columns (C) within total- relation matrix TR by Eqs. (4)–(6)

$$TR = tr_{ij}, \quad i, j = 1, 2, \dots, n \tag{5}$$

$$R = \sum_{j=1}^n tr_{ij} \tag{6}$$

$$C = \sum_{i=1}^n tr_{ij} \tag{7}$$

Step 6: A casual diagram is drawn with the horizontal axis as (R + C) and the vertical axis as (R - C), which will help to conclude about the relationship between factors.

### 3.3. Fuzzy DEMATEL analysis

Decision making comprises of a set of 'n' criteria which are represented by  $A = \{A_1, A_2, \dots, A_n\}$ .

Possible alternatives should be assessed on these 'n' criteria. In this paper, direct –relation fuzzy matrix 'B' is formed as shown in Eq. (8) where  $B_{ij} = (B_{ij,l}, B_{ij,m}, B_{ij,u})$ . Linguistic variables are symbolised as (l, m, u) where 'l' denotes a lower limit, 'u' denotes an upper limit, and 'm' denotes middle limit where the degree of membership is 1, i.e. 100%;  $l \leq m \leq u$ .

$$B = \begin{matrix} & A_1 & A_2 & \dots & A_n \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} & \begin{bmatrix} 0 & B_{12} & \dots & B_{1n} \\ B_{21} & 0 & \dots & B_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ B_{n1} & B_{n2} & \dots & 0 \end{bmatrix} \end{matrix} \tag{8}$$

Eq. (9) gives a direct-relation fuzzy matrix

$$B = \begin{bmatrix} 0 & B_{12} & \dots & B_{1n} \\ B_{21} & 0 & \dots & B_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ B_{n1} & B_{n2} & \dots & 0 \end{bmatrix} \tag{9}$$

where

$$D_{ij} = \frac{B_{ij}}{E} = \left( \frac{B_{ij,l}}{e_l}, \frac{B_{ij,m}}{e_m}, \frac{B_{ij,u}}{e_u} \right),$$

$$E = (e_l, e_m, e_u)$$

$$e_s = \max \left( \sum_{j=1}^n B_{ij,s} \right) \quad \forall s = l, m, u$$

With the assumption of at least one 'i' such that  $\sum_{j=1}^n B_{ij} \leq e_s \quad \forall s = l, m, u$

Eq. (9) can be separated into distinct sub-matrices, as  $(D_l, D_m, D_u)$ . Goodman (1988) proven  $\lim (D_s)^x = N$  and  $\lim (1 + D_s + \dots + D_s^2 + \dots + D_s^k) = (1 - D)^{-1}$ ,  $\forall s = l, m, u$ , where  $N$  - null matrix.

Now the total-relation fuzzy matrix 'T' can be calculated as [34]:

$$T = \lim_{x \rightarrow \infty} (D + D^2 + \dots + D^x) = D(1 - D)^{-1} \tag{10}$$

Therefore, the T matrix is as shown in Eq. (11) as follows.

$$T = \begin{bmatrix} t_{11} & t_{12} & \dots & t_{1n} \\ t_{21} & t_{22} & \dots & t_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ t_{n2} & t_{n2} & \dots & t_{nn} \end{bmatrix} \tag{11}$$

Where  $t_{ij} = (t_{ij,l}, t_{ij,m}, t_{ij,u})$  is overall influence rating of 'i' against 'j.'

The sum of rows and columns of the sub-matrices  $T_l, T_m, T_n$  denoted by the fuzzy numbers  $RO$  and  $CO$ , respectively, can be calculated using Eqs. (12) and (13) respectively [34].

$$RO_i = \sum_{j=1}^n t_{ij} \quad (i = 1, 2, \dots, n) \tag{12}$$

$$CO_i = \sum_{i=1}^n t_{ij} \quad (j = 1, 2, \dots, n) \tag{13}$$

Defuzzification is required to get the criteria; here signed distance method proposed by Yao and Wu [165] is used. Defuzzification of  $RO_i$  and  $CO_i$  calculated by Eq. (14) as follows.

$$s(D_{ij}, 0) = \frac{1}{4}(D_{ij,l} + 2D_{ij,m} + D_{ij,u}) \tag{14}$$

defuzzifying  $RO_i$  and  $CO_i$  by using above the Eq. (14) gives  $RO_i^{def}$  and  $CO_i^{def}$  respectively.  $(RO_i^{def} + CO_i^{def})$  is termed as 'Prominence' and plotted on the horizontal axis and  $(RO_i^{def} - CO_i^{def})$  is termed as 'Relation' and plotted on the vertical axis [34].

The rank of the criteria is calculated using Eq. (15) as follows.

$$Y_i = \{(RO_i^{def} + CO_i^{def})^2 + (RO_i^{def} - CO_i^{def})^2\}^{\frac{1}{2}} \tag{15}$$

Eq. (16) normalized value of importance of criteria.

$$Y_i = \frac{Y_i}{\sum_{i=1}^n Y_i} \tag{16}$$

$Y_i$  represents the final criteria weight for decision making [34].

### 3.4. Fuzzy AHP model

Since its development, analytical hierarchy process (AHP) is extensively used as multiple criteria decision-making (MCDM) due to its flexibility, simplicity, and ease of use [118]. Significant steps in AHP are constructing hierarchy, priority analysis and verification of consistency. In AHP, firstly we need to develop a hierarchy of problem in the graphical representation, followed by the construction of pairwise comparison matrix, synthesis, consistency test, and overall priority ranking (Ho, 2008). Zadeh [169] and Zimmermann [172] introduced fuzzy logic in multi-attribute decision-making (MADM). To reduce cumbersome computations of MADM methods, Chen and Hwang [30] introduced fuzzy raking methods and fuzzy MADM methods. Fuzzy MADM contained some methods to assess the relative importance of multiple attributes. Some of the popular methods in Fuzzy MADM includes Fuzzy simple additive weighting method, Fuzzy AHP, Fuzzy Maximin method, etc. Fuzzy AHP is more prevalent in researchers,



some of the examples are automotive manufacturing [74], knowledge management [157], supplier-buyer relationship [89], etc.

Author refined the version used by Cheng and Mon [31], Wichapa and Khokhajaikiat [159], and Halder et al. [59] for steps used in Fuzzy AHP as follows:

**Step 1: Formulate aggregated fuzzy hierarchy matrix**

Corresponding to the triangular fuzzy number, the scale of matrix A is listed. All major diagonal elements are one as it compares criteria with itself. For the rest of the values, fuzzy scale (n1, n2, n3) is listed. Suppose criteria C<sub>1</sub> against criteria C<sub>2</sub> is listed as (2, 3, 4) shows C<sub>1</sub> more important than C<sub>2</sub>; then the corresponding value of C<sub>2</sub> against C<sub>1</sub> will be (1/4, 1/3, 1/2). Thus based on the expert's opinion, the aggregated matrix is formed as shown in Eq. (17).

$$F = \begin{bmatrix} f_{11} & \dots & f_{1j} & \dots & f_{1m} \\ \dots & \dots & \dots & \dots & \dots \\ f_{i1} & \dots & f_{ij} & \dots & f_{im} \\ \dots & \dots & \dots & \dots & \dots \\ f_{m1} & \dots & f_{mj} & \dots & f_{mm} \end{bmatrix}, \tag{17}$$

**Step 2: Computation of geometric mean**

The geometric mean of 'm' numbers is the m<sup>th</sup> root of the product of those 'm' numbers. In triangular membership function, we need to consider (n<sub>i</sub> / grade of membership) for each fuzzy number. Eq. (8) gives a geometric mean for each criterion.

$$p_k = \left( \prod_{i=1}^m f_{ij} \right)^{1/m} \tag{18}$$

**Step 3: Calculation of relative fuzzy weights**

Based on the geometric mean of each criterion, fuzzy weight is calculated by Eq. (9) given as.

$$W_j = p_1 \oplus (p_1 \oplus p_2 \oplus \dots \oplus p_m)^{-1} \tag{19}$$

After finding geometric summation mean of each p<sub>k</sub>, the inverse of summation is calculated. Lastly, fuzzy weight is a multiplication of each p<sub>k</sub> with this reverse vector.

**Step 4: Calculation of non-fuzzy weight**

Defuzzification is calculating the crisp (non-fuzzy) value. There are various methods of defuzzification like centroid method, the min-max

method, the center of the area, etc. Based on the centre of the area method, the non-fuzzy weight of U<sub>j</sub> is calculated by Eq. (20) as.

$$U_j = (n_1W_j + n_2W_j + n_3W_j)/3 \tag{20}$$

Here the relative crisp weight of each criterion is the average of fuzzy numbers.

**Step 5: Determination of normalised weight**

The non-fuzzy number U<sub>j</sub> needs to be normalised for each criterion. Eq. (11) calculates final score of each criterion by dividing criterion weight by total summation of weights.

$$V_j = \frac{U_j}{\sum_{j=1}^m (U_j)} \tag{21}$$

$$I_{FM} = \begin{matrix} Goal \\ FA_1 \\ FA_1 \\ \vdots \\ FA_p \\ FA_n \end{matrix} \begin{bmatrix} Aw_1 \\ Aw_2 \\ \vdots \\ Aw_p \\ Aw_n \end{bmatrix} \tag{22}$$

Where I<sub>FM</sub> matrix represents the weights of data for the final factors, FA represents for factors. The loading/weights in Kahraman's (2008) method applied regarding linguistic statements. However, in the proposed tool, the weights are obtained from the modified fuzzy DEMATEL approach whose main/final loading weights are crisp. It is also required to allocate the weights of final factors to sub-factors. The WF matrix which denotes the weights at the lower level of the hierarchy is obtained by using the following equation;

$$WF = Z_{ff} * Z_{sf} \tag{23}$$

The final value calculated for each criterion as well each alternative can be ranked so that decision-makers can take the decisions.

**4. Method of analysis**

Fig. 2 shows the adopted research methodology.

**4.1. Study area**

Industry ABC Pvt. Ltd. is a food processing industry situated on Mumbai-Bangalore highway, India. The industry produces and deals with different products such as dairy, bakery, beverage and fruits and vegetable segments. In the dairy category, products such as butter, ghee, milk, cheese, and cream. Bakery category deals with dairy-free

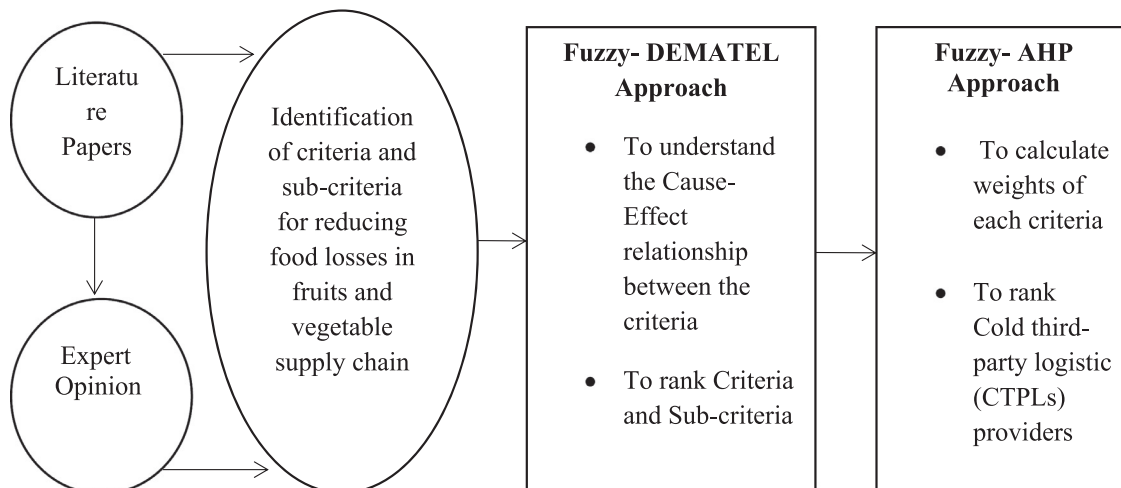


Fig. 2. Research methodology.

cream and other byproducts. In the last category, beverage deals with tea, tea bags, and other food items. In fruits and vegetables, fresh and frozen products serve to national and international markets. Presently, ABC Ltd. is more in fresh potatoes, apples, tomatoes, and dehydrated onions and prawns. These all the products are packaged in the different type of containers as well as different sizes of plastics polythene bags, corrugated boxes, and tin cartons containers. The organisation has a unique business model which stems from its detailed understanding of the various business opportunities and challenges at every step of the food supply chain, i.e., farm to fork. The organisation is committed to helping farmers and growers find a suitable market for their production.

As the firm is working with 25 vendors, 400 progressive dairy and fruits and vegetable farmers, 40 distant direct vendors, and various village milk collection centres. The collection of raw milk from different farmers and producers is around forty thousand, and for this purpose, they have to travel near and around small villages and towns: everyday raw milk collection and processed milk to collect and delivery within 100 km distance from the plant. To handle these complexities ABC Pvt. Ltd. is considered for the case study.

Even though the supply chain team of ABC Ltd. have extensive and vast experience, the amount of food loss and waste is quite considerable. Also, the reasonable cost of production and distribution operations is a concern for top management. The firm spread/distribute their costs over different items and brands to bring better value to its customers as well as suppliers. However, in the whole process, dairy and bakery products are crucial and challenging products. The dairy, beverage, and fruits and vegetable items are limited shelf life. The collection, transportation, storage, and inspection of the items is a trick and complicated processes, including challenging distribution processes. In the overall processes, the quality and on-time delivery are the two significant challenges, and because of this reasons, the firms have decided to outsource these activities to the cold-third party logistics service provider (CTPLs).

4.2. Data collection and analysis

The top management and strategic team of the firm have formed an expert team of ten associates to evaluate a trustworthy, reliable and well-suited CTPLs provider with whom the firm can work a collaborative work. The expert's team members are working in the field of CSCM and having more than eight years of experience in the perishable food industry. Based on the extensive literature review and expert's opinion, five large category factors divided into thirty sub-factors were short-listed for the evaluation and selection of CTPLs (Table 2). The core experts committee then decided the relative weight of the filtered factors using theories of scientific criteria and Fuzzy-DEMATEL and fuzzy-AHP as presented in methodology sections. These CTPLs (CTPL1, CTPL2, CTPL3, and CTPL4) were rated using linguistic variables as depicted in Table 2.

The pairwise comparative matrix for all the factors as formulated by the expert's team based on the Eq. (8) as given in Table 3a (Pairwise comparison of criteria). Table 3b represents the assessment inputs of the scientific evaluation of the expert. Next, the initial normalised direct relationship fuzzy matrix for the factors is achieved by Eq. (9).

By using (11) and (12) fuzzy relative weight matrix for all criteria are achieved and is shown in Table 4.

Table 2 Linguistics inputs for the rating of criteria.

S. no.	Linguistic word	Linguistics numbers
1.	No	(0, 1, 2)
2.	Very Low	(2,3,4)
3.	Moderate	(4,5,6)
4.	High	(6,7,8)
5.	Very high	(8,9,9)

Table 3a Sample of expert's input (Linguistic words).

	KITM	BGA	SSCA	MAM	RELC
KITM	0	VH	VL	H	VH
BGA	VL	0	VL	VH	VH
SSCA	VH	VL	0	H	NO
MAM	H	VH	M	0	H
RELC	VH	VH	H	H	0

Table 3b Sample of expert's input (Linguistic numbers).

	KITM	BGA	SSCA	MAM	RELC
KITM	(0,0,0)	(8,9,9)	(2,3,4)	(6,7,8)	(8,9,9)
BGA	(2,3,4)	(0,0,0)	(2,3,4)	(8,9,9)	(8,9,9)
SSCA	(8,9,9)	(2,3,4)	(0,0,0)	(6,7,8)	(0,1,2)
MAM	(6,7,8)	(8,9,9)	(4,5,6)	(0,0,0)	(6,7,8)
RELC	(8,9,9)	(8,9,9)	(6,7,8)	(6,7,8)	(0,0,0)

Table 4 Initial normalised direct-relation fuzzy matrix.

	KITM	BGA	SSCA	MAM	RELC
KITM	0	8.75	3	7	8.75
BGA	3	0	3	8.75	8.75
SSCA	8.75	3	0	7	1
MAM	7	8.75	5	0	7
RELC	8.75	8.75	7	7	0

By using Eqs. (12) to (16).

The weights normalised matrix is determined by using the equation no (21). Table 5 shows the cause and effect relationship matrix and corresponding weights of the primary five factors. Obtaining the weights of the main factors used further for calculating the sub-criteria loading of each level of hierarchies. Table 6 shows the weights of each sub-criteria and ranking accordingly. After causal and effect diagram can be drawn by plotting the values of RO-CO and RO+CO, where RO-CO is on X-axis and RO+CO is on Y-axis.

By using the Eqs. (17)-(22), the following values are obtained as shown in Table 7.

5. Results and discussion

The weight values of five criteria and six service providers confirm the most important criteria and most suitable service provider. Table 5 outcome show that rank of criteria 'Refrigerator and loading capacity' is highest with a value of 0.216, followed by 'Knowledge and Information technology management' (0.206), and 'Maintenance management'(0.205). 'Budget and Government approvals' (0.194) and 'Safety, security, comfort, convenience, and aesthetics' (0.179) criteria found to be least significant.

Referring to Table 6, the importance order of sub-factor is RELC1-BGA1- MAM1- KITM1-SSCA1- MAM2. As an output, CTPL1 is the most crucial player to win the bid for the logistics process of firm ABC Ltd. CTPL1 is succeeded by CTPL2, CTPL3, CTPL4, CTPL6, and CTPL5. The outcome of the results or ranking of these players because of its strength on Refrigerator and loading capacity; Knowledge and Information technology management; Maintenance Management; Budget and Government approvals; and Safety, security, comfort, convenience, and aesthetics view.

Venkatesh et al. [154] identified Indian legislation, underdeveloped technologies, lack of infrastructure, and lack of collaboration as a significant barrier in the logistics supply chain. Patil and Kant [110] used Fuzzy multi-criteria decision-making hybrid approach along with fuzzy DEMATEL to conclude that knowledge management plays a significant

**Table 5**  
Total relationship (Cause and effect relationship) and weights of the factors.

	KITM	BGA	SSCA	MAM	RELC	RO	RO-CO	RO+CO	weights	V-weights	Ranking
KITM	0.934	1.278	0.763	1.218	1.187	5.382	0.264	10.499	10.503	0.206	2.000
BGA	0.924	0.933	0.689	1.132	1.067	4.745	-0.373	9.863	9.870	0.194	4.000
SSCA	0.911	0.863	0.484	0.938	0.748	3.944	-1.174	9.061	9.137	0.179	5.000
MAM	1.107	1.261	0.799	1.026	1.133	5.326	0.208	10.444	10.446	0.205	3.000
RELC	1.242	1.364	0.911	1.312	1.044	5.873	0.755	10.991	11.016	0.216	1.000
CO	5.118	5.699	3.646	5.626	5.180	25.269			50.972	1.000	
$\alpha = 1.011$											

**Table 6**  
Sub-criteria weights and ranking.

Sub-criteria	Weights	Ranking
RELC1	0.098	1
BGA1	0.089	2
MAM1	0.087	3
KITM1	0.079	4
SSCA1	0.079	5
MAM2	0.061	6
KITM2	0.057	7
SSCA2	0.053	8
BGA2	0.043	9
RELC2	0.041	10
RELC3	0.041	11
KITM3	0.040	12
BGA3	0.036	13
MAM3	0.030	14
SSCA3	0.026	15
RELC4	0.021	16
KITM4	0.014	17
MAM4	0.013	18
BGA4	0.012	19
SSCA4	0.009	20
RELC6	0.008	21
KITM5	0.008	22
KITM6	0.008	23
MAM6	0.007	24
BGA5	0.007	25
BGA6	0.007	26
RELC5	0.007	27
SSCA5	0.006	28
SSCA6	0.006	29
MAM5	0.006	30

**Table 7**  
Final weights and ranking of the CTPLs.

	Weights	CTPL1	CTPL2	CTPL3	CTPL4	CTPL5	CTPL6
KITM	0.206	0.321	0.278	0.232	0.076	0.043	0.030
BGA	0.194	0.429	0.243	0.185	0.088	0.034	0.027
SSCA	0.179	0.397	0.152	0.212	0.072	0.036	0.036
MAM	0.205	0.373	0.299	0.159	0.069	0.029	0.035
RELC	0.216	0.298	0.228	0.228	0.176	0.034	0.020
Weights		0.361	0.242	0.203	0.098	0.035	0.029
Ranking		1	2	3	4	6	5

role in the adoption of the supply chain. Knowledge management helps in proper distribution planning of the resources [21]. In developing countries like India, lack of government policy, lack of farmers' awareness and knowledge, and lack of technology are prominent for sustainable food supply chain [130]. Knowledge management helps in proper distribution planning of the resources [21]. In developing countries like India, lack of government policy, lack of farmers' awareness and knowledge, and lack of technology are prominent for sustainable food supply chain [130].

Further, based on "RO-CO" values classifies criteria into two distinctive groups: "influential/cause" and "influenced/effect." A positive value of "RO-CO" indicates a cause parameter and criteria RELC

(0.755), KITM (0.264), and MAM (0.208) fall under cause category. A negative value of "RO-CO" indicates an effect parameter, criteria SSCA (-1.174), and BGA (-0.373) fall under effect category. The obtained results are deliberated again with the subject experts to obtain insights on the cause-effect parameters. It has helped to understand the effective implementation of the CSCM.

The result of the Fuzzy DEMATEL – Fuzzy AHP analysis provides the significance order of each criterion. One must note that improving one or two criteria, overall system performance will not improve due to the existent of inter-relationship between the criteria. Thus for making a practical decision, criteria need to be categorised into the cause (influential) and effect (influenced) group. Further criteria were ranked to understand necessary measures and sub-criteria. This section details about influencing and influenced criteria, sub-criteria ranking, and ranking of service providers as follows.

### 5.1. Influencing criteria

Three criteria are identified as influential and are considered necessary for effective CSCM of perishable fruits and vegetables. Furthermore, the improvement in influencing criteria brings enhancement in the other influenced criteria. The highest "RO-CO" score is "Refrigerator and loading capacity" (RELC). Refrigeration is mainly responsible for food quality and safety, which is non-negotiable. "Refrigerator and loading capacity" is a collective responsibility of logistics provider, producer, government, and certification bodies. The second highest influencing criterion between the identified criteria is "Knowledge and Information technology management" (KITM). According to Irani et al. [70], knowledge of stakeholders acts a positive influence and recent up-gradation in technology is making an impact on "Knowledge and Information technology management." Based on "RO-CO" score, the most influenced criteria is the "Safety, security, comfort, convenience, and aesthetics view" (SSCA), as it is influenced by the driver listed above.

### 5.2. Ranking of sub-criteria

Based on the analysis, the highest weight of sub-criteria is "Efficient precooling and temperature variability-controlling equipment facility" (RELC1). Precooling ensures fewer loads on the refrigeration system, whereas advancements in sensor technologies have helped in better control.

Increasing fuel prices affect the logistic cost, which is a concern of supplier, retailer, and customer. It is indicated in this study with "Low fuel consumption" (BGA1) rated as the second most significant sub-criteria. Maintenance management can be enhanced with more number of service stations and "Large numbers of the service station and capacity facilities" (MAM1) is rated the third most significant sub-criteria. Recent advancements in the Internet of Things (IoT) has affected many domains, and CSCM is not the exception. In this study "Inbuilt RFID system" (KITM1) is rated the fourth most significant sub-factor.

### 5.3. Ranking of service providers

As dynamics of the market environment or volatile market conditions regarding volume and freshness/quality of the products, on-time delivery, and government rules and regulations after one tax policy in India, i.e., GST implementation process, SMART city, Make in India, etc. CTPLs need to be active in relations of all these fluctuations. The results indicate that the first top three players, i.e., CTLPs are working very close to each other represents the sensitive environment of CSCM. It also shows that CTPLs market condition is very competitive, and within this environment to provide high-quality on-time delivery to the customer at the minimum cost with maximum loading capacity, thus giving an economic edge over its challenges.

Comparing the results with previous studies carried in different countries is as follows. Baykasog˘lu et al. [13] study on truck selection found maintenance as a significant factor, whereas factor comfort and aesthetic least significant, which supports our study. Gunasekaran and Negi [57] study signify the importance of knowledge and information sharing to achieve agility in the supply chain. Irani et al. [70] found social and people-level knowledge as a driver in the food supply chain. However, a few findings of the present study contradict with previous studies as follows. Studies of Kumar and Singh [82], Baykasog˘lu et al. [13] found the economy aspect most significant, which contradict with our result.

## 6. Conclusion

Evaluation and selection of CTPLs problem become more critical for the effectiveness of the food supply chain. The selection of CTPLs is depended on various factors. The factors and their hierarchies are identified by one to one interaction with the experts of a food firm in India. In this article, thirty sub-criteria clubbed into five broad categories, i.e., Knowledge and Information technology management; Budget and Government approvals; Safety, security, comfort, convenience, and aesthetics view; Maintenance Management; Refrigerator and loading capacity. The CSCM sector, CTPLs have to work in a very volatile and uncertain fuzzy environment. That is the reason an integrated tool of Fuzzy –DEMATEL and Fuzzy-AHP has been explained with the help of a real case from Indian fruits and vegetable industry, i.e., the food industry. Fuzzy-DEMATEL is used to calculate the relative weights of the various factors accepted for CTPLs selection and evaluation process in the CSCM. After determining the weights of the qualifying factors, fuzzy-AHP is used to rank the six CTLPs (i.e., alternatives) for selecting the suitable CTLPs under volatile and fuzzy environment. This integrated tool includes the fuzziness related to real industry problem decision, thus increasing the reliability and effectiveness of the system.

### 6.1. Managerial implications

Developing countries like India must reduce perishable food losses in the supply chain. The study is beneficial to the food industry to reduce loses. Professionals/managers involved in the supply chain cannot focus on all criteria. Thus, they need to focus on significant drivers and can extend the implementation to less significant drivers. The study helps managers to take decisions on a service provider by understanding significant factors and sub-factors. The knowledge of criteria is critical in the elimination of food loses, cost reduction, higher security, and maintenance. The paper motivates practitioners of developing economies for taking the initiatives towards implementation of the productive system in the perishable food supply chain.

The paper provides a theoretical basis for selection of cold third-party logistics by criteria and sub-criteria. The knowledge of criteria can help 3PL provider to focus on essential facilities to be provided to customers. Understanding the selecting criteria will improve the service quality of 3 PL. This paper may assist various stakeholders of CSCM in

understanding the current status of perishable food products. This study can be helpful to policymaker/government for evaluation of new and existing policies. Policymakers can use findings of this study for a reasonable basis by which the perishable food supply chain can be more resilient. Policymaker can analyse/simulate the cause and effect criteria group for the formulation of policies which can improve the performance of CSCM. This study identifies the primary drivers and can be utilised for developing a framework of Halal supply chain, bulk gain supply chain, food supply chain, etc.

### 6.2. Limitations and future scope of the study

The study is based on inputs from expert's team members of CSCM; however, the expert's opinion can be biased, which may affect the outcomes. In this paper, only five criteria with a total of thirty sub-criteria were deliberated for analysis. Some other criteria/sub-criteria in the context of a diverse country can be involved in further analysis. As this study has been carried out in the Indian context, appropriate modifications are needed to apply it to other developing economies. Findings between other developing economies can be compared to draw necessary inferences. Also, this study is focused on the CSCM of vegetable and fruits; it can be expended for the meat supply chain, fish supply chain, and Halal supply chain.

The methodology adopted for analysis is Fuzzy DEMATEL and Fuzzy AHP. The adopted methodology has limitations such as MCDM methods like VIKOR and GRA considers a target level of choices. Further approaches like TOPSIS, ISM, etc. along with Fuzzy AHP, Fuzzy DEMATEL can enhance the accuracy and reliability of the proposed study. Also use of Fuzzy cognitive map [70], and fuzzy heuristic logic [162] can help in identifying simultaneous interrelationships and enhancing robustness respectively. Grey DEMATEL with sensitivity analysis can be used to eliminate potential bias [171].

Further, pricing decision with closed-loop supply chain with random demand and random yield can be incorporated [51,124]. Also, the influence of Industry 4.0 on food supply chain needs to be investigated [108]. In a future study, the proposed model can be validated using a structural equation modelling approach.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.orp.2019.100117](https://doi.org/10.1016/j.orp.2019.100117).

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