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Jayakrishna Kandasamy [a], K.E.K. Vimal [b], Aditya Pratap Singh [a], Aaryan Magnani [a], Ameya Gokhale [a], Sandeep Jagtap [c,d,*]

[a] School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu, India
[b] Department of Production Engineering, National Institute of Technology, Tiruchirappalli, Tamil Nadu, India
[c] Division of Engineering Logistics, Lund University, Lund, Sweden
[d] Sustainable Manufacturing Systems Centre, Cranfield University, UK

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ABSTRACT

Implementing FEFO practices has become essential for organizations globally to minimize spoilage, enhance inventory turnover, and ensure compliance with health and safety standards. To aid stakeholders in effectively adopting FEFO, it is crucial to identify and address the challenges involved in its implementation. Through an extensive literature review using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) methodology and insights from industry experts, this study identifies thirteen core challenges that hinder FEFO adoption. PRISMA methodology was used to systematically organize the existing literature for the purpose of this study. Using tools like Decision Making Trial and Evaluation Laboratory (DEMATEL) and Total Interpretive Structural Modelling (TISM), the challenges were examined and ranked according to their interdependencies, providing insights into the cause-effect relationships among them. After applying DEMATEL, an alpha threshold value of 0.368 revealed that challenges in effective storage management are the primary barrier in implementing FEFO practices. With level partitioning, this challenge emerged as the most significant, forming the foundation for a roadmap designed to assist stakeholders. The findings from this study offer managers actionable insights for implementing effective FEFO techniques within their organizations. The study's novelty lies in its combination of DEMATEL and TISM methodologies, along with a roadmap that highlights strategic and policy-focused recommendations to support efficient FEFO adoption and the systematic study of challenges preventing effective FEFO adoption. This paper aids implementation of FEFO for better inventory control and management, reduced wastage and greater efficiency. The paper also effectively outlines and analyses the order of importance of challenges in FEFO implementation and their interdependence.

1. Introduction

The Perishable Food Supply Chain (PFSC) faces unique challenges where the shelf-life of products has an impact on both the economic viability and safety of food items. The shelf life of items in the perishable food industry directly affects factors such as safety and economic viability [1]. To minimize waste and ensure timely distribution of goods, effective inventory management is required. Earlier First-In, First-Out (FIFO) method was used, an inventory management method where the oldest items are used or sold first before newer items [2]. It is often used to manage stock rotation and ensure that older products are used or sold first. It keeps accurate chronological flow of goods incoming and outgoing and is commonly applied in industries dealing with perishable goods, such as dairy, meat, poultry, fruits, vegetables, pharmaceuticals etc. One inventory management approach that fulfils the criteria of both safety and minimal waste is the First Expired, First Out (FEFO) method that aims to reduce health hazards associated with consumption of expired goods [3]. The FEFO method works by dispatching items that are closest to expiry while still being safe for use unlike the (FIFO) method where dispatch of goods is solely decided by the order in which the items are received. FIFO leads to higher food waste as oldest item may not be closest to expiry [4]. It requires careful organization to ensure older items are at the front, leading to disorganization. FIFO can result in selling expired products, legal issues, or loss of trust.

* Corresponding author. Division of Engineering Logistics, Lund University, Lund, Sweden.
E-mail address: sandeep.jagtap@tlog.lth.se (S. Jagtap).

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Implementing FIFO requires diligent tracking and management, which is complex and time consuming [5]. Also needs a lot of space to rotate inventory properly and it must be well-organized.

Adopting the FEFO approach in the PFSC management raises some practical problems that act as bottlenecks to implementing FEFO. As each method has its advantages and disadvantages, the FEFO approach, while boosting productivity by minimising wastage, is also difficult to implement due to various challenges discussed in the paper. A key challenge to implementing FEFO in PFSCs is the difficulty in constantly maintaining inventory and expiry date tracking [6]. Unlike items that don't go bad, perishables need close watching of their use-by dates at every step from production to retail [7]. This poses a significant drawback because different products have different shelf lives, and all stakeholders need reliable, relevant and up-to-date information about the product and its expiration date. Perishability of goods also depends upon the temperature at which they are stored and transported which adds cost and difficulty due to maintenance of cold chain throughout the process. Generally, these goods are stored and transported at temperatures of −20 °C to −24 °C [8]. Advanced technological solutions, such as automated inventory management systems and IoT-enabled sensor systems to track and measure the product and its perishability can be used to resolve the challenges which are outlined in the later sections of the paper [9]. However, these solutions have their own restrictions such as high implementation costs, data integration, and the need for employee training. These challenges act as a significant barrier to the widespread use of these technologies.

Fragmented coordination and collaboration among supply chain partners is also a prime reason that makes it difficult to apply FEFO technique in the PFSC [10]. This process involves several layers of the supply chain, including suppliers, manufacturers, distributors, and retailers, each with their own preferences and operational constraints [11]. Misaligned goals, lack of trust, and infrequent information flow can hinder collaboration and lead to suboptimal outcomes. Furthermore, non-standard regulatory compliances and practices across the supply chain network add another layer of complexity, as supply chain partners must account for differing requirements related to food safety, labelling, and inventory rotation.

Aligning the PFSC with sustainable development goals (SDGs) adds yet another dimension to the obstacles of FEFO implementation. Three important SDGs are covered in the study: SDG 12 (Responsible Consumption and Production), SDG 2 (Zero Hunger), and SDG 1 (No Poverty). The study finds the difficulties of implementing FEFO in PFSC. It seeks to resolve several issues. FEFO helps businesses save money by reducing food waste [12]. This supports SDG 1 by lowering costs and help fighting poverty. Essential food items become more available and cheaper [13]. FEFO helps with SDG 2 by sending out food items before they expire, reducing waste and getting more food to people. This helps fight hunger by making better use of available food [14]. This efficient channelling of food products helps meet demand consistently, alleviating food insecurity.

The study encourages responsible production, which advances SDG 12. It does this by selling and distributing items based on their expiration dates. Companies therefore improve their inventory turnover. They also cut down on the waste produced. It identifies the challenges and proposes solutions to it. This can be effective for making sustainable food supply chain methods. By implementing the findings, stakeholders in the perishable food industry may increase food security, reduce poverty, and advance sustainability. As sustainable practices become the norm and regulators increasingly demand sustainability in the supply chain, supply chain managers must balance the need for efficient inventory turnover with the minimization of food waste and environmental impact [15].

Due to the interconnectedness of the challenges and their impact on the implementation of FEFO in the PFSC, it is imperative to analyse and understand how each factor influences the others and which factor acts as a bottleneck to enacting FEFO in the supply chain. Through this paper, authors aim to analyse these challenges through a multi-layered approach after a comprehensive literature review including both research papers and industry insights. Therefore, by identifying the technological, collaborative, and sustainability issues in FEFO, this paper aims to develop a framework for addressing such bottlenecks and increasing the stability and efficiency of the PFSC. This study hence identifies two research questions to address the challenges faced in implementing FEFO:

RQ1. What are the key challenges in implementing FEFO for PFSCs?
RQ2. How to analyse the influence of one factor on other factors?

To address RQ1 and RQ2, the paper also identifies the following research objectives:

RO1. To identify key challenges preventing implementation of FEFO in PFSC.
RO2. To develop network relationship map and level partitioning chart to analyse interrelationship between the identified challenges.

The study reviews major challenges including good inventory tracking, different product expiration dates, staff training and consumer related behaviour. The aim of the study is to analyse these challenges and how they influence each other as well as their impact on implementing FEFO in the PFSC.

This study proposes a unique method of inventory control and storage for the PFSC. Through FEFO, suppliers and retailers can maximize their profits by cutting down on costs and wastage. The study's scope also includes analysis of challenges preventing FEFO implementation. This paper leverages Decision Making Trial and Evaluation Laboratory (DEMATEL) and Total Interpretive Structural Modelling (TISM) and other Multi-criteria Decision Making (MCDM) techniques to rank the challenges based on their order of influence on other issues so that a broad view of which challenges can affect the other factors to the greatest degree can be obtained. This study adds to the existing literature by comprehensively analysing obstacles to integrating FEFO with the PFSC and identifying which of these challenges need to be solved first.

This paper follows the following structure: Section 1 elaborates on the introduction – giving a brief overview of the paper, the RQs identified and ROs the paper hopes to achieve. Section 2 focuses on the literature review for the study using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) technique. Section 3 details the methodology used in the paper while Section 4 focuses on the data collection method along with the DEMATEL technique. Section 5 includes the results and discussion where matrix analysis is conducted; while Section 6 deals with the implications of the results along with the Level Partitioning Chart. Section 7 introduces future scope of the study and the conclusion while the final Section 8 includes the references.

2. Literature review

An extensive literature review using the PRISMA methodology, focusing FIFO, FEFO, DEMATEL, and TISM were sourced from various sources, with ten relevant papers selected for in-depth meta-data analysis. The PRISMA approach facilitated the systematic organization of selected papers to meet the objectives of this study is presented in Fig. 1. PRISMA is employed to ensure a systematic, transparent, and reproducible literature review process. Given the complexity of perishable food logistics, a structured approach is essential to comprehensively identify relevant studies on FEFO (First-Expired, First-Out) implementation challenges and PRISMA facilitates the elimination of selection bias, ensuring that only high-quality, peer-reviewed sources contribute to the analysis.

In recent years, there has been a surge in research interest surrounding PFSCs. This increase is evident from the growing body of

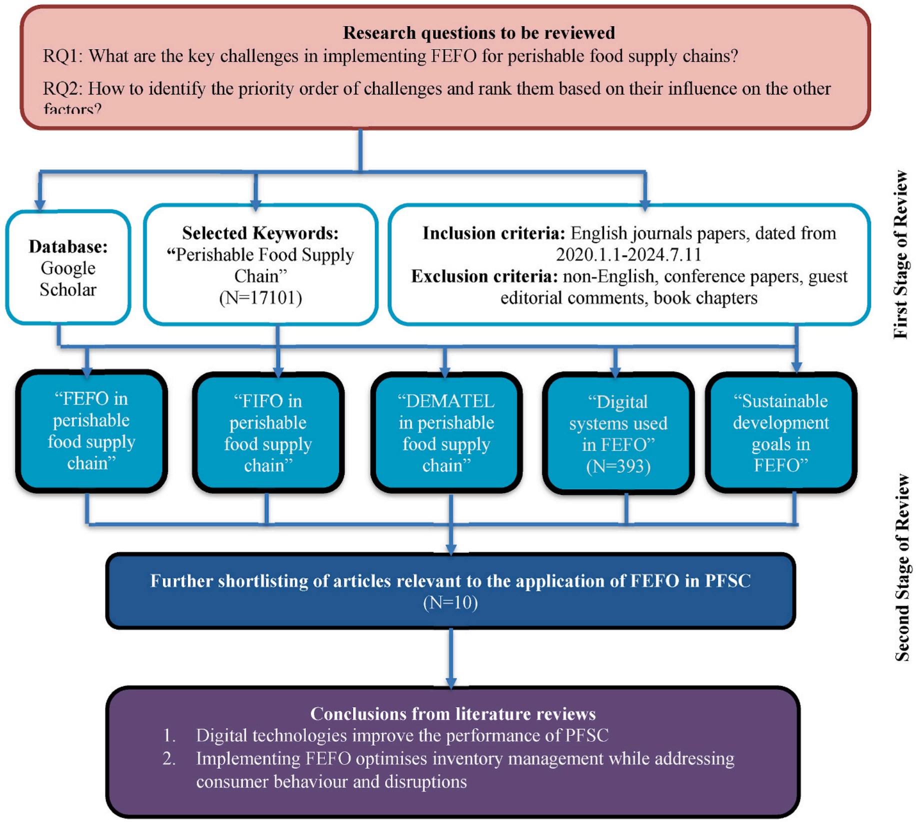

Fig. 1. PRISMA approach.

literature dedicated to optimizing inventory management strategies, such as FEFO and FIFO methods. Between 2022 and 2024, over 17,101 publications have focused on PFSC, reflecting its critical role in efficient supply chain management. FEFO-specific research has 191 publications focusing on its application in PFSC. It has shown a sign of growth in the field. 836 papers have addressed FIFO systems in PFSC. The integration of digital systems in FEFO is gaining momentum. There are 393 papers focused on using digital technologies to enhance FEFO in PFSC. 255 papers have been written sustainable development goals achieved in FEFO.

The application of the DEMATEL method has become a valuable tool in FEFO-related PFSC studies, as evidenced by 1090 publications. DEMATEL's ability to analyse complex causal relationships between factors influencing perishable inventory decisions has proven useful for researchers aiming to prioritize sustainability in PFSC [16]. This growing body of literature reflects the increasing interest in leveraging digital solutions and advanced decision-making frameworks to support FEFO in PFSC, addressing both efficiency and sustainability as key objectives in the perishable goods industry.

2.1. Perishable Food Supply Chain (PFSC)

A PFSC is a system for managing the journey of fresh food products. Perishable items like fruits, vegetables, dairy, and meat from production to the consumer are met through this system [17]. Unlike non-perishable products, these foods quickly lose quality therefore they should be handled carefully. To keep them fresh and safe the system takes decision about where to store the food, how to transport it and when to move it. Environmental conditions, like temperature, are crucial to food spoilage. High temperatures can quickly spoil the food [18].

There is rising significance of FEFO in controlling PFSCs. FEFO helps to improve inventory control [19]. It also helps in decreasing food waste as customer demands fresh goods [20]. Using advanced technological innovations enhance shelf-life tracking and real time visibility of the product [21]. These technologies affect positively in streamlining FEFO procedures. Every year there is a steady rise in the quantity of research articles on PFSC management [22]. Integration of digital technology reduce food waste. Growing interest in sustainability have contributed to the increase in research papers [23]. Researchers are now focusing on how FEFO can maximize inventory turnover. They are studying how it minimizes food waste in interrupted supply networks. Supply chain management (SCM) has become digital because of this, supply chain relies heavily on digital solutions [24].

2.2. Challenges faced in PFSC

The PFSC faces number of challenges. The major factors that affect the SC are shelf life of the products and demand being unpredictable [25]. These problems lead to high food waste rates. Reliable and timely information is therefore important. This information helps improve resilience and sustainability in the PFSC [26]. Earlier, in the perishable food sector FIFO was used for managing inventory [27]. SCM techniques focused on optimizing transportation, inventory, and logistics. Earlier, systems lacked digital integration. They lacked the flexibility needed to handle large-scale disruptions [28]. Effective SCM can increase revenue. It does this by maximizing delivery schedules, decreasing waste. It raises the product market value [29]. Studies indicate that a well-structured PFSC can increase sustainability. The environmental impact increases by 108 % as a result of refrigeration. The sustainability of the SC is increased by 137 % with a 23 % increase in economic awareness. Costs, environmental effects, and social implications are all balanced by PFSC principles [30]. COVID-19 changed consumer behaviour in terms of perishable food [31]. Lockdowns made consumers choose durable goods. They preferred items like pasta, canned foods, and frozen products. As a result of restaurants closing, customers had to buy online and at supermarkets. They made fewer trips. Food waste increased significantly due to hoarding and transportation interruptions. This happened because of supply chain constraints [32]. It caused perishable goods to be overbought or thrown out. These behaviours stressed PFSC. It influenced both demand and waste patterns [33]. Pricing for perishable food is difficult because these items are time sensitive. Products near their expiration dates their prices are reduced to boost sales and minimize waste [34]. This leads to different consumer behaviours. Price-sensitive shoppers are attracted to discounts which increases the demand [35]. Some focus on freshness and therefore avoid items that are close to expiration. Pricing changes, such as dynamic pricing, reflect supply chain disruptions [36]. They also indicate changes in consumer demand. It affects overall consumption patterns. This is true during events like the pandemic. Consumers make quicker decisions when products are perishable. Discounts or promotions entice them to buy, reducing losses for shops. The focus on lower prices can lead to impulsive or bulk buying. This may ultimately increase food waste. Buying too many discounted perishables might cause them to spoil before they are consumed. Sellers use dynamic pricing models based on product freshness, seasonality, and demand [36]. Issues in supply chain reflects in significant price changes. It happens due to delivery delays and changes in production costs. Panic buying during the pandemic impacts pricing [37]. Long-shelf-life items are preferred by consumers, which raises journey expenses. Food waste increases because of spoilage, leading to higher demand for fresh produce [38]. This causes shortages and drives up the prices of perishable goods. Table 1 lists the challenges identified that prevent FEFO implementation in PFSC.

2.3. Technologies supporting First Expired, First Out (FEFO)

Global supply chains are becoming more complex. Also, the demand for fresh and safe food products is on rise. Products having limited shelf life increases the risk in perishable food. Improper handling of these items results in financial loss, food waste and health risks to consumers.

The FEFO method helps reduce waste by selling older goods before newer ones. This method has its advantages but implementing FEFO has some challenges to tackle. Traditional supply chain systems often struggle to meet the simple needs of FEFO. Inventory control and handling of products with different expiration dates are some of them. Factors such as insufficient employee training and impulsive customer behaviour affect adopting FEFO. These challenges prompted us to explore new solutions. The solutions which create a bridge between theory and practice in FEFO implementation.

The rapid development of digital technologies is a unique way to overcome these barriers. Use of IOT and Blockchain technology management allows to increase transparency and efficiency. Using these technologies, supply chain managers can understand inventory levels. Understanding the product movements, allows better decision making.

2.4. Gaps in the literature

Research has been conducted on FEFO warehousing systems and PFSCs but there is limited literature on integrating FEFO in PFSC. Current literature does not include how advanced technologies like Blockchain and IoT can benefit and remove challenges from implementing FEFO in the PFSC. Another blind-spot is the behaviour of consumers and how it acts as a barrier to implementing FEFO in the supply chain.

3. Methodology

DEMATEL helps to analyse the interdependencies among factors in complex decision-making scenarios. Experts evaluate the direct influence of each criterion on others. A robust dataset is created which helps in producing a cause-effect diagram. This allows stakeholders to visualize the influence network. It also helps to identify core factors. By understanding the cause-effect relationships, an accurate assessment of correlation between factors can be obtained.

Table 1
Challenges blocking FEFO implementation.

Notation	Challenges Identified	Explanation	Source
P1	High Costs in Implementing FEFO	Implementing the FEFO system incurs high costs due to the need for specialized inventory software and skilled workers, alongside significant upfront expenses for detailed expiration tracking, posing a financial challenge for small and medium-sized enterprises.	[14,29,39]
P2	Management of Suppliers for Effective FEFO Implementation	Effective FEFO implementation requires thorough supplier management and accurate information flow to ensure timely deliveries and proper expiration tracking. Misalignment or poor coordination with suppliers and distributors can hinder traceability and disrupt the FEFO process.	[12,23,40]
P3	Integration of FEFO in Existing Systems	Integrating FEFO into existing inventory management systems and software can be complex. FEFO requires precise tracking of expiration dates for all inventory items, which can be complex and time-consuming, especially for large inventories with diverse products.	[40–42]
P4	Inventory Rotation	Constantly rotating inventory to ensure that the oldest products are sold first can be challenging, especially for businesses with limited storage space.	[37,42,43]
P5	Challenges in Effective Storage Management for FEFO	Effective FEFO storage management faces challenges like limited space, the need for meticulous control over conditions, and logistical difficulties in organizing products by expiration dates. These issues may require significant redesigns of storage systems, and inadequate solutions can lead to waste and financial losses.	[12,44,45]
P6	Seasonal Availability and Supply Variation	Perishable goods often have seasonal availability, making it hard to maintain consistent stock levels. This variability requires flexible and responsive inventory management strategies.	[14,23,46]
P7	Consumer Demand Fluctuations	Sudden changes in consumer demand, influenced by trends, seasons, or unforeseen events, can disrupt FEFO management. For instance, a spike in demand for certain seasonal fruits can lead to stock imbalances and difficulty in managing expiration dates.	[3,47,48]
P8	Consumer Behaviour	Consumers often choose products from the back of the shelf rather than the soon-to-be expired front shelved products due to wanting fresh products rather than old ones.	[4,49–51]

(continued on next page)

Table 1 (*continued*)

Notation	Challenges Identified	Explanation	Source
P9	Regulatory Compliance and Training	Ensuring compliance with regulatory requirements for food safety and quality control can be challenging. Staff must be adequately trained to understand and implement FEFO processes correctly. Ensuring consistent compliance across all levels of the organization is difficult and requires ongoing training and monitoring.	[52–54]
P10	Operational Efficiency	Managing inventory based on expiration dates can sometimes conflict with other operational efficiencies, such as minimising handling time or optimizing storage space. This can lead to increased labour costs and reduced overall efficiency	[19,55]
P11	Data Accuracy and Reliability	Implementing FEFO relies heavily on accurate and reliable data regarding the expiration dates of products. Inaccurate data can lead to expired products being shipped, resulting in customer dissatisfaction and potential health risks	[11,55, 56]
P12	System Maintenance	Maintaining the FEFO system and ensuring that it continues to function effectively over time can be challenging, especially if the system is complex or has multiple components.	[12,57]
P13	Technological Requirements for Inventory and Expiration Date Tracking	Proper tracking of inventory levels and expiration dates is crucial for FEFO implementation. Advanced technological solutions like warehouse management systems and inventory tracking software are often needed, requiring significant investment in hardware and software.	[14, 58–60]

3.1. Data collection

The required data regarding interconnectedness of factors was collected from industry experts and professionals. After filling out a questionnaire, the panel assigned a number from 0 to 5 based on the degree of influence of one factor on another. This rating was conducted for all 13 factors, leading to a 13 × 13 matrix from each expert whose details are mentioned in Table 2. To ensure fairness and no sampling bias, professionals from various sectors and industries were chosen based on random sampling. Table 2 displays the expert's details, including their field, years of experience and proficiency. The challenges listed in Table 1 were obtained by conducting a literature review of obstacles faced in implementation of FEFO method. The average matrix (B) is compiled which depicts pairwise comparison of influence of the factors based on scale scores assigned by the experts. For statistical significance, a panel of ten members was determined to be the most practicable sample size for this research. The purpose of this panel is to provide important information about the challenges faced while implementing FEFO as well as how these factors affect each other.

To analyse and overcome the difficulties in FEFO implementation, an understanding of the factors and their interdependencies is necessary so that identification of the primary challenges and their solutions can occur. Causal dependency is defined as the linkage between cause and effect of two factors. To analyse the causal dependency, many methods such as TISM, Structural Equation Modelling (SEM), and DEMATEL etc. can be utilized. To aid decision making and easily observe interdependency of factors, the use of DEMATEL technique which is an MCDM technique is utilized (Braga et al., 2021). It also allows us to reframe causes and consequences and the way they are arranged in the structural framework. In comparison to other MCDM techniques like Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), DEMATEL offers clear benefits such as assisting in establishment of interdependence between factors and mapping the challenges in a way that demonstrates relative links between challenges in the form of a Network Relationship Map [61]. Apart from DEMATEL, a level partitioning chart is created in the study to divide the challenges P1 to P13 according to their criticality. This is done to provide a more robust and transparent road map for addressing the obstacles which is a component of the TISM approach. Fig. 2 explains the step by step approach for the research methodology.

Table 2
Expert details for data collection.

Name	Organization	Designation	Experience (years)	Expertise
Expert 1	Dairy Industry	Head of Operations	13	Product rollout, Demand forecasting
Expert 2	Horticulture Industry	Plantation Manager	10	Crop production, Staff management
Expert 3	FMCG Industry	Category Manager	19	Product positioning, Competitive analysis
Expert 4	Supply Chain Expert	Director of Logistics	22	Warehousing logistics, Transportation
Expert 5	Agricultural Industry	Manager	12	Production, logistics
Expert 6	Leather Industry	Plant Manager	8	Inventory control
Expert 7	Supermarket	Division Head	17	Product control, inventory rotation
Expert 8	Automotive Industry	Assembly Line Supervisor	10	Scheduling, Quality Control
Expert 9	Hotel	Manager	15	Logistics, management
Expert 10	Restaurant	Head Chef	18	Inventory, procurement, quality control

Step-1: An expert panel is organized to weigh in on the correlation of factor i on other all other factors j, denoted by a_{ij}. After the data is being collected the panel will rate the challenges on a scale of 0–5 as follows: 0 – no relation, 1 – minimal relation, 2 – low relation, 3 – moderate relation, 4 – high relation and 5 – maximal relation. As each expert was asked to rate the relationship between factors, a matrix with values from the given scale $X^k = [x_{ij}^k]$ was created. Using Equation (1), an average matrix B was created as an aggregate of the expert matrices.

$$B = [a_{ij}] = \frac{1}{n}\sum_{i=1}^{n} x_{ij}^{k} \quad (1)$$

Step-2: The average B matrix undergoes normalization to adjust values in a range of 0–1 using Equations (2) and (3).

$$N = \frac{B}{u} \quad (2)$$

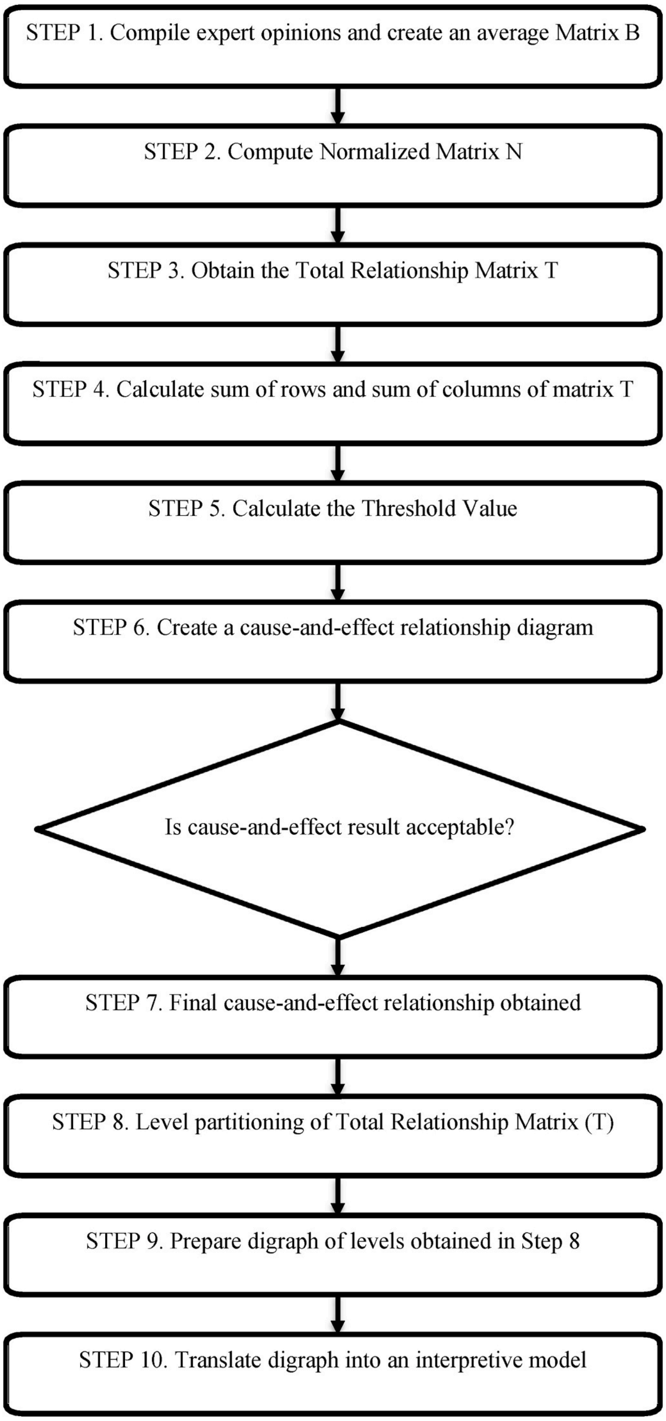

Fig. 2. Research methodology flow chart.

$$u = 1 \leq i \leq n \left\{ \sum_{j=1}^{n} a_{ij} \right\} \tag{3}$$

Step-3: Using the Normalised matrix formed, the Total Relationship Matrix (TRM) is calculated via Equation (4) where 'I' represents the identity matrix. Overall relationship between each set of factors taken under consideration is represented by the TRM.

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

Step-4: To form the matrices, the sums of rows and columns are calculated using Equations (5) and (6). Factors such as dependency and driving power are represented by the matrices.

$$K = \left[\sum_{j=1}^{n} m_{ij} \right] = (k_1, k_2, \ldots., k_i, \ldots., k_n) \tag{5}$$

$$J = \left[\sum_{i=1}^{n} m_{ij} \right]' = (j_1, j_2, \ldots., j_i, \ldots., j_n) \tag{6}$$

$$M = m_{ij} \quad (i, j) = 1, 2, 3, \ldots., n \tag{7}$$

Step-5: Threshold value (α) is calculated using Equation (7) for DEMATEL technique.

$$\alpha = \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} k_{ij}}{n^2} \tag{8}$$

Step-6: Using K and J, cause and effect relationship is obtained by plotting the set

$\{r_i + s_i, r_i - s_i\}, \forall i \in n$. X-Axis = $(r_i + s_i)$, Y-Axis = $(r_i - s_i)$.

Digraph is a valuable tool for decision making as it clearly defines the interrelationship between the challenges.

3.1.1. *Case study of dairy industries implementing FEFO & FIFO*

In the dairy supply chain, effective inventory management is critical due to the perishable nature of many products, such as milk, cream, and yogurt. FIFO is the most widely used inventory management system to ensure product quality. Opting for a different inventory control system like FEFO comes with many benefits such as reduced waste, lower cost and optimized supply chain efficiency. FIFO is particularly important for dairy products with longer shelf life, such as cheese or yogurt. In this system, the oldest products in inventory are sold or used first, ensuring that products reach consumers before they lose freshness. FIFO is essential in maintaining consistent product quality and is particularly useful for dairy items that have a relatively longer shelf life compared to highly perishable products like milk. On the other hand, FEFO is applied in managing products that are highly perishable, such as milk and fresh cream, which have a short shelf life. In this system, products that are closest to their expiration date are prioritized for distribution, ensuring that older stock is consumed or sold first. This method is particularly beneficial in dairy operations where products need to be consumed quickly to avoid spoilage and minimize waste. FEFO allows dairy suppliers to align product distribution with expiration dates, significantly reducing the risk of expired goods reaching consumers. By effectively tracking and managing expiration dates, FEFO helps dairy companies improve their sustainability by cutting down on food waste and enhancing the overall efficiency of the supply chain.

4. Results and discussion

4.1. *Study of correlation between factors*

DEMATEL technique is facilitated by a panel of industry experts who provide data on interdependence of factors. The expert's data are listed in Tables A3-A7 in the Appendix. The rating criteria and scale listed depicts the degree of influence of one factor on another and allows us to use DEMATEL technique and Level Partitioning Chart to identify critical factors.

Step 1: Collecting data from experts.

Equation (1) is used on the gathered data, to create the average B matrix.

The values provided by experts are listed in Table 3.

Step 2: Normalising average matrix

Add all the row values to obtain row-wise sum and divide the average matrix B by the highest row sum. The new matrix obtained, N, is the normalised matrix. Matrix N is displayed in Table 4.

Step 3: TRM Computation

Using Eq. (4), the normalised matrix N is converted into the total relation matrix T. The T Matrix is computed using MATLAB to evaluate the normalised matrix and calculate cell values using equation. T Matrix is shown in Table 5.

Step 4: Calculation of row sum and column sum. (Sr and Sc). The sum of rows and sum of columns is calculated for the Total Relation Matrix (T). Sr and Sc values are calculated and Table 6 displays these values next to the matrix T.

Step 5: Determine the alpha threshold value

As we have 13 key factors, they form a 13 × 13 matrix and we use n = 169 while computing the threshold value, alpha. This value is found to be 0.368462. The alpha threshold is determined by taking the average of all matrix values as it determines a base level of interdependency below which correlation is not significant. The alpha values are fitted into the T Matrix and all values below threshold are eliminated, thus making the Adjusted Total Relation Matrix. The Adjusted TRM is shown in Table 7.

Step 6: Building a directed causal network

The values of Sr + Sc and Sr–Sc are used as the horizontal and vertical axes, respectively, in the causal plot for the DEMATEL process. Consequently, y = Sr - Sc and x = Sr + Sc. Table 7 presents the significant relationship matrix S, derived after applying the threshold value used to construct the directed causal graph. The interrelationships between the obstacles to implementation of the FEFO method in the PFSC are better understood with the aid of this map. Studying the essential barrier among the 13 problems described is aided by the plot as well. The digraph is displayed in Fig. 3, and the final causal matrix is displayed in Table A2.

Adopting advanced inventory management techniques like the FEFO system has become essential as the perishable food industry faces increasing pressure to increase operational efficiency while reducing waste. By shipping goods as close to their expiration date as possible, this strategy lowers the possibility of health risks and minimizes food waste. Traditional inventory techniques like FIFO (First In First Out) and LIFO (Last In First Out) do not take product perishability into account as much as FEFO does. Real-time expiration date monitoring, the requirement for technology advancements, and efficient stakeholder collaboration throughout the supply chain are some of the challenges that FEFO implementation faces.

Because perishable products have short shelf lives and need continual supervision, the PFSC is complicated and depends on precise data for decision-making. Although there are drawbacks, including high implementation costs and the requirement for expert labour, integrating IoT-enabled sensors with automated inventory systems can offer a solution. Additionally, there is frequently a lack of coordination between SC participants, such as distributors, retailers, and suppliers, which results in inefficiencies during the FEFO implementation process.

Using the DEMATEL method, which aids in visualising and quantifying the cause-and-effect links among the different obstacles, this study seeks to identify and assess these issues. The study will produce a roadmap for removing the obstacles to FEFO implementation by gathering data from industry experts and conducting pairwise comparisons, which will ultimately result in a PFSC that is more robust and sustainable.

4.2. Level partitioning on PFSC

For FEFO to be used, inventory levels and expiration dates must be monitored precisely. Often, sophisticated technological solutions are needed, including warehouse management systems and inventory tracking software such as Katana and NetSuite. Significant investments are required for both software and hardware. A comprehensive examination of the difficulties encountered while applying the FEFO strategy in the PFSC may thus be conducted by combining the DEMATEL and TISM approaches. These tools facilitate the examination, visualisation and analysis of key challenges to FEFO implementation in the PFSC. Given the short shelf life of products, specific obstacles must be addressed to ensure effective inventory management using methods like FEFO. It is crucial to identify which barriers has the most impact and are more influenced by external factors to successfully implement FEFO. By solving most important issues that indirectly affect other, less critical factors, FEFO can be smoothly implemented with the least amount of effort and greatest efficiency.

To tackle these challenges, an average matrix B is drawn based on insights obtained from a panel of industry experts. This matrix is then normalised to create a Total Relation Matrix (TRM), which illustrates the cause-and-effect relationships, based on an approach used in prominent research articles. These challenges are then categorised into levels where their rank priority is decided using the Total Relationship Matrix based on DEMATEL methodology. Factors related to FEFO implementation, such as inconsistent stakeholder coordination, technological constraints, and inventory management issues etc. are ranked according to their significance and influence on other challenges.

Issues like P13 may rank highly because they affect several other problems that are ranked lower. It's important to solve operational and technological problems first. This ensures smooth FEFO functioning

Table 3
Average B matrix with interdependencies ranked.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
P1	1	2	2	1	4	0	2	4	2	2	3	2	1
P2	0	1	2	0	4	2	3	4	0	3	2	3	2
P3	4	3	1	4	0	1	3	4	1	0	3	4	2
P4	3	1	3	1	1	3	4	2	1	4	1	4	3
P5	3	3	4	2	1	4	0	1	3	3	3	3	2
P6	3	3	0	1	1	1	1	2	1	0	1	3	4
P7	3	4	3	4	4	1	1	2	0	1	2	0	1
P8	0	1	0	4	1	1	1	1	2	1	0	2	4
P9	3	1	1	1	3	1	4	2	1	0	3	4	3
P10	0	2	3	1	2	1	4	0	0	1	4	4	2
P11	4	2	3	0	3	1	3	0	1	3	1	1	3
P12	3	1	3	4	0	1	1	3	4	0	3	1	4
P13	4	2	0	0	4	2	1	3	4	4	3	1	1

Table 4
Normalised matrix (N).

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
P1	0.03125	0.0625	0.0625	0.03125	0.125	0	0.0625	0.125	0.0625	0.0625	0.09375	0.0625	0.03125
P2	0	0.03125	0.0625	0	0.125	0.0625	0.09375	0.125	0	0.09375	0.0625	0.09375	0.0625
P3	0.125	0.09375	0.03125	0.125	0	0.03125	0.09375	0.125	0.03125	0	0.09375	0.125	0.0625
P4	0.09375	0.03125	0.09375	0.03125	0.03125	0.09375	0.125	0.0625	0.03125	0.125	0.03125	0.125	0.09375
P5	0.09375	0.09375	0.125	0.0625	0.03125	0.125	0	0.03125	0.09375	0.09375	0.09375	0.09375	0.0625
P6	0.09375	0.09375	0	0.03125	0.03125	0.03125	0.03125	0.0625	0.03125	0	0.03125	0.09375	0.125
P7	0.09375	0.125	0.09375	0.125	0.125	0.03125	0.03125	0.0625	0	0.03125	0.0625	0	0.03125
P8	0	0.03125	0	0.125	0.03125	0.03125	0.03125	0.03125	0.0625	0.03125	0	0.0625	0.125
P9	0.09375	0.03125	0.03125	0.03125	0.09375	0.03125	0.125	0.0625	0.03125	0	0.09375	0.125	0.09375
P10	0	0.0625	0.09375	0.03125	0.0625	0.03125	0.125	0	0	0.03125	0.125	0.125	0.0625
P11	0.125	0.0625	0.09375	0	0.09375	0.03125	0.09375	0	0.03125	0.09375	0.03125	0.03125	0.09375
P12	0.09375	0.03125	0.09375	0.125	0	0.03125	0.03125	0.09375	0.125	0	0.09375	0.03125	0.125
P13	0.125	0.0625	0	0	0.125	0.0625	0.03125	0.09375	0.125	0.125	0.09375	0.03125	0.03125

Table 5
Total relation matrix calculated.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
P1	0.3803	0.3545	0.355	0.3024	0.4432	0.2187	0.3653	0.4378	0.3048	0.3221	0.4222	0.4075	0.3884
P2	0.3452	0.3244	0.3469	0.272	0.4331	0.2771	0.3823	0.4316	0.2423	0.3447	0.3863	0.4285	0.4154
P3	0.5209	0.4199	0.358	0.431	0.3714	0.272	0.4408	0.497	0.3091	0.3012	0.4594	0.5081	0.47
P4	0.5085	0.3822	0.4313	0.3532	0.4111	0.34	0.4815	0.445	0.3174	0.4212	0.4265	0.527	0.5103
P5	0.5271	0.45	0.4713	0.3801	0.4231	0.3819	0.3823	0.431	0.3879	0.4039	0.5016	0.5244	0.5021
P6	0.3729	0.3233	0.2252	0.2379	0.3001	0.2037	0.2694	0.329	0.2373	0.2159	0.2972	0.3631	0.4088
P7	0.4484	0.4256	0.3944	0.3923	0.4526	0.2603	0.3463	0.3958	0.2422	0.3097	0.3971	0.3628	0.3913
P8	0.2574	0.2354	0.2024	0.3079	0.2628	0.1915	0.2512	0.2614	0.2428	0.2253	0.2369	0.3109	0.3799
P9	0.4714	0.3429	0.3386	0.3151	0.4383	0.2572	0.434	0.4021	0.2956	0.2762	0.4411	0.4732	0.4639
P10	0.3481	0.348	0.3768	0.2896	0.3684	0.2361	0.4117	0.3068	0.2295	0.2785	0.4402	0.442	0.3975
P11	0.4699	0.3597	0.3815	0.2591	0.4204	0.2415	0.3916	0.322	0.2675	0.3501	0.3684	0.3703	0.4292
P12	0.4828	0.3422	0.3938	0.4063	0.3553	0.2607	0.3699	0.4462	0.3901	0.2864	0.4468	0.4063	0.5094
P13	0.4986	0.3816	0.3178	0.2796	0.4844	0.2954	0.3652	0.433	0.3869	0.4054	0.4596	0.4124	0.4188

Table 6
TRM with row sum and column sum.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	ROW_SUM
P1	0.3803	0.3545	0.355	0.3024	0.4432	0.2187	0.3653	0.4378	0.3048	0.3221	0.4222	0.4075	0.3884	4.7022
P2	0.3452	0.3244	0.3469	0.272	0.4331	0.2771	0.3823	0.4316	0.2423	0.3447	0.3863	0.4285	0.4154	4.6298
P3	0.5209	0.4199	0.358	0.431	0.3714	0.272	0.4408	0.497	0.3091	0.3012	0.4594	0.5081	0.47	5.3588
P4	0.5085	0.3822	0.4313	0.3532	0.4111	0.34	0.4815	0.445	0.3174	0.4212	0.4265	0.527	0.5103	5.5552
P5	0.5271	0.45	0.4713	0.3801	0.4231	0.3819	0.3823	0.431	0.3879	0.4039	0.5016	0.5244	0.5021	5.7667
P6	0.3729	0.3233	0.2252	0.2379	0.3001	0.2037	0.2694	0.329	0.2373	0.2159	0.2972	0.3631	0.4088	3.7838
P7	0.4484	0.4256	0.3944	0.3923	0.4526	0.2603	0.3463	0.3958	0.2422	0.3097	0.3971	0.3628	0.3913	4.8188
P8	0.2574	0.2354	0.2024	0.3079	0.2628	0.1915	0.2512	0.2614	0.2428	0.2253	0.2369	0.3109	0.3799	3.3658
P9	0.4714	0.3429	0.3386	0.3151	0.4383	0.2572	0.434	0.4021	0.2956	0.2762	0.4411	0.4732	0.4639	4.9496
P10	0.3481	0.348	0.3768	0.2896	0.3684	0.2361	0.4117	0.3068	0.2295	0.2785	0.4402	0.442	0.3975	4.4732
P11	0.4699	0.3597	0.3815	0.2591	0.4204	0.2415	0.3916	0.322	0.2675	0.3501	0.3684	0.3703	0.4292	4.6312
P12	0.4828	0.3422	0.3938	0.4063	0.3553	0.2607	0.3699	0.4462	0.3901	0.2864	0.4468	0.4063	0.5094	5.0962
P13	0.4986	0.3816	0.3178	0.2796	0.4844	0.2954	0.3652	0.433	0.3869	0.4054	0.4596	0.4124	0.4188	5.1387
COL_SUM	5.6315	4.6897	4.593	4.2265	5.1642	3.4361	4.8915	5.1387	3.8534	4.1406	5.2833	5.5365	5.685	

Table 7
Adjusted total relation matrix as per alpha threshold.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
P1	-				0.4432			0.4378			0.4222	0.4075	0.3884
P2		-			0.4331		0.3823	0.4316			0.3863	0.4285	0.4154
P3	0.5209	0.4199	-	0.431	0.3714		0.4408	0.497			0.4594	0.5081	0.47
P4	0.5085	0.3822	0.4313	-	0.4111		0.4815	0.445		0.4212	0.4265	0.527	0.5103
P5	0.5271	0.45	0.4713	0.3801	-	0.3819	0.3823	0.431	0.3879	0.4039	0.5016	0.5244	0.5021
P6	0.3729					-							0.4088
P7	0.4484	0.4256	0.3944	0.3923	0.4526		-	0.3958			0.3971		0.3913
P8								-					0.3799
P9	0.4714				0.4383		0.434	0.4021	-		0.4411	0.4732	0.4639
P10			0.3768		0.3684		0.4117			-	0.4402	0.442	0.3975
P11	0.4699		0.3815		0.4204		0.3916				-	0.3703	0.4292
P12	0.4828		0.3938	0.4063			0.3699	0.4462	0.3901		0.4468	-	0.5094
P13	0.4986	0.3816			0.4844			0.433	0.3869	0.4054	0.4596	0.4124	-

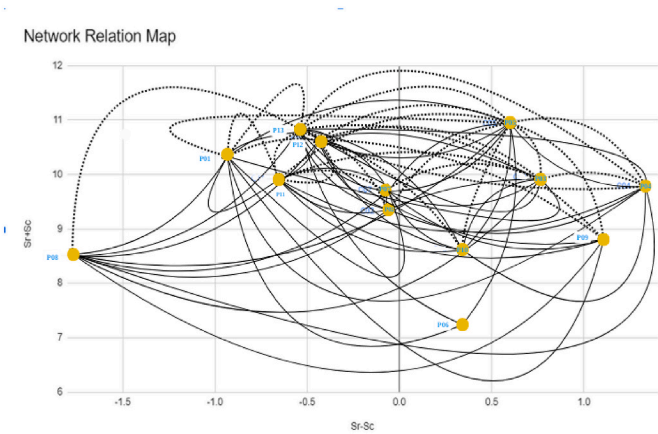

Fig. 3. Network relation map.

before addressing lower-level issues like P10. Supply chain managers can then create a roadmap that concentrates on resolving the most important obstacles first by breaking these issues down into tiers, which will make the FEFO method implementation easier. This is done via the Level Partitioning Chart made using the TRM. Table 8 shows the level partitioning matrix which describes how the challenges are being influenced and are getting influences by other challenges.

The challenges, after performing a level partitioning procedure, are separated into seven levels. At top there is Consumer Behaviour (P8), Data Accuracy and Reliability (P11) and Technological Requirements for Inventory and Expiration Date Tracking (P13). These challenges at the top-level show that they are the least influential on other challenges, but they are influenced the most by other challenges (Fig. 4). Table A1 explains the interrelationship between the barriers after level partitioning. The lack of access to technology for real-time, efficient monitoring of inventory and expiry date tracking is one of the key challenges holding back implementation of FEFO in PFSCs.

This, combined with the challenge of consumer behaviour and data accuracy illustrates that P8, P11 and P13 are not the crucial pivotal challenges, but they are the challenges influenced by the highest number of factors. P13 is influenced by every other 12 challenges identified in the model, inferring that finding solutions for the other challenges would help solve the challenges posed by barrier P13. In Level 1 challenges, consumer behaviour comes next (P8). P8 is influenced by every other challenge except P6. Similarly, P11 is influenced by every factor apart from P6 and P8 - implying that solving these challenges will automatically resolve the barriers at the topmost level of the level partitioning chart.

At the second level, high cost of implementing FEFO (P1) is the only challenge, and it highlights how cost influences various factors such as P8, P9, P11, P12, P13 etc. while also being influenced by factors such as P3, P4, P5, P6 etc. To solve issues on this layer, cost optimization needs to be carried out by resolving the factors that influence cost - hence offering partial solutions to factors being influenced by cost such as P13.

The third level includes challenges such as seasonal availability and supply variation (P6) and consumer demand fluctuations (P7). Level 3 challenges are based on the basic stumbling block of demand and supply variability. As the perishable food industry is a dynamic and time-sensitive market, demand and supply inevitably fluctuates - with certain products only available in certain seasons and demand also depending on time periods and conditions. So, these challenges are influenced by other factors like inventory rotation (P4), storage management (P5) etc. Solving these challenges by accounting for seasonal variability and shifts in supply and demand can also influence challenges in the previous layers.

The fourth level comprises roadblocks like regulatory compliance and training (P9) and system maintenance (P12). This layer addresses the issue of permanence and maintenance necessary for implementing FEFO. As inventory control in FEFO is much more complex due to integration of time dependent processes and expiration date tracking, maintaining these systems for a long duration also poses a substantial challenge and as new employees are not familiar with the workflow and FEFO method, once experienced employees leave or are no longer available, the system can crumble and decay over time. To solve this issue, regular training and development of standardised workflows is necessary along with periodic maintenance and checking. The challenges on this layer are influenced by factors like P2, P11 and P13.

The challenges in the fifth layer are Management of Suppliers for Effective FEFO Implementation (P2) and Challenges in Effective Storage Management for FEFO (P5). These challenges are related to the issues faced in managing the supply chain and complexity of inventory control, expiry date tracking and maintaining clear communication lines across all layers of the SC. These are some of the fundamental challenges that need to be solved before FEFO can be implemented with optimal efficiency. They are also influenced by other challenges such as P3, P4, P5, P7, P9, P10, P11 and P13 showing their complex interdependence on other factors. Integration of real time data monitoring systems, IoT and Blockchain are possible solutions for the challenges in this layer.

The sixth layer is made up of challenges such as Integration of FEFO in existing systems (P3) and inventory rotation (P4). These challenges illustrate the difficulties faced while shifting from one inventory management system to another as well as issues faced in inventory rotation in the FEFO system, especially with limited storage space. A major shift in company policy, working methodology, standards etc. needs to take place if FEFO is to be successfully implemented. This can be extremely challenging for businesses with established methods and traditions and requires a lot of time and resource investment. Possible solutions might be to shift focus to FEFO on a project by project basis while adopting it as

Table 8
Level partitioning matrix with final iteration.

Challenges	Influencing	Influenced By	Intersection Set	Levels
P1	P1, P5, P8, P11, P12, P13	P1, P3, P4, P5, P6, P7, P9, P11, P12, P13	P1, P5, P11, P12, P13	2
P2	P2, P5, P7, P8, P11, P12, P13	P2, P3, P4, P5, P7, P13	P2, P5, P7, P13	5
P3	P1, P2, P3, P4, P5, P7, P8, P11, P12, P13	P3, P4, P5, P7, P10, P11, P12	P3, P4, P5, P7, P11, P12	6
P4	P1, P2, P3, P4, P5, P7, P8, P10, P11, P12, P13	P3, P4, P5, P7, P12	P3, P4, P5, P7, P12	6
P5	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13	P1, P2, P3, P4, P5, P7, P9, P10, P11, P13	P1, P2, P3, P4, P5, P7, P9, P10, P11, P13	5
P6	P1, P6, P13	P5, P6	P6	3
P7	P1, P2, P3, P4, P5, P7, P8, P11, P13	P2, P3, P4, P5, P7, P9, P10, P11, P12	P2, P3, P4, P5, P7, P11	3
P8	P8, P13	P1, P2, P3, P4, P5, P7, P8, P9, P12, P13	P8, P13	1
P9	P1, P5, P7, P8, P9, P11, P12, P13	P5, P9, P12, P13	P5, P9, P12, P13	4
P10	P3, P5, P7, P10, P11, P12, P13	P4, P5, P10, P13	P5, P10, P13	7
P11	P1, P3, P5, P7, P11, P12, P13	P1, P2, P3, P4, P5, P7, P9, P10, P11, P12, P13	P1, P3, P5, P7, P11, P12, P13	1
P12	P1, P3, P4, P7, P8, P9, P11, P12, P13	P1, P2, P3, P4, P5, P9, P10, P11, P12, P13	P1, P3, P4, P9, P11, P12, P13	4
P13	P1, P2, P5, P8, P9, P10, P11, P12, P13	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13	P1, P2, P5, P8, P9, P10, P11, P12, P13	1

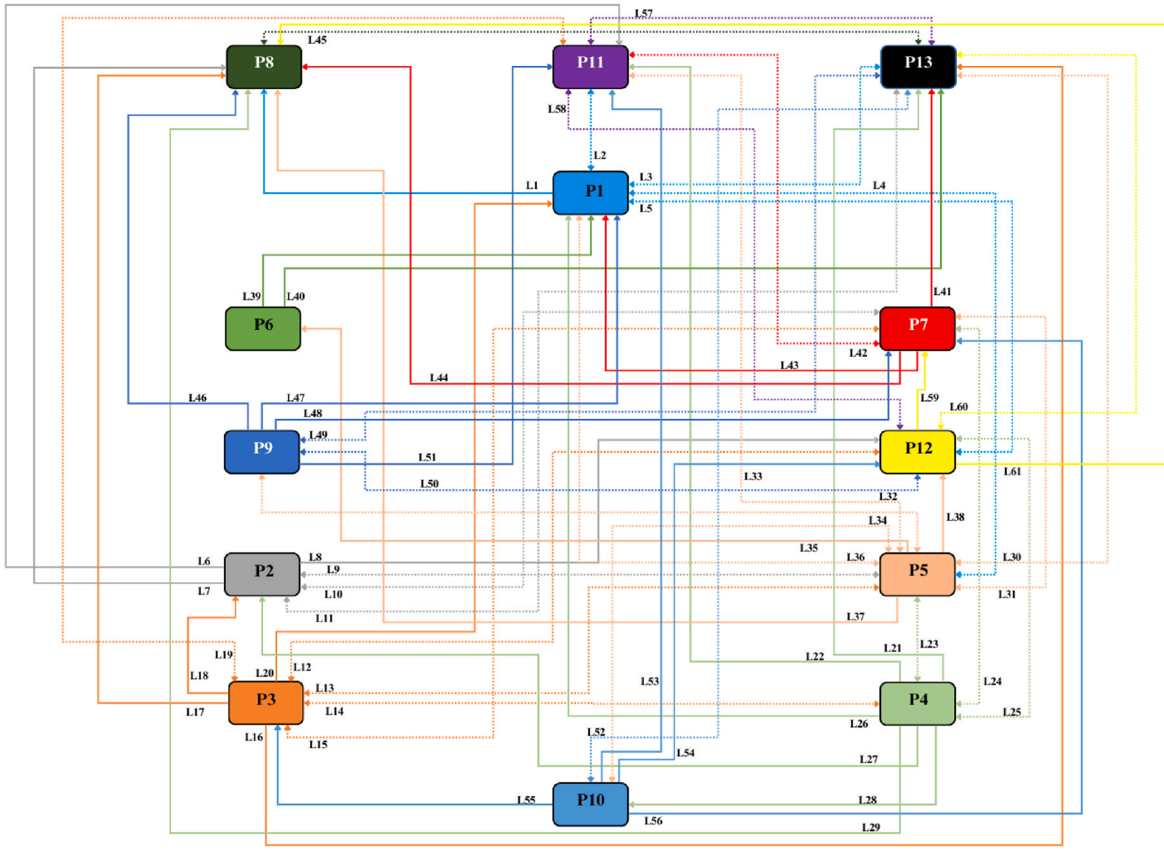

Fig. 4. Level partitioning chart.

the standard model of inventory control for future products or shipments. These challenges are influenced by challenges like P5, P7 and P12. They also influence a majority of challenges such as P1, P2, P5 P7, P8, P10, P11, P12 and P13 thus showcasing their importance and how their resolution can help solve the other challenges.

The seventh and final layer has only one challenge i.e. operational efficiency (P10). Managing inventory based on expiration dates can sometimes conflict with other operational efficiencies, such as minimising handling time or optimizing storage space. This can lead to increased labour costs and reduced overall efficiency. This is a key challenge as it directly conflicts with the core mandate of the FEFO method and hence is influenced by very few factors like P4, P5 and P13. On the other hand, it influences other factors like P4, P5, P7, P11, P12 and P13. Improving operational efficiency while sticking to the core concept of FEFO by eliminating waste and resource allocation to other non-critical areas is one of the possible ways in which this challenge can be resolved. The influence of factors and their levels of interdependence are shown in Fig. 4.

5. Implications

5.1. Theoretical implications

The FEFO method is gaining traction in the PFSC industry because of its potential for food safety and minimising waste. This study offers insight into the challenges and the way they are interconnected during the implementation of FEFO in a dynamic and time-sensitive industry like perishable foods. Through this research, the observation and analysis of complex roadblocks to integrating FEFO in the supply chain is done and a framework for implementing time sensitive processes in the SC is laid out.

This paper identifies and prioritises critical challenges such as technological readiness, accuracy of expiration tracking systems, and the need for seamless communication across the SC. Building an efficient FEFO system that enhances product quality, reduces wastage and increases customer satisfaction is highly dependent on factors such as seamless communication, technological readiness and accurate inventory control. Moreover, the research highlights the importance of transparency and open communications at all layers of supply chain and real-time data sharing, which allows easy integration of real time data monitoring systems in applications such as inventory tracking and control.

This research also offers a base from which future studies into supply chain management can be carried out by using MCDM techniques like TISM and DEMATEL. By focusing on real time monitoring and data integration, this research increases the understanding on topics like inventory management and the logistics of time-sensitive products. It introduces an improved understanding of the interaction between information flow, product life cycle, and decision-making processes in inventory management. It also delves into how 'soft' problems like consumer behaviour, shelf stocking etc. can impact the implementation of FEFO.

The findings also highlight the role of communication and cooperation between supply chain partners in reducing inefficiencies and preventing bullwhip effect. FEFO allows fast moving flow of goods and information and also increases the efficiency of the PFSC, hence acting as a tool for optimizing the supply chain operations.

5.2. Practical implications

The FEFO approach has a direct impact on operating efficiency, waste reduction, and product quality, all of which present substantial hurdles to implementation of FEFO. However, this strategy provides enormous benefits to both enterprises and consumers. The core directive of FEFO is that near-expiry products be sold or consumed first, preventing the delivery of expired stock and useless inventory, resulting in less waste. This is consistent with the growing need for sustainability in both commercial and individual contexts, as defined by the Sustainable Development Goals (SDGs). Waste reduction and improved product quality are the core benefits offered by the FEFO approach.

FEFO implementation requires real-time tracking systems capable of monitoring product expiration dates and inventory levels. Using IoT, barcodes, RFID tagging etc. are some of the main ways with which ensuring perishable items are accurately tracked from the moment they enter the warehouse until they reach the consumer are done. Integrating these technologies into the FEFO system also comes with logistical challenges such as revamping current inventory control methods, high technological requirements, complex inventory tracking etc. but offers significant benefits in the form of improved inventory turnover, product quality, efficiency, reduced wastage etc. This paper lays the framework from where future research on solutions can be conducted for adopting FEFO in the PFSC.

Just like any inventory and supply chain control system, FEFO relies on smooth flow of materials and information across all strata of the supply chain. Collaboration and transparency are some of the key pillars on which a well implemented and efficient FEFO system is built. Clear communication regarding product expiry date, shelf life and stock levels allows movement of inventory in an efficient manner through the supply chain, minimising the risk of spoilage. Other challenges such as reconfiguring warehouse and retail operations to shift from current methodology (FIFO) to proposed methodology (FEFO) is necessary. This might mean changing storage conditions, conventions, stock rotation, staff training methods as well as supply chain management.

Implementing FEFO not only benefits consumers and people due to its sustainability but also helps business and companies as it allows reduced waste-related and spoilt inventory costs and boosts consumer satisfaction. Consumers get the satisfaction of getting fresher products, while companies gain a competitive advantage by minimising waste, increasing profits in the long term and enhancing their reputation and brand identity by conforming to health and safety standards while simultaneously boosting the sustainability of their operations. Moreover, FEFO supports sustainability goals SDG 9, 11 and 12 by directly addressing food waste, conforming business practices with the initiative to promote sustainable consumption and production.

By adopting the FEFO method, businesses can optimize their supply chains, ensuring that perishable goods are available as needed and are in optimal condition with minimal spoilage. This makes FEFO a more consumer-centric supply chain model that benefits both the business and the consumer.

This article focuses on the implementation of the FEFO approach in PFSC, outlining and discussing 13 significant difficulties based on a thorough literature assessment and input from industry specialists. FEFO is a strategy that offers significant advantages over traditional approaches, such as FIFO and LIFO, by taking expiration dates into account while dispatching; it eliminates health concerns and food waste. However, FEFO faces substantial implementation obstacles, including technological limits such as the requirement for enhanced tracking systems as well as issues with efficient collaboration among many parties. To solve these hurdles, the research used the DEMATEL technique, which results in a relational diagram that depicts the causal linkages between the obstacles.

According to the report, the most major problem is proper storage management, which is driven by a variety of interconnected elements such as inventory tracking technology requirements. By categorizing these barriers hierarchically, this study provides stakeholders with a methodical framework for directing efforts ranging from critical technological investments to synergistic improvements throughout the SC. These findings highlight the importance of balancing FEFO implementation tactics with technology requirements, interdisciplinary collaboration, and sustainability. Building off of this research, a more thorough analysis would include engaging a greater, more diverse panel of industry experts, optimizing FEFO to include identification of industry specific changes, and an alternative approach that has manageable barriers or greater efficiency. This thesis offers PFSC managers a systematic guide that allows them to adopt the FEFO method to increase sustainability and efficiency while reducing waste.

6. Conclusions

The FIFO method is usually used for inventory rotation and control in PFSCs but it is insufficient for management of perishable goods because of its challenges such as imprecise tracking of spoilt goods and wastage. This not only increases spoilage but also increases the hazards associated with consumer health and regulatory compliance. Cases such as spoilage, food poisoning, health risks etc. are a cause for concern. Relying on FIFO, businesses face challenges such as loss of inventory, inefficiency and higher overhead costs thus impacting profitability and undermining supply chain sustainability. These limitations can be addressed by shifting to a new inventory management system such as FEFO which promises better results for PFSCs. This study identified two main research objectives which are identification and analysis of key challenges blockading implementation of FEFO and analysing interdependencies between these factors. This study adhered to strict methodology and proper scientific method. The literature review was conducted according to the PRISMA technique, and a panel of experts were consulted before the challenges could be rated. MCDM techniques such as DEMATEL and TISM were used to analyse and rate the 13 key challenges identified that prevent implementation of FEFO in PFSC. Causal dependencies between the factors were identified and influence of one factor on another was documented. DEMATEL was used to facilitate the identification of the challenges while TISM was used to form the causal diagram from which Network Relationship Map and Level Partitioning Chart were created that visually depicted correlation between challenges and level of influence. This structured approach allowed for the identification of key challenges such as effective storage management, high cost of implementing FEFO, consumer behaviour, technological dependence etc. The results identified that the most critical challenge was Effective Storage Management and tracking of expiry dates with an alpha threshold value of 0.368. This finding aligns with the FEFO methodology as proper storage and expiration date tracking is the core component for FEFO implementation. The findings from this study successfully aligned with the research objectives as a fair and accurate assessment of the key challenges was conducted and their interdependencies were calculated. This study builds on previous research conducted on general inventory strategies for perishable food items. Unlike current literature which focused on the FIFO approach or proposed theoretical frameworks, this research delves into the specifics of the FEFO method and proactively aims to identify challenges faced while implementing FEFO. Practical considerations such as consumer behaviour and difficulties in expiration date tracking were also considered and correlation between factors was identified allowing for smoother implementation of FEFO in PFSC in the future. The implications of this research extend beyond PFSCs and are relevant to a variety of industries that require stringent inventory management. The study's insights are particularly useful for pharmaceuticals, healthcare, and retail sectors where product freshness and regulatory compliance are critical. Additionally, logistics providers, cold storage facilities, and distributors can benefit from adopting the FEFO framework to minimize waste, increase product quality, and improve overall supply chain efficiency. By focusing on core elements such as data accuracy and storage optimization, this study can serve as a blueprint for other industries managing perishable inventory, thereby contributing to broader sustainability and waste reduction goals as well as target SDG 1 (No Poverty), SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production). While the study presents valuable insights, it has some limitations. This study is primarily theoretical, with no practical implementation or pilot testing of the proposed FEFO roadmap. Consequently, while the recommendations are grounded in thorough analysis, real-world testing is required to validate the proposed model's effectiveness. Furthermore, the study does not extensively explore emerging technologies like IoT, AI, or blockchain, which could provide dynamic solutions to challenges in data accuracy and inventory tracking. Future research should focus on testing the proposed roadmap in actual supply chain settings to assess its practicality and effectiveness. Pilot programs in sectors such as food retail or pharmaceuticals could yield valuable insights and highlight additional challenges or considerations. Future studies might also explore the scalability of FEFO practices for large organizations, as well as the potential integration of automated sorting systems to streamline inventory management in highly complex supply chains.

CRediT authorship contribution statement

Jayakrishna Kandasamy: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **K.E.K. Vimal:** Writing – original draft, Visualization, Validation, Investigation, Formal analysis, Data curation. **Aditya Pratap Singh:** Writing – original draft, Formal analysis, Data curation. **Aaryan Magnani:** Writing – original draft, Investigation, Formal analysis, Data curation. **Ameya Gokhale:** Writing – original draft, Investigation, Formal analysis, Data curation. **Sandeep Jagtap:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Annexure.

Table A1
Inference from level partitioning chart for each causal linkage

ID	Description
I1	High costs in implementing FEFO are responsible for inconsistent demand from consumers.
I2	High costs in implementing FEFO affect data accuracy and reliability.
I3	High costs in implementing FEFO are affected due to the need for advanced technology required for inventory and expiration date tracking.
I4	High costs in implementing FEFO can arise from the need for specialized storage systems.
I5	High costs in implementing FEFO are amplified by the ongoing expenses of system maintenance.
I6	Ineffective supplier management results in inaccurate data and reliability.
I7	Ineffective supplier management is responsible for inconsistent demand from customers.
I8	Ineffective supplier management leads to disruptions in system maintenance.
I9	Ineffective supplier management affects the storage management for FEFO.
I10	The management of suppliers for effective FEFO implementation is interrelated with consumer demand fluctuations.
I11	The management of suppliers for effective FEFO implementation leads to difficulties in required technological advancements in Inventory and Expiration Date tracking.
I12	Integration of FEFO in existing system impedes effective storage management.
I13	Integration of FEFO in existing systems is crucial for system maintenance.
I14	Inventory rotation relies upon Integration of FEFO in existing systems.
I15	Consumer demand fluctuations challenge the integration of FEFO in existing systems.
I16	Technological requirements for Inventory and Expiration Date tracking are essential for enabling integration of FEFO in existing systems.
I17	Understanding consumer behaviour is essential for integration of FEFO in existing systems.
I18	Management of suppliers for effective FEFO is vital for ensuring the integration of FEFO in existing systems.
I19	Data accuracy and reliability are crucial for integration of FEFO in existing systems.
I20	High costs in implementing FEFO hinder the integration of FEFO in existing systems.
I21	Effective inventory relies on advanced tracking systems for inventory and expiry dates.
I22	Data accuracy and reliability are essential for inventory rotation.
I23	Inventory rotation benefits effective storage management for FEFO.
I24	Consumer demand fluctuations impact inventory rotation.
I25	System maintenance is essential for inventory rotation.
I26	Inventory rotation elevates the costs in implementing FEFO.
I27	Management of suppliers for effective FEFO implementation influences inventory rotation.
I28	Inventory rotation enhances operational efficiency.
I29	Consumer behavioural patterns help optimize inventory rotations.
I30	Challenges in effective storage management lead to high costs in implementing FEFO.
I31	Consumer demand fluctuations lead to challenges in effective storage management.
I32	Unreliable and inaccurate data leads to challenges in effective storage management.
I33	Challenges in effective storage management for FEFO lead to noncompliance with regulations.
I34	Challenges in effective storage management affect operational efficiency.
I35	Seasonal availability and supply variations complicate effective storage management.
I36	Effective storage management elevates the high costs in implementing FEFO.
I37	Consumer behaviour and purchasing patterns affect storage management.
I38	Improper system maintenance hinders the ability to have effective storage management.
I39	Seasonal availability and supply variation lead to increased expenses in implementing FEFO.
I40	Advanced technology for inventory and expiration date tracking is essential for managing seasonal availability and supply variation.
I41	Accurate tracking technologies are crucial for adapting to changing demand patterns.
I42	Precise and trustworthy data is essential for predicting demand patterns.
I43	Unpredictable demand can lead to overstocking or stockouts.
I44	Consumer demand fluctuations are interrelated with consumer behaviour.
I45	Understanding consumer preferences and purchasing patterns can drive the need for advanced tracking systems.

(*continued on next page*)

Table A1 (*continued*)

ID	Description
I46	Understanding consumer preferences and expectations can inform compliance strategies.
I47	Adhering to regulations often requires significant investments in staff training and technology.
I48	Changes in consumer preferences may necessitate updates to compliance standards.
I49	Compliance standards often dictate the need for specific tracking technologies.
I50	Regular upkeep of inventory management systems is essential to ensure they function correctly and meet compliance standards.
I51	Data accuracy and reliability are important for regular compliance and training.
I52	Advanced tracking technologies streamline inventory management processes while reducing manual errors.
I53	Accurate and reliable data is essential for operational efficiency.
I54	Regular maintenance of systems ensures they function optimally and reduces downtime.
I55	Effectively incorporating FEFO practices into current workflows enhances inventory management processes.
I56	Effectively responding to changes in demand requires streamlined operations that can adapt quickly, ensuring that inventory levels align with consumer needs.
I57	Advanced tracking technologies are essential for capturing precise and accurate data.
I58	Regular maintenance of data management systems is essential to ensure that data remains accurate and reliable.
I59	Maintaining inventory management systems is crucial for adapting to changing demand patterns.
I60	Ongoing maintenance of tracking systems is essential to ensure they operate effectively.
I61	Regular upkeep of systems is vital for preventing errors, ensuring that data is correctly processed and stored.

Table A2
Causal matrix

Notation	Challenges	Sr	Sc	Sr-Sc	Sr + Sc	Cause/Effect	Ranking
P1	P1	4.7022	5.6315	−0.9293	10.3337	Effect	4
P2	P2	4.6298	4.6897	−0.0599	9.3195	Effect	9
P3	P3	5.3588	4.593	0.7658	9.9518	Cause	5
P4	P4	5.5552	4.2265	1.3287	9.7817	Cause	7
P5	P5	5.7667	5.1642	0.6025	10.9309	Cause	1
P6	P6	3.7838	3.4361	0.3477	7.2199	Cause	13
P7	P7	4.8188	4.8915	−0.0727	9.7103	Effect	8
P8	P8	3.3658	5.1387	−1.7729	8.5045	Effect	12
P9	P9	4.9496	3.8534	1.0962	8.803	Cause	10
P10	P10	4.4732	4.1406	0.3326	8.6138	Cause	11
P11	P11	4.6312	5.2833	−0.6521	9.9145	Effect	6
P12	P12	5.0962	5.5365	−0.4403	10.6327	Effect	3
P13	P13	5.1387	5.685	−0.5463	10.8237	Effect	2

Table A3
Expert 1 Matrix

	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13
C01	1	1	0	0	3	2	3	2	3	1	3	0	2
C02	1	1	3	1	4	4	1	4	2	1	1	3	2
C03	3	2	1	1	3	3	2	4	0	3	2	2	2
C04	3	2	0	1	2	4	4	4	3	1	2	3	1
C05	1	1	3	3	1	3	3	0	4	1	0	3	1
C06	3	3	1	4	4	1	2	3	4	0	3	2	1
C07	1	2	1	4	0	0	1	3	3	1	1	2	2
C08	3	3	3	1	0	0	2	1	3	2	4	3	0
C09	3	1	2	3	3	2	2	3	1	2	3	0	1
C10	0	1	3	2	1	4	3	3	4	1	0	0	3
C11	1	3	4	4	4	2	2	0	2	1	1	3	4
C12	0	3	1	2	1	2	4	1	4	3	1	1	2
C13	3	1	1	1	1	2	1	3	1	1	4	2	1

Table A4
Expert 2 Matrix

	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13
C01	1	1	3	4	3	3	0	2	1	2	4	3	0
C02	1	1	4	2	4	2	4	1	3	1	2	1	0
C03	1	0	1	3	4	4	3	0	4	2	0	0	2
C04	3	0	3	1	0	1	0	3	0	0	3	0	2
C05	2	4	0	3	1	2	2	2	2	0	1	4	2
C06	4	0	1	2	0	1	1	1	0	1	0	3	1
C07	2	2	4	4	3	2	1	2	0	2	4	2	2
C08	1	4	0	1	4	2	4	1	3	1	0	1	3
C09	1	1	4	2	4	4	0	2	1	1	0	1	1

(*continued on next page*)

Table A4 (*continued*)

	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13
C10	2	3	2	3	1	1	0	4	1	1	1	4	2
C11	2	4	1	4	1	4	4	4	4	1	1	3	1
C12	3	3	2	4	1	2	3	3	1	4	0	1	2
C13	3	4	2	3	4	0	0	3	3	0	2	1	1

Table A5
Expert 3 Matrix

	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13
C01	1	3	1	4	3	4	0	2	3	2	2	3	2
C02	3	1	2	4	0	1	4	0	2	0	4	1	0
C03	3	0	1	0	0	1	1	4	4	1	0	3	1
C04	0	3	4	1	3	1	1	4	3	1	3	2	1
C05	4	4	4	4	1	4	4	1	1	2	2	4	4
C06	2	1	4	1	2	1	3	4	2	4	0	0	4
C07	0	0	0	2	3	0	1	1	2	1	2	4	2
C08	2	3	1	4	4	4	4	1	2	0	4	1	4
C09	3	4	4	0	3	0	4	1	1	1	0	4	1
C10	0	1	4	1	2	0	4	0	2	1	2	3	1
C11	1	2	0	0	0	4	3	3	3	1	1	2	3
C12	2	4	3	4	2	2	0	3	0	4	4	1	2
C13	3	2	3	2	1	3	2	2	1	3	1	3	1

Table A6
Expert 4 Matrix

	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13
C01	1	3	2	2	4	2	3	4	1	3	0	3	4
C02	2	1	0	2	2	0	4	2	2	1	4	0	1
C03	0	2	1	1	4	4	2	1	3	1	3	3	1
C04	1	4	3	1	2	1	3	1	0	4	0	4	0
C05	2	1	0	1	1	4	4	3	2	0	4	4	1
C06	4	3	1	0	2	1	4	4	4	4	0	0	2
C07	3	2	0	0	4	4	1	3	4	0	2	1	3
C08	2	3	3	1	3	1	4	1	3	4	4	2	1
C09	0	2	4	4	3	3	2	3	1	1	1	2	0
C10	4	2	1	2	0	1	0	2	0	1	4	2	0
C11	4	2	0	0	3	3	4	3	2	0	1	1	0
C12	0	0	4	1	3	3	0	0	1	3	3	1	0
C13	3	1	3	2	0	4	1	4	1	2	1	2	1

Table A7
Expert 5 Matrix

	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13
C01	1	2	0	4	1	1	0	0	2	1	4	1	4
C02	3	1	3	2	1	3	1	1	2	2	2	0	4
C03	0	1	1	3	0	4	3	3	0	2	4	4	4
C04	1	2	1	1	3	0	1	0	3	3	0	1	1
C05	3	3	2	0	1	2	0	3	2	4	4	2	4
C06	3	1	2	3	0	1	2	2	0	3	0	1	2
C07	1	1	3	3	4	4	1	3	2	4	3	3	3
C08	0	0	0	2	4	3	1	1	4	0	0	1	2
C09	3	1	4	4	1	0	3	1	1	4	1	3	4
C10	2	3	4	1	1	3	2	2	3	1	3	2	3
C11	0	1	2	4	2	2	3	2	0	4	1	4	0
C12	4	1	2	1	3	2	1	0	2	3	0	1	0
C13	1	2	0	0	2	0	4	3	1	4	2	3	1

Data availability

Data will be made available on request.

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