A Hybrid MCDM Framework for Resilient Food Supply Chain Optimization at Mega Events: Challenges, Insights, and a Strategic Roadmap

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Abstract

Purpose : This study aims to optimize food supply chain management at Mahakumbh, one of the largest religious gatherings in the world, by identifying and prioritizing the challenges faced in this complex logistical environment. By employing a combination of the Delphi technique, Pythagorean Fuzzy AHP, and empirical validation, the research aims to provide actionable insights for stakeholders involved in food supply management during mega-events.

Design/Methodology/Approach : A mixed-methods research design was employed, initially using the Delphi technique to solicit the experts' opinions regarding the issues in the food supply chain management. Then, the Pythagorean Fuzzy AHP technique employed a series of 13 post-graduate qualified suppliers as input in ranking the issues. Empirical validation was then carried out using the snowball and purposive sampling methods with the aid of 140 respondents to collect more general opinions among the attendees at the Mahakumbh.

Findings : The results indicated a consensus across the top problems, the most significant being the effective transport and storage of food (C4), followed by making the practices more sustainable (C6) and the reduction of food waste (C5). This ranking reflects the logistical challenges inherent in managing the food supply chain for big events when the large numbers attending the event mean that very detailed planning and control are needed. Solving these problems will be a key requirement for the success of the Mahakumbh and the health and welfare of the tens of thousands of pilgrims who participate in this important religious festival.

Research Limitation/Implications : The study's emphasis on post-graduate responses limits it and might not fairly represent the opinions of all the participants engaged in food supply management for the event. Furthermore, depending too much on professional judgments might bring prejudice. Future studies should use a more varied sample to reflect a greater spectrum of viewpoints and experiences.

Originality : This study adds knowledge to the body of literature on mega-events food supply chain management by integrating innovative methods such as Pythagorean Fuzzy AHP with empirical proof, providing a systematic model for comprehending and responding to the peculiar challenges faced by the food supply chain in major religious events.

Keywords: Food Supply Chain Management; Mega Events; Challenges; Delphi Technique; Pythagorean Fuzzy AHP

Introduction

The Kumbh Mela, also known as the Mahakumbh, is among the world's largest and most complex religious festivals, with tens of millions of pilgrims converging on the destination over a few weeks (Gautam et al., 2021; Kanaujiya & Tiwari, 2022; Vanumu et al., 2020). The large population creates a unique logistical difficulty mainly related to the supply chain management for food and other basic goods. The importance of the event calls for a strong and effective food supply chain able to meet the wide needs and different dietary requirements of a diversified populace. Generally speaking, the current infrastructure for food supplies is not enough to satisfy the needs related with such big gatherings. Serving millions of pilgrims during the Mahakumbh, the food supply chain management is naturally difficult. A major percentage of which are perishable, the logistical issues include procurement, storage, transportation, and distribution of big amounts of food goods (Akbari et al., 2023; Oliveira et al., 2022; Permata & Sari, 2023). Accurate prediction and efficient resource allocation depend greatly on the fluctuations in demand throughout the course of the event. Roads, warehouses, and sanitation facilities make up the current infrastructure, which is usually not suited to handle the sudden population increase and the consequent sanitary needs (Deng, 2023; Kanaujiya & Tiwari, 2022; Verma et al., 2019). These choke points seriously jeopardize public health by causing shortages of food supply, higher waste, and compromises in food safety.

The welfare of the pilgrims depends on effective food distribution during the Mahakumbh to lower food waste and maintain food safety precautions (Ab Abdullah et al., 2021; Bhat et al., 2021; Kaur et al., 2022). Pilgrim dietary needs from many cultures and faiths must be satisfied, hence a flexible and responsive supply chain is required to offer a wide range of consumables to suit this need. Given the size of the event and the environmental and financial impact of food waste, reducing it is very vital. Handling wastage properly is necessary to avert the spread of sickness and create a clean environment for millions of tourists. Optimization of the food supply chain at the Mahakumbh is thus of prime importance not only to deliver a smooth success of the event but also to enhance efficiency, avert wastage, and uphold the precepts of sustainability. This research addresses this imperative of the highest order by determining the most critical challenges in managing the Mahakumbh food supply chain, analyzing innovative solutions from the existing literature on supply chain management and sustainable principles, and proposing a strategic framework for future events. Key research questions include:

RQ1: What are the primary challenges in managing the food supply chain at Mahakumbh?

RQ2: What innovative solutions can be implemented to improve efficiency, reduce waste, and enhance sustainability?

RQ3: What is a comprehensive strategic roadmap for optimizing food supply chain management at future Mahakumbh Melas?

This research will contribute valuable insights to the academic body of work on large-scale food supply chain management and the practical improvement of provisioning food at events of this size. As the food supply chain of Mahakumbh is such a challenge and opportunity, research on its optimization is vital. This research aims to analyze the existing food supply chain of Mahakumbh, identifying the key challenges and proposing innovative ways of making it more efficient, robust, and sustainable. The findings will inform deep insights into food supply chain management at mega-events, influencing the development of best practices and strategies for food security and preventing food wastage. The broader relevance of this study lies in large event logistics and planning and establishing better food security arrangements for varied contexts, focusing mainly on developing countries.

Theoretical Background

With over 663 million pilgrims expected to attend the festival, the Mahakumbh 2025 presented formidable hurdles. Important concerns covered extreme infrastructure neglect, crowd control, sanitation, and government. Even with pre-event preparations, the sheer number of people overloaded facilities, resulting in stampedes, packed transit hubs, and sanitary problems included untreated garbage and tainted water. Although advanced technology like drones and artificial intelligence-driven crowd surveillance were used, they were unable to stop critical bottlenecks and anarchy at strategic sites. To make matters worse were inadequate shelters, bad signs, and minimal medical assistance. Governance shortcomings such as VIP treatment being given more importance than public welfare and delayed crisis responses highlighted administrative inefficiencies even more. Along with claiming lives, these challenges compromised India's worldwide reputation (Rai, 2025b; Bisht, 2025; Singh, 2025). Mega-scale events, particularly religious ones like the Mahakumbh, have challenging supply chain management but perhaps rich implications. This literature review attempts to address the state of the art of research on food supply chain management for mega-events and religious gatherings to assess the issues, solutions suggested, and areas of future possibilities.

Managing food supplies for mega-events like religious celebrations like the Mahakumbh is a somewhat difficult chore. Getz (2005) underlines the short-term and erratic demand patterns of such events, therefore stressing the distinctiveness of event logistics. Regarding the Mahakumbh, with millions of people flocking temporarily, these difficulties are much more pronounced. Emphasizing catering to various dietary demands and food preferences and guaranteeing food quality and safety, Raj and Vignali (2010) underline the difficulty of religious festival food supply chain management. Their research of the Kumbh Mela of India reveals the difficult preparation required to accommodate millions of guests with different dietary requirements over a limited period of time. One of the more crucial problems with food supply chain management in mega-events is exact demand forecasts. Cudny (2016) underlines how difficult it is to predict attendance and consumption levels, which may lead to shortages or waste of extra food. It is especially relevant during the Mahakumbh, when participants rely on lucky times and weather. Roche (2000) further underlines the logistical difficulties of food distribution, storage, and transportation across large amounts over usually undeveloped or makeshift infrastructure. Strict standards for food safety practices just exacerbate these difficulties, as Chappelet and Parent (2015) noted in their analysis of mega-event planning.

Scholars and practitioners have proposed solutions and best practices for resolving mega-events food supply chain management. Some suggest implementing sustainable practices in event management, including sourcing seasonal food and local food to reduce transport and environmental costs (Mair & Whitford, 2013). The solution not only overcomes logistical challenges but also satisfies the increasing trend towards sustainability in event management; for religious events such as the Mahakumbh, indigenous food distribution channels with new supply chain technologies are recommended by Shinde (2018) for greater efficiency and authenticity. State-of-the-art technologies in managing the food supply chain are also cited as the solution to most issues. Tum et al. (2006) analyze information systems and data analysis as applied to event logistics, noting their potential to improve demand forecasting and inventory management. Cooperation and partnership are critical factors in mega-events effective food supply chain management. Successful relationships between the organizers of events, local authorities, and food suppliers must be ensured by Jones (2018) to enable smooth flow and rapid reaction to unforeseen events.

Some of the most important areas of focus towards improving food supply chain management of mega-events, such as the Mahakumbh, have been recognized in the future. Sustainability remains on the agenda, with authors like Getz and Page (2016) recommending a more systematic approach to event management with long-term social and environmental considerations in mind. It involves minimizing the wastage of food, locally sourcing it, and minimizing packaging in food supply chains. Concerning religious events, Shinde and Rizello (2014) propose the creation of end-use-focused specialist supply chain structures with due consideration to the religious and cultural background of food consumption so as not to sacrifice efficiency in terms of tradition and religious expression. New generations of innovative technologies and data-driven decision-making will become increasingly important in future event food supply chain management. According to Bowdin et al. (2012), more significant deployment of machine learning and artificial intelligence programs towards optimizing supply chain operations, ranging from forecasting demand to real-time inventory management, can intervene in such events as periodic ones such as the Mahakumbh, where aggregating historical data and analysis can become very relevant to planning and operations. Lockstone-Binney et al. (2016) also propose the potential of mobile technologies and social media as modes of improving communication and coordination among the stakeholders of an event's supply chain.

For the enormous number of over 663 million pilgrims, the Mahakumbh 2025 used numerous cutting-edge technologies to properly manage garbage. Developed by ISRO and BARC, the hybrid granular sequencing batch reactor (HGSBR) used natural bacteria to treat faecal sludge and greywater in prefabricated treatment plants, therefore guaranteeing environmental cleanliness (Rai, 2025a, 2025b). Sludge dewatering was done using geotube technology, permeable designed fabric containers to separate pollutantsmwhile bioremediation methods used helpful microorganisms in big ponds to recycle greywater (Rai, 2025a, 2025b). UltraTech Cement has started the Mahakumbh ka Mahasankalp program to gather plastic trash and use it as substitute fuel for cement production (UltraTech Cement, 2025). Complementing these initiatives were portable toilets, GPS-enabled rubbish collecting vans, and prohibitions on plastic products, therefore encouraging environmentally responsible habits and sustainable waste management (BW Online Bureau, 2025). These steps guaranteed less environmental disturbance during the event. Future approaches also prioritize food supply chain resilience and flexibility. With mega-event uncertainty coupled with climatic change-induced disruption possibilities, scholars such as Pernecky (2015) suggest building flexible yet strong supply chain designs. Scenario planning, risk analysis, and formulation of contingency plans for food security and safety under diverse situations fall under this category. Regarding religious festivals like the Mahakumbh, which are highly cultural, the food supply chain resilience guarantee becomes very important to facilitate logistical success, continuity, and integrity in such vital cultural activities.

Table 1: Identified Challenges

Code	Challenge	Description	Reference
C1	Accurate demand forecasting for fluctuating attendance	Food demand for events with variable attendance is hard to estimate. Adding to the problem is the effect of weather and favorable dates for religious celebrations.	Cudny (2016)
C2	Managing diverse dietary requirements and cultural preferences	Meeting the requirements of various diets, like religious and cultural restrictions. Special arrangements and a variety of ingredients would be required for this.	Raj & Vignali (2010)
C3	Ensuring food safety and quality in temporary settings	Maintaining high food safety standards in improvised or short-term facilities is challenging . This involves implementing strong food handling practices and quality controls under less-than-ideal conditions.	Chappelet & Parent (2015)
C4	Efficient transportation and storage of large food quantities	Transporting and storing large volumes of food in normally underdeveloped places is logistically challenging . Transport solutions and the construction of suitable warehouse facilities will be required.	Roche (2000)

Code	Challenge	Description	Reference
C5	Minimizing food waste while preventing shortages	Achieving a balance of having enough food supply for the demand and avoiding excess leading to wastage. This is a problem that calls for careful planning and flexible channels of distribution.	Getz & Page (2016)
C6	Implementing sustainable practices in large-scale events	Incorporating environmentally friendly practices in temporary, large -scale food operations. This includes sourcing local produce, minimizing packaging, and managing waste effectively.	Mair & Whitford (2013)
C7	Integrating traditional systems with modern technologies	Blending traditional food distribution methods with contemporary supply chain technologies. This integration aims to enhance efficiency while respecting cultural norms and practices.	Shinde (2018)
C8	Establishing effective multi-stakeholder collaborations	Coordinating among various entities , including organizers, suppliers, local authorities, and volunteers. Effective collaboration is crucial for smooth operations and quick problem-solving.	Jones (2018)
C9	Maintaining cultural authenticity while improving efficiency	Preserving the cultural significance of food practices while introducing modern efficiency measures. This balance is critical in religious events like the Mahakumbh.	Shinde & Rizello (2014)
C10	Adapting to unforeseen circumstances and disruptions	Developing strong systems that will be responsive to unexpected events or emergencies. These involve contingency plans for several possible disruptions of the food supply chain.	Pernecky (2015)
C11	Balancing cost-effectiveness with food quality and safety	Managing the financial side of food supply with the utmost safety and quality standards . This includes effective cost -saving strategies with no compromise of essential standards	Bowdin et al. (2012)

The comprehensive literature review shows a research gap in food supply chain management for mega religious festivals like the Mahakumbh. While the existing body of work has addressed several aspects of event management and generic supply chain logistics, the gap concerning the unique issues and solutions of food supply chains for large-scale religious festivals is notably noted. The gap is particularly noted concerning the alignment of conventional food distribution processes with modern supply chain technologies, the application of sustainable principles on temporary infrastructure, and the development of intense systems capable of handling the unpredictable nature of such events. There is also limited research on the balance of operational efficiency with sensitivity toward the culture and varied dietary requirements of individuals in a religious context. The application of emerging technologies like blockchain and AI for this context is underresearched, as is the development of effective stakeholder cooperation frameworks tailored for the unique needs of events like those of the Mahakumbh. In similar high-risk, complex sectors like Indian pharmaceuticals and MSMEs, fuzzy logic-based approaches have proven effective in modeling supply chain barriers and improving decision-making (Vishwakarma, Garg, & Barua, 2019; Gupta, Prakash, Vishwakarma, & Barua, 2017; Vishwakarma, Prakash, & Barua, 2016), despite their potential to enhance traceability, transparency, and trust in complex multi-stakeholder food supply chains, as is the development of effective stakeholder cooperation frameworks tailored for the unique needs of events like those of the Mahakumbh. There is also limited longitudinal research on the long-term impact of food supply chain strategies on host communities and the environment. Plugging these gaps would go a long way toward optimizing food supply chain management for mega-religious festivals, providing valuable insights for organizers, policymakers, and researchers in this niche area.

Methodology

This study seeks to maximize the food supply chain management during the 13 January to 26 February 2025

Prayag Maha Kumbh Mela. We visited three sites to Prayag in order to get a whole knowledge. The study design included qualitative and quantitative techniques. We began intentional sampling among those handling food and beverages for Maha Kumbh events. First, we identified and prioritized important food supply chain management concerns pertinent to the Maha Kumbh scenario using the Delphi approach. The iterative procedure produced a comprehensive list of problems and helped consensus among the professionals. Second, we ranked and gave the above problems top priority using the Pythagorean Fuzzy AHP approach. The approach provided a quantitative and graphical representation of the relative relevance and urgency of problems, which helped us to arrange and give top priority to the most crucial elements for optimization. The approach of the technique combines expert opinion, iterative optimization, and quantification with strong foundations to provide strong underpinnings for understanding and address food supply chain management peculiarities in the extremely unique Maha Kumbh Mela setting.

Delphi Technique

Particularly in those very unpredictable and evolving sectors, the Delphi Technique is still a potent and dynamic tool for fostering consensus among experts. Its importance stems from its capacity to gradually shape ideas from professionals and lower prevalent individual and groupthink biases (Avella, 2016). Recent applications have shown it appropriate for policy-making, technical forecasting, and resolution of difficult health concerns as well as for technology (Niederberger & Spranger, 2020). Higher degrees of easiness and efficiency offered by the technique's adaptability to internet platforms have also helped to lower iteration cycles and increase participation (Hirschhorn, 2019). The combination of qualitative and quantitative data of the Delphi Technique makes it an effective instrument for several industries' planning and multiple decision-making (Veugelers et al., 2020). Step-by-Step Process of Conducting the Delphi Technique:

Step 1: Clearly articulate the research question or issue to be addressed.

Step 2: Identify and recruit a diverse group of experts relevant to the topic.

Step 3: Create an initial set of open-ended questions.

Step 4: Send the questionnaire to panelists and gather responses.

Step 5: Summarize and analyze the initial feedback.

Step 6: Create follow-up questionnaires based on previous responses.

Step 7: Distribute follow-up questionnaires and collect responses, allowing experts to refine their opinions.

Step 8: Continue iterations until consensus is reached or response stability occurs.

Step 9: Compile and present the final results and insights.

Pythagorean Fuzzy AHP

The significance of the Pythagorean Fuzzy-AHP method lies in its advanced capability to handle uncertainty and vagueness in decision-making processes by integrating the flexibility of Pythagorean fuzzy sets with the structured pairwise comparison framework of the Analytic Hierarchy Process, thereby enabling decision makers to model ambiguous human judgments more effectively in complex multi-criteria decision-making (MCDM) problems; this method not only overcomes the limitations of traditional crisp AHP by allowing the sum of the squares of membership and non-membership degrees to be less than or equal to one which offers a more comprehensive representation of hesitancy and uncertainty but also provides a robust framework for aggregating subjective evaluations from multiple experts into a consistent set of criteria weights, thereby ensuring enhanced accuracy and reliability in the decision outcomes (Shete et al., 2020); furthermore, by facilitating the use of linguistic variables to express experts' opinions, the method bridges the gap between qualitative assessments and quantitative analysis, making it highly applicable in areas such as sustainable supply chain management, risk assessment in hazardous material transportation, and the evaluation of smart buildings, where the inherent uncertainty in human judgment is a critical challenge (Milošević et al., 2023); additionally, this approach has been demonstrated to provide new directions in solving MCDM problems by offering a systematic way to defuzzify aggregated judgments while maintaining consistency and reducing potential errors from subjective bias, as evidenced by its successful application in various empirical studies and research works that highlight its role in improving decision quality and robustness (Mohd and and Abdullah, 2017); moreover, the integration of this method with other MCDM techniques, such as COPRAS and TOPSIS, further exemplifies its versatility and adaptability across different fields, which has been underscored by recent comparative analyses that reveal similar ranking results and enhanced discrimination among alternatives even when dealing with incomplete or imprecise data (Ayyildiz and Taskin Gumus, 2021); in essence, the Pythagorean Fuzzy-AHP method is significant because it not only refines the conventional decision-making process by quantifying uncertainty in a mathematically rigorous manner but also supports more informed, transparent, and robust decision outcomes in environments where human judgments are inherently subjective, a feature that is further validated by its growing adoption in research and practice as well as by studies that utilize citation context analysis to underscore its impact on evolving scientific discourse. The following step-by-step process is used to determine the weight of challenges.

Step 1: Construct a pairwise comparison matrix for the drivers based on expert evaluations. Express these comparisons using linguistic terms according to the scale provided in Table 2.

Table 2: Scale of relative importance for AHP (Liu et al., 2021)

Linguistic Term	Abbreviation	PFN as IVPFN			
		α_L	α_U	β_L	β_U
Certainly Low Influence	CLI	0	0	0.90	1
Very Low Influence	VLI	0.10	0.20	0.80	0.90
Low Influence	LI	0.20	0.35	0.65	0.8
Below Average Influence	BAI	0.35	0.45	0.55	0.65
Average Influence	AI	0.45	0.55	0.45	0.55
Above Average Influence	AAI	0.55	0.65	0.35	0.45
High Influence	HI	0.65	0.80	0.2	0.35
Very High Influence	VHI	0.80	0.90	0.10	0.20
Certainly High Influence	CHI	0.90	1	0	0
Exactly Equal Influence	EE	0.1965	0.1965	0.1965	0.1965

Step 2: Develop the Differences Matrix by determining the variation between the upper and lower values of the membership and non-membership functions. Apply Equations (1) and (2) for this computation.:

$$a_{ijL} = b_{ijL}^2 - c_{ijU}^2 \quad (1)$$

$$a_{ijU} = b_{ijU}^2 - c_{ijL}^2 \quad (2)$$

Step 3: Generate the interval multiplicative matrix by utilizing Equations (3) and (4):

$$w_{ijL} = \sqrt{1000^{d_L}} \quad (3)$$

$$w_{ijU} = \sqrt{1000^{d_U}} \quad (4)$$

Step 4: Compute the determinacy value for each entry in matrix R (obtained from Step 2) using Equation (5).

$$s_{ij} = 1 - \left(b_{ijU}^2 - b_{ijL}^2\right) - \left(c_{ijU}^2 - c_{ijL}^2\right) \quad (5)$$

Step 5: Establish the preliminary weights before normalization by applying Equation (6).

$$\xi_{ij} = \frac{w_{ijL} + w_{ijU}}{2} s_{ij} \quad (6)$$

Step 6: Derive the final weights for the drivers using Equation (7).

$$W_i = \frac{\sum_{j=1}^{m} \xi_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{m} \xi_{ij}} \quad (7)$$

Result Analysis

This work is of utmost importance because it focuses on finding a solution for optimizing food supply chain management for the world's largest religious congregation, the Mahakumbh. Prioritization of the problem is important because it will allow organizers, stakeholders, and other involved organizations to focus their limited efforts and resources on the most important issues, with maximum impact and efficiency of event management. Combining the Delphi technique, Pythagorean Fuzzy AHP, and Empirical Validation provides a robust and integrated framework for solving this complex problem. The Delphi technique allows structured collection and expertise refinement, where diverse views are considered when determining crucial issues. The Pythagorean fuzzy AHP proves to be a very effective tool when dealing with uncertainty and subjectivity when ranking these issues, enabling advanced decision-making. Lastly, Empirical Validation brings down the theories into reality, so results from the work become more practically applicable. All these procedures together create a sound toolset to identify and rank issues and form practical, evidence-based strategies towards their solution, eventually guiding efficient management of food supply chains to large-scale religious festivals such as the Mahakumbh.

Delphi Result

A formal Delphi approach was undertaken to address RQ1 and identify the most important food supply chain management issues at Mahakumbh. As the initial step, a review of the literature on large-scale religious festivals and food supply chain management led to the generation of 15 critical issues. These were the demand forecasting complexities, food safety, logistics inefficiency, sustainability, and cultural aspects. However, because the operational dynamics of the Mahakumbh were peculiar, these issues needed to be validated and refined with direct interaction with stakeholders engaged in food distribution during the event.

To render the analysis practically applicable, site visits were conducted at Mahakumbh, where interactions with food and beverage vendors, supply chain managers, and event organizers provided insights into the practical limitations and coping strategies on the ground. The preliminary list was refined from these expert perceptions and observations, summarizing the issues into a final list of 11 core issues. These issues accurately reflect the complexity of food supply chain management for a one-off but large-scale religious event, ensuring that practical experience and academically grounded insights comprehensively understand the problem.

Pythagorean Fuzzy AHP Result

Within the food supply chain optimization framework for the Mahakumbh, the Pythagorean Fuzzy Analytic Hierarchy Process is a significant methodological advancement. The technique, a development of the initial Delphi method, facilitates the experts' perceptions of the issues identified being better differentiated and quantified. By engaging the same group of experts involved with the Delphi process and explicitly targeting the vendors with post-graduate levels of qualification, the research guarantees a high level of expertise and homogeneity of the evaluation. Responses from the 13 qualified vendors provide a robust dataset for analysis. Pythagorean Fuzzy AHP is relevant here since the technique is qualified to handle the vagueness and complexity of evaluating food supply chain matters for a mega-event like the Mahakumbh. The technique facilitates a better articulation of the experts' judgments, considering the intensity of the membership and non-membership of a particular preference, which is critical with the complexity of food supply chain management for large-scale religious events. The resultant ranking provides valuable insights for event organizers, policymakers, and stakeholders, such that their efforts and resources can be focused on the most critical issues, thus making the food supply chain management at Mahakumbh effective and successful. The technique facilitates decision-makers handling vagueness and expert judgment uncertainty. Some significant tables are reported for systematically presenting the computational procedure and results. Table 3 presents the pairwise comparison of the issues identified for the food supply chain management of Mahakumbh. Table 4 is the Matrix of Differences of the Lower and the Upper Values, which covers the diversity of expert opinion in fuzzy decision-making. Table 5, Interval Multiplicative Inverse, presents the reciprocal values for testing the consistency of the comparisons. Table 6, Indeterminacy Degree, presents the indeterminacy of the expert answers, a characteristic of Pythagorean fuzzy analysis. Table 7, Weight and Rank of Challenges, presents the final calculated weights of each challenge, defining their relative importance for food supply chain management. These tables collectively present a formal structure for ranking and analyzing the challenges, aiming for a robust decision-making process.

Table 3.1: Pairwise Comparison

Challenge	C1				C2				C3				C4			
C1	0.197	0.197	0.197	0.197	0.103	0.387	0.548	0.591	0.656	0.411	0.552	0.389	0.365	0.194	0.113	0.131
C2	0.163	0.238	0.292	0.350	0.197	0.197	0.197	0.197	0.179	0.136	0.642	0.157	0.414	0.573	0.293	0.335
C3	0.258	0.279	0.181	0.513	0.470	0.169	0.468	0.317	0.197	0.197	0.197	0.197	0.283	0.364	0.464	0.435
C4	0.658	0.579	0.354	0.358	0.433	0.115	0.619	0.509	0.198	0.347	0.351	0.446	0.197	0.197	0.197	0.197
C5	0.317	0.296	0.245	0.257	0.665	0.233	0.283	0.435	0.589	0.311	0.397	0.594	0.145	0.241	0.575	0.137
C6	0.179	0.136	0.642	0.157	0.250	0.350	0.641	0.150	0.528	0.328	0.364	0.128	0.318	0.468	0.586	0.682
C7	0.341	0.486	0.568	0.659	0.341	0.486	0.568	0.659	0.528	0.328	0.364	0.128	0.341	0.486	0.568	0.659
C8	0.470	0.169	0.468	0.317	0.318	0.468	0.586	0.682	0.341	0.486	0.568	0.659	0.331	0.031	0.038	0.546
C9	0.318	0.468	0.586	0.682	0.179	0.136	0.642	0.157	0.250	0.350	0.641	0.150	0.179	0.136	0.642	0.157
C10	0.250	0.350	0.641	0.150	0.331	0.031	0.038	0.546	0.470	0.169	0.468	0.317	0.331	0.031	0.038	0.546
C11	0.318	0.468	0.586	0.682	0.528	0.328	0.364	0.128	0.331	0.031	0.038	0.546	0.528	0.328	0.364	0.128

Table 3.2: Pairwise Comparison

Challenge	C5				C6				C7				C8			
C1	0.537	0.673	0.552	0.634	0.341	0.486	0.568	0.659	0.318	0.468	0.586	0.682	0.528	0.328	0.364	0.128
C2	0.533	0.623	0.401	0.224	0.528	0.328	0.364	0.128	0.331	0.031	0.038	0.546	0.179	0.136	0.642	0.157
C3	0.615	0.210	0.138	0.555	0.179	0.136	0.642	0.157	0.179	0.136	0.642	0.157	0.454	0.111	0.103	0.284
C4	0.545	0.396	0.328	0.379	0.250	0.350	0.641	0.150	0.454	0.111	0.103	0.284	0.331	0.031	0.038	0.546
C5	0.197	0.197	0.197	0.197	0.528	0.328	0.364	0.128	0.318	0.468	0.586	0.682	0.470	0.169	0.468	0.317
C6	0.528	0.328	0.364	0.128	0.197	0.197	0.197	0.197	0.229	0.480	0.698	0.735	0.528	0.328	0.364	0.128
C7	0.250	0.350	0.641	0.150	0.318	0.468	0.586	0.682	0.197	0.197	0.197	0.197	0.331	0.031	0.038	0.546
C8	0.331	0.031	0.038	0.546	0.470	0.169	0.468	0.317	0.454	0.111	0.103	0.284	0.197	0.197	0.197	0.197
C9	0.250	0.350	0.641	0.150	0.179	0.136	0.642	0.157	0.528	0.328	0.364	0.128	0.229	0.480	0.698	0.735
C10	0.454	0.111	0.103	0.284	0.331	0.031	0.038	0.546	0.229	0.480	0.698	0.735	0.250	0.350	0.641	0.150
C11	0.318	0.468	0.586	0.682	0.250	0.350	0.641	0.150	0.331	0.031	0.038	0.546	0.318	0.468	0.586	0.682

Table 3.3: Pairwise Comparison

Challenge	C9				C10				C11			
C1	0.318	0.468	0.586	0.682	0.341	0.486	0.568	0.659	0.318	0.468	0.586	0.682
C2	0.229	0.480	0.698	0.735	0.331	0.031	0.038	0.546	0.250	0.350	0.641	0.150
C3	0.250	0.350	0.641	0.150	0.470	0.169	0.468	0.317	0.331	0.031	0.038	0.546
C4	0.454	0.111	0.103	0.284	0.528	0.328	0.364	0.128	0.470	0.169	0.468	0.317
C5	0.318	0.468	0.586	0.682	0.454	0.111	0.103	0.284	0.454	0.111	0.103	0.284
C6	0.528	0.328	0.364	0.128	0.331	0.031	0.038	0.546	0.341	0.486	0.568	0.659
C7	0.454	0.111	0.103	0.284	0.250	0.350	0.641	0.150	0.454	0.111	0.103	0.284
C8	0.229	0.480	0.698	0.735	0.179	0.136	0.642	0.157	0.318	0.468	0.586	0.682
C9	0.197	0.197	0.197	0.197	0.454	0.111	0.103	0.284	0.229	0.480	0.698	0.735
C10	0.331	0.031	0.038	0.546	0.197	0.197	0.197	0.197	0.528	0.328	0.364	0.128
C11	0.318	0.468	0.586	0.682	0.331	0.031	0.038	0.546	0.197	0.197	0.197	0.197

Table 4: Matrix of differences b/w lower and upper values

Challenge	C1		C2		C3		C4		C5		C6		C7		C8		C9		C10		C11	
C1	0.0000	0.0000	-0.3387	-0.1508	0.2789	-0.1359	0.1160	0.0249	-0.1141	0.1492	-0.3182	-0.0863	-0.3636	-0.1246	0.2623	0.0912	-0.3636	-0.1246	-0.3182	-0.0863	-0.3636	-0.1246
C2	-0.0958	-0.0288	0.0000	0.0000	0.0075	-0.3933	0.0597	0.2423	0.2339	0.2266	0.2623	-0.0252	-0.1889	-0.0005	0.0075	-0.0063	-0.4877	-0.2561	-0.1889	-0.0005	0.0400	-0.2883
C3	-0.1963	0.0450	0.1205	-0.1900	0.0000	0.0000	-0.1096	-0.0833	0.0695	0.0252	0.0075	-0.3933	0.0075	-0.3933	0.1255	-0.0685	0.0400	-0.2883	0.1205	-0.1900	-0.1889	-0.0005
C4	0.3047	0.2103	-0.0717	-0.3700	-0.1594	-0.0024	0.0000	0.0000	0.1536	0.0498	0.0400	-0.2883	0.1255	0.0017	-0.1889	-0.2976	0.1255	0.0017	0.2623	-0.0252	0.1205	-0.1900
C5	0.0347	0.0281	0.2529	-0.0259	-0.0066	-0.0610	0.0022	-0.2727	0.0000	0.0000	0.2623	-0.0252	-0.3636	-0.1246	0.1205	-0.0717	-0.3636	-0.1246	0.1255	0.0017	0.1255	0.0017
C6	0.0075	-0.3933	0.0400	-0.2883	0.2623	-0.0252	-0.3636	-0.1246	0.2623	-0.0252	0.0000	0.0000	-0.4877	-0.2561	0.2623	0.0912	0.2623	-0.0252	-0.1889	-0.0005	-0.3182	-0.0863
C7	-0.3182	-0.0863	-0.3182	-0.0863	0.2623	-0.0252	-0.3182	-0.0863	0.0400	-0.2883	-0.3636	-0.1246	0.0000	0.0000	-0.1889	-0.2976	0.1255	0.0017	0.0400	-0.2883	0.1255	0.0017
C8	0.1205	-0.1900	-0.3636	-0.1246	-0.3182	-0.0863	-0.1889	-0.0005	-0.1889	-0.0005	0.1205	-0.1900	0.1255	0.0017	0.0000	0.0000	-0.4877	-0.2561	0.0075	-0.3933	-0.3636	-0.1246
C9	-0.3636	-0.1246	0.0075	-0.3933	0.0400	-0.2883	0.0075	-0.3933	0.0400	-0.2883	0.0075	-0.3933	0.2623	-0.0252	-0.4877	-0.3093	0.0000	0.0000	0.1255	0.0017	-0.4877	-0.2561
C10	0.0400	-0.2883	-0.1889	-0.0005	0.1205	-0.1900	-0.1889	-0.0005	0.1255	0.0017	-0.1889	-0.0005	-0.4877	-0.2561	0.0400	0.1000	-0.1889	-0.0005	0.0000	0.0000	0.2623	-0.0252
C11	-0.3636	-0.1246	0.2623	-0.0252	-0.1889	-0.0005	0.2623	-0.0252	-0.3636	-0.1246	0.0400	-0.2883	-0.1889	-0.0005	-0.3636	-0.2457	-0.3636	-0.1246	-0.1889	-0.0005	0.0000	0.0000

Table 5: Interval Multiplicative Inverse

Challenge	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	1.000	0.812	1.415	1.091	0.737	0.768	0.761	1.287	0.761	0.768	0.761
C2	0.933	1.000	1.401	0.817	1.007	1.287	0.812	1.401	0.768	0.812	1.328
C3	0.759	1.311	1.000	0.974	1.044	1.401	1.401	1.124	1.328	1.311	0.812
C4	1.094	1.298	0.843	1.000	1.104	1.328	1.124	0.812	1.124	1.287	1.311
C5	1.007	1.279	1.054	1.275	1.000	1.287	0.761	1.311	0.761	1.124	1.124
C6	1.401	1.328	1.287	0.761	1.287	1.000	0.768	1.287	1.287	0.812	0.768
C7	0.768	0.768	1.287	0.768	1.328	0.761	1.000	0.812	1.124	1.328	1.124
C8	1.311	0.761	0.768	0.812	0.812	1.311	1.124	1.000	0.768	1.401	0.761
C9	0.761	1.401	1.328	1.401	1.328	1.401	1.287	0.768	1.000	1.124	0.768
C10	1.328	0.812	1.311	0.812	1.124	0.812	0.768	1.328	0.812	1.000	1.287
C11	0.761	1.287	0.812	1.287	0.761	1.328	0.812	0.761	0.761	0.812	1.000

Table 6: Indeterminacy degree

Challenge	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	1.000	0.367	2.296	1.409	0.865	0.413	0.356	2.475	0.356	0.413	0.356
C2	0.757	1.000	0.899	1.446	2.231	2.183	0.617	1.404	0.230	0.617	1.008
C3	0.636	1.334	1.000	0.699	1.234	0.899	0.899	1.310	1.008	1.334	0.617
C4	2.699	0.688	0.661	1.000	1.594	1.008	1.432	0.357	1.432	2.183	1.334
C5	1.122	2.116	0.942	0.891	1.000	2.183	0.356	1.505	0.356	1.432	1.432
C6	0.899	1.008	2.183	0.356	2.183	1.000	0.230	2.475	2.183	0.617	0.413
C7	0.413	0.413	2.183	0.413	1.008	0.356	1.000	0.357	1.432	1.008	1.432
C8	1.334	0.356	0.413	0.617	0.617	1.334	1.432	1.000	0.230	0.899	0.356
C9	0.356	0.899	1.008	0.899	1.008	0.899	2.183	0.203	1.000	1.432	0.230
C10	1.008	0.617	1.334	0.617	1.432	0.617	0.230	1.701	0.617	1.000	2.183
C11	0.356	2.183	0.617	2.183	0.356	1.008	0.617	0.271	0.356	0.617	1.000

Table 7: Weight and Rank of Challenges

Challenge	Weight	Rank
C1	0.090	7.000
C2	0.108	4.000
C3	0.096	6.000
C4	0.126	1.000
C5	0.117	3.000
C6	0.119	2.000
C7	0.088	9.000
C8	0.075	11.000
C9	0.089	8.000
C10	0.099	5.000
C11	0.084	10.000

The following identified food supply chain optimization challenges of the Mahakumbh event represent a complex interaction of logistical, environmental, and cultural factors. The number one ranked challenge (C4) is the efficient transport and storage of large quantities of food. In keeping with the finding of Roche (2000) of the vast logistical challenge of transporting and storing food under short-term or underdeveloped infrastructural conditions, this is the most serious challenge. A strong logistics strategy is required to set up modular, easily transportable store units and develop a comprehensive transport plan that leverages local networks. advanced tracing systems and real-time stock management (Gupta et al., 2017) could significantly improve food transport and storage efficiency during the event, especially for MSME-run kitchens and supply units..

The two and three most critical issues (C6 and C5) are sustainability and resource management. Using practices conducive to sustainability in significant events (C6) has increasingly become vital, as Mair and Whitford (2013) noted in their suggestions for sustainable event management. The solutions may involve sourcing food close to its production location to reduce transport emissions, using biodegradable packaging, and having quality waste handling systems. Reducing food wastage and avoiding stock-outs (C5) are also closely associated and critical. The issue here is a balancing act, as Getz and Page (2016) noted in their discussion of sustainable event management. Reducing this may be possible by utilizing real-time inventory tracking tools, establishing flexible distribution networks, and using predictive analysis to enhance supply-demand matching. The fourth and fifth-ranked issues (C2 and C10) are those of diversity and adaptability. Coping with the dietary requirements and cultural preferences of a diverse group (C2) is dealing with a multicultural crowd of pilgrims, an issue analyzed by Raj and Vignali (2010) concerning religious festivities. Solutions may involve planning a diverse menu supportive of multiple dietary requirements, marking foodstuffs, and giving full details about ingredients and preparation. Coping with unexpected situations and interruptions (C10) is also very important to the event's success. According to Pernecky (2015), flexible and robust supply chain structures should be designed. Scenario planning, contingency plans over potential interruptions, and quick response protocols may be involved.

The sixth and seventh-ranked challenges (C3 and C1) are food safety and demand forecasting. Temporary site food safety and quality assurance (C3) are essential due to the enormous size of the event and health considerations. Chappelet and Parent (2015) highlight the necessity of robust food safety controls in managing mega-events. Controls can encompass imposing vigilant quality control procedures, utilizing mobile food safety testing units, and conducting full training of all food handlers. Reliable demand forecasting for variable attendance (C1) underlies all other issues. Cudny (2016) identifies the issue of forecasting attendance and consumption patterns in mega-events. To address this, advanced data analysis and machine learning programs can examine historical and real-time data, rendering demand forecasting more certain.

Even if still important, the lower-ranked issues can be seen as less critical or as a byproduct of the solution of the higher-ranked ones. Maintaining cultural authenticity with greater efficiency (C9) and introducing traditional systems with up-to-date technologies (C7) reflect the unique character of religious festivals like Mahakumbh. Shinde (2018) suggests integrating age-old food distribution systems with up-to-date supply chain technologies for greater efficiency with the preservation of cultural significance. Balancing cost-effectiveness with food safety and quality (C11) emphasizes the significance of effective optimization of resources with no compromise on the standards required, as observed by Bowdin et al. (2012). Finally, the successful institution of multi-stakeholder collaborations (C8) is critical for the event's success. Jones (2018) emphasizes the importance of effective relationships among event organizers, the local administration, and the food suppliers for smooth operation and quick response to unexpected incidents.

Empirical Validation

Analysis of the empirical results and Pythagorean Fuzzy AHP ranking shows consistencies and inconsistencies in ranking the food supply chain management challenges of Mahakumbh. Pythagorean Fuzzy AHP utilized data from 13 expert suppliers, while empirical validation was conducted on the larger dataset of 140 respondents. Snowball and purposive sampling were utilized to select the respondents, considering the mammoth attendance of 66 crore visitors at Mahakumbh. Post-graduate level respondents were chosen for this study only to get quality responses. Table 8 shows the comparative ranking obtained from empirical and Pythagorean fuzzy AHP.

Several challenges had consistent rankings across the two approaches, showing strong agreement on their relative importance. Challenge C4 (Effective transportation and storage of large volumes of food) was ranked the highest by consensus, demonstrating its imperative position in the food supply chain management of the event. Challenge C6 (Sustainable practices for large-scale events) and C5 (Reducing food wastage and averting shortages) also held their respective second and third positions across the two approaches. The fact that these were consistent shows the importance of logistics efficiency, sustainability, and resource management in the context of the Mahakumbh. Challenges C2 (Handling varied dietary needs and preferences) and C10 (Responding to unexpected disruptions and circumstances) also held their positions (fourth and fifth, respectively) across the two approaches, stressing the importance of sensitivity and adaptability for the context of event management. Some of the challenges, however, had significant differences in their ranking across the two approaches. Challenge C1 (Demand forecasting for variable attendance) was ranked 10th according to the empirical approach but 7th according to the AHP ranking, showing that the experts may prioritize this factor over the general respondents. Challenge C8 (Forming effective collaborations with multiple stakeholders), on the other hand, was ranked 8th according to the empirical approach but 11th according to the AHP approach, showing that the vendors may think this is less critical compared to other operational issues. These discrepancies highlight the necessity of implementing the two methods of ranking the issues, as these mirror the diverse perspectives and nuances of assessing the food supply chain management issues of Mahakumbh. The discrepancies also reveal the complexity of planning such a huge event, as diverse stakeholders will likely perceive diverse relative weights of particular issues based on their roles and expertise.

Table 8: Empirical Result

Challenge	Mean Value	Empirical Rank	AHP Rank
C1	2.317	10	7
C2	3.355	4	4
C3	2.883	6	6
C4	4.014	1	1
C5	3.536	3	3
C6	3.771	2	2
C7	2.223	11	9
C8	2.585	8	11
C9	2.865	7	8
C10	3.043	5	5
C11	2.505	9	10

Managerial and Theoretical Implications

The research highlights the imperative of robust logistical plans suited to the needs of large-scale events such as the Maha Kumbh Mela. Organizers and stakeholders are urged to adopt cutting-edge technologies, including real-time inventory management and predictive analytics, to increase food supply chain efficiency and ability to change at short notice. The call towards sustainability implies sourcing food locally, reducing waste, and using biodegradable packaging materials. All this addresses logistically challenging food supplies and aligns with international sustainability norms, setting a model to follow by other mass-scale events. The road map offered by the study empowers managers with actionable data to maximize resource utilization, enhance stakeholder coordination, and facilitate a smooth and culturally appropriate food distribution process.

This study adds to the academic knowledge of food supply chain management in large-scale events by applying new decision-making tools such as the Delphi Technique and Pythagorean Fuzzy AHP. They enhance decision-making with a disciplined approach to dealing with uncertainty and complexity, improving the reliability of challenging task prioritization in dynamic situations. The research also adds to scholarly writing on sustainable supply chain practices by promoting a balanced approach respecting cultural customs while applying new efficiencies. Focusing on operational efficiency against cultural authenticity interdependency, the study opens the path for future academic research to maximize supply chains in religious and cultural events by connecting conventional techniques with current technology.

Conclusion

Emphasizing the need for effective logistics, sustainability, and cultural sensitivity, this study shows the difficulties of maximizing food supply chain management at Mahakumbh. The study used a mixed-methods approach, first gathering expert opinions on the difficulties in food supply chain management using the Delphi methodology, then prioritizing based on insights from a small group of 13 post-graduate certified vendors using Pythagorean fuzzy AHP. A larger sample of 140 respondents was also used for empirical validation, offering a whole picture of the difficulties noted.

The results agreed on the vital relevance of effective food storage and transportation (C4), which came first among all the challenges of both approaches. This emphasizes the logistical difficulties in running food chains for such events. Moreover, the survey revealed the second and third most important issues, such as applying sustainable practices (C6) and reducing food waste (C5), thereby stressing the importance of environmentally friendly solutions in the administration of events. The differences between the rankings of professional vendors and general respondents highlighted different opinions about the importance of specific issues, including demand forecasting (C1) and stakeholder involvement (C8).

Future studies could expand this investigation by integrating local food sellers, government officials, participants with different educational backgrounds, and more varied responders. Moreover, longitudinal studies might be conducted to evaluate the effectiveness of applied policies across several Mahakumbh repetitions, thereby improving knowledge of changing issues and solutions in food supply chain management during mega-events. This might also entail investigating how newly developed technologies like artificial intelligence and blockchain could help further streamline food supply networks at events of comparable size. Using these insights would help stakeholders be more ready for the complexity of food supply management in Mahakumbh and other such mega-events.

Ethics declarations

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical Approval: The research did not require ethical review board approval because the data collection methods involved anonymous surveys and did not involve vulnerable populations.

Informed Consent: Not applicable.

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