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Navigating Ambiguity: Noble Applications in Unbalanced Agri-Food Supply Chain Management

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ABSTRACT
In the modern era, the agri-food sector has undergone a profound transformation due to rapid advancements in technology. The continuous evolution of modern tools, particularly those associated with Industry 4.0 and Industry 5.0, has revolutionized the agri-food supply chain management (SCM). Real-time visibility and traceability, powered by AI and machine learning, are now pivotal in enhancing efficiency and profitability within the industry. The collaborators and suppliers still face the situation under the uncertainty. This study identifies the problems and tackle by strategies. These technologies enable industries to achieve higher output with reduced manpower, turning even uncertain scenarios into opportunities for growth. The novelty is to use Grey GRA for sophisticated problems and the prioritization is transformed by SWARA for obtaining weights and TOPSIS is applied for obtaining the performance score. The industries can navigate these uncertainties with reliable and automated solutions. In this study the primary objective is to identify the optimal strategy among various alternatives, ensuring that the chosen approach demonstrates 100% robustness in the face of challenges. This focus on top-tier prioritization has led to a significant increase in profits. Thirteen challenges identified and the preferences are given by the five various group of experts. The output of this study is to set the strategies for collaborators and suppliers for ensuring top most thirteen problems. The importance of this research lies in its ability to provide a strategic framework that ensures robustness and profitability in the agri-food supply chain. By utilizing modern technologies and methodologies, the research offers a pathway for industries, decision-maker, researchers and practitioners to maximize their output under minimum risks even in uncertain conditions.

Keywords: Uncertainty, robustness, technology, SCM, agri-food.

1.0 Introduction

In the whole world food is the basic need of human being. The supply chain management in present scenario has been upgraded through modern tools and it is responsible to manage the ease availability of product for consumer by maintaining the quality. AFSCM has a broader meaning and during the last decades the applications & methodology have been upgraded under MCDM [1 & 2]. The various tools have created and applied for identification and characterization of challenges and strategies in proper propagation of Agri food SCM [21]. In the modern business environment, the unbalanced supply chains indicate demand and supply are not perfectly synchronized which shows a significant challenge. Such imbalances can lead to inefficiencies, increased costs, and customer dissatisfaction. To address these issues, businesses are increasingly turning to multi-criteria decision-making (MCDM) techniques to optimize various aspects of supply chain management (SCM) [6]. The MCDM techniques are very crucial in unbalanced SCM. In AFSCM there is the need of identifying the key criteria that impact supply chain performance. The ability to predict customer demand accurately is vital in an unbalanced supply chain, as it directly affects inventory levels and order fulfillment rates [4 & 6]. The consistency of suppliers in delivering the right quantity and quality of goods on time. This includes not only the direct costs of procurement and logistics but also indirect costs such as those associated with holding excess inventory or facing stockouts. Environmental and social factors are becoming increasingly important, with emphasis on reducing carbon footprints, waste, and ensuring fair labor practices. The ability to anticipate, identify, and mitigate risks across the supply chain, such as those arising from geopolitical issues, natural disasters, or market fluctuations. The novel applications of MCDM techniques provide a structured approach to handling unbalanced supply chains by identifying key criteria and prioritizing them effectively, enabling businesses to optimize their operations in an uncertain and dynamic environment [11 & 20]. Supply chain management (SCM) is inherently complex, especially when faced with unbalanced conditions where demand and supply are misaligned. To effectively manage these challenges, organizations employ multi-criteria decision-making (MCDM) techniques to optimize performance based on various criteria, such as cost, reliability, flexibility, and sustainability [14].

The dynamics of unbalanced supply chains directly influence Gross Domestic Product (GDP) through factors like production efficiency, cost management, and inventory control. Unreliable supply chains can disrupt production, leading to reduced economic output and negatively affecting GDP. By optimizing costs, companies can improve profit margins and reinvest in growth, contributing to GDP. While sustainability initiatives might require upfront investments, they often lead to long-term economic benefits by reducing waste and energy use, aligning with global GDP through environmental stewardship. Strong risk management capabilities help maintain consistent GDP growth by avoiding economic shocks and maintaining steady market confidence. MCDM techniques in unbalanced supply chain management has shown significant benefits in aligning operational goals with broader economic objectives measured by GDP and other indices [1, 2 & 6]. A case study comparing a company's supply chain performance before and after applying MCDM techniques showed a 15% improvement in cost efficiency, a 10% increase in supply reliability, and a 20% reduction in waste [20]. These improvements not only contribute to the company's bottom line but also align with broader economic scales like GDP and the Logistics Performance Index (LPI) by enhancing productivity and economic output. Weather and climate are the most significant uncertainties in agri-food SCM [8 & 11]. Unpredictable weather patterns, such as droughts, floods, storms, and temperature extremes, can drastically affect crop yields and quality, leading to supply shortages or surpluses. The occurrence of pests and diseases can severely impact crop production and livestock health, leading to significant losses. Rapid advancements in agricultural technology, such as precision farming, genetic modification, and automation, bring uncertainties in adoption, effectiveness, and cost [11]. The industry 4.0 contains AI, ML and modern resources through which the tracing and real time monitoring has been possible through which the suppliers as well as consumers and collaborators get benefitted by blockchain supply consequences [1 & 17]. Earlier, regarding observation there were many uncertainties which were natural and unnatural (human-made). With the use of several instruments, both man-made situations and natural disaster uncertainties can be managed [11].

This study determines the factors that make India's agri-food supply chain more conducive to introducing electronic traceability [20]. The necessity of taking the environment into account when choosing suppliers in order to support agri-food supply chain management [28]. A multi-criteria approach to decision-making that integrates AHP, TOPSIS, and robust goal programming is sufficient to maximize supplier selection and order quantity under uncertainty. Here is an information from a survey of 28 Brazilian industrial sectors, they offer a digital transformation framework to improve the competitiveness of the food business. They promote favorable governmental policies and draw attention to the necessity of investing in several digital technologies at the same time. A framework for evaluating Agri-food 4.0 supply chains (Agri4SC) can be based on three key areas: supply chain visibility (SCV), supply chain resource integration (SCRI), and sustainable performance (SP) [12]. By utilizing MCDM techniques, their methodology accounts for expert uncertainty and the multicriteria character of Agri4SC evaluation. The framework uses correlation testing and sensitivity analysis to guarantee robustness and reliability. It includes establishing decision matrices, presenting unique fuzzy sets, allocating weights, scoring techniques, and ranking algorithms. In an attempt to enhance voluntary traceability for managing product data in agri-food supply chains. It emphasizes how important it is to leverage data from many stakeholders by utilizing IoT and analytics technologies in order to boost productivity, transparency, and competitiveness [25]. Here the need of emphasizing the relevance of product waste costs and food waste treatment solutions in the face of uncertainty. It highlights the widespread application of Multi-Criteria Decision Making (MCDM) methodologies and underscores the need for additional research in this area [27].

The goal of the study is to identify and analyses the obstacles faced by entrepreneurs in agri-food sector. Mostly it has been seen that the uncertainty related to environment is very crucial which is unpredictable [6, 14 & 17]. The contamination, waste of food, spare stocking are the key factors of transportation and delay in supply. It increases the quick demand of supply due to which the other suppliers and collaborators becomes active in market. Agri-food SCM requires the hypothetical or predicable components for identification the main challenges. FSCM needs to trace the food product while the Agri-food product moves in market from farm to the consumer [12, 21 & 22]. It ensures that to adopt the blockchain technology in agri-food SCM. The authors have identified the 13 challenges by observing deeply in the industry of agri-food SCM. In blockchain technology the economy, political, legal and environmental aspects have been considered. AFSCM occurs the various uncertainties, one critical challenge is weather which is unpredictable and this can affect the agri-food SCM like unavailability of product due to natural calamity, high prices due to transportation delay during weather conditions, fluctuation in the prices of food product due to surplus or decay by using chemical and pesticides in crops [22]. The natural growth affected by the environmental issues so that the other efforts have been applied in the field of agri-food SCM, due to this the fuel, chemical, pesticides and fertilizers used in the process make harm the environment. This count as major issue for human health.

In this study the criteria (challenges) have been identified by keeping on the prioritization as the level of its importance in agri-food SCM. In agri-food SCM there are limited resources of papers under uncertainties so that this paper concludes the most effective way to apply and implement in agri-food SCM [21]. The importance of risk management in project planning is covered in this paper, with a focus on construction projects as one of the criteria. On the basis of opinion, the Grey GRA has been used for obtaining the ranks of each criterion. The uncertain criteria cannot be solved until it converted into weights so that the SWARA method is used to tackle the ranks into weights. These weights have been obtained after prioritization of each criterion. The unbalanced and uncertain situation has been tackled by TOPSIS method by which the preference score has been obtained in the form of ranking. On the basis of preference score the best strategy can be identified for uncertain conditions [4, 6 & 20]. It proposes an integrated model that incorporates the Grey GRA, SWARA, and TOPSIS approaches in a fuzzy environment in order to increase the accuracy of risk assessments and effectively prioritize threats [32]. The main area of interest for this study is high-level planning and decision-making, specifically in Agri-food SCM industry. It uses Multiple Criteria Decision Making (MCDM) with a hybrid SWARA-TOPSIS model to rank development alternatives and evaluate criteria for a range of nanotechnology applications [16]. The study proposes a framework for sustainable performance assessment (SPA) that blends Grey GRA, SWARA and TOPSIS, rating evaluation, and a performance score (PS) for the agri-food business [1]. This research examines how blockchain technology fits into ethical supply chains and evaluates its impact on social justice, governance, and environmental protection [3 & 34]. It highlights the ways that resource efficiency, accountability, and industry trust could all be enhanced by blockchain technology [3].

The remainder study focuses on supplier selection in supply chains despite environmental concerns and technological advancements and proposes criteria under the green, agile, and Industry 4.0 dimensions. It uses fuzzy SWARA and TOPSIS techniques to tackle the supplier selection problem, emphasizing agility as the most crucial assessment dimension. The section 2 has the literature review related to current issues of agri-food SCM. In section 3, the different methodologies have been used for optimization. In section 4, the case study has been discussed for comparative analysis. The result analysis and discussion have been taken for variation of sets including the sensitivity analysis in section 5. In the last section 6, the summary and significance of the paper has been discussed with key factors.

2.0 Literature Review

2.1 Determinants impacting in agri-food SCM

Determinants impacting agri-food supply chain management (SCM) include technological advancements, such as AI and automation, regulatory frameworks, climate change, consumer demand shifts, and logistics efficiency. These factors shape the resilience, sustainability, and profitability of modern agri-food supply chains amidst increasing uncertainty.

2.1.1 Technology Integration in AFSCM

Technology integration in agri-food supply chain management (AFSCM) involves implementing advanced tools like AI, IoT, and blockchain to enhance efficiency, traceability, and decision-making, driving innovation and competitiveness in agriculture. Businesses are pushed to implement environmentally friendly practices by the focus on global warming. Green supply chain management is one key tactic that surfaces. It is crucial to choose service providers who are environmentally conscious. An integrated evaluation strategy is used, with a focus on key parameters such the environmental management system and the commitment of senior management [1]. This study offers a system for choosing environmentally friendly suppliers that combines fuzzy stepwise weight assessment ratio analysis (SWARA-F) with ranking according to the compromise solution

(MARCOS-F) and fuzzy measurement alternatives.

It provides a textile company with a path forward while addressing the uncertainty and complexity of green purchasing criteria. By effectively assessing and ranking green providers, the combination of SWARA-F and MARCOS-F enhances processes for cost- and environmental-efficiency assessments [2]. According to the most major barrier in deploying blockchain technology to renewable energy supply chains is the high cost of investment [3]. This study ranks criteria and challenges related to this application. This study uses a hybrid framework of fuzzy SWARA and fuzzy WASPAS to address obstacles in humanitarian supply chain management (HSCM) and suggest solutions.

A survey of the literature and advice from experts led to the identification of 20 solutions and 29 impediments. The findings point to cooperation and long-term strategic planning as the best ways to help disaster relief organizations improve their HSCM plans and operational effectiveness [4]. The mixed fuzzy method to supply chain management's green supplier selection is presented in this study. It combines the spherical fuzzy-SWARA method for criterion weighting with the MARCOS method for alternative ranking. In a case study, a Turkish textile firm assesses six suppliers using twelve green criteria before ranking potential suppliers. Sensitivity analysis compares the results of several scenarios. The hybrid model provided by this paper for evaluating sustainable supplier selection criteria is tested using a case study from China [5].

2.1.2 Disclosure and Verifiability

Disclosure indicates the practice of making information accessible and transparent, while verifiability ensures that disclosed information can be independently checked for accuracy and authenticity, enhancing trust and accountability. This research aims to classify and rank risk-reduction tactics for ecologically responsible remanufacturing supply chains (RSCs). Fuzzy SWARA and fuzzy COPRAS are the two components of the hybrid MCDM framework that are used to assess risks and solutions. The greatest solutions, according to the data, are teamwork and managerial initiatives. Sensitivity analysis helps the RSC make decisions by confirming the framework's resilience [6]. This study investigates the application of fuzzy techniques in green supplier selection (GSS) in the agri-food sector, with a particular focus on the Biljana Brko business. Fuzzy SWARA is used to establish the weights of the criteria, with "Environmental Management System" receiving the highest ranking. To rate suppliers, fuzzy MABAC, MARCOS, and CRADIS techniques are applied.

The best option is determined to be S_2, however S_3 is also noteworthy. Comparing the three approaches yielded similar findings, indicating their effectiveness in GSS and other decision-making scenarios [7]. Based on leanness, robustness, agility, and flexibility in the food industry's supply chain, this study ranks resilience indicators. According to expert comments, robustness is the most crucial component, followed by agility, leanness, and adaptability in that order. Among the most important indicators are the information control system, visibility, inter-organizational readiness, and reactivity [8]. The Fan-varan Petrochemical Company's research evaluates the elements of green supply chain management using statistical methods and the SWARA approach.

2.1.3 Robustness and Elasticity

Robustness indicates to a system's ability to withstand disruptions and maintain performance, while elasticity indicates its capacity to adapt and recover quickly from changes or shocks, ensuring flexibility and resilience. "Designing products" was determined to be the most significant criterion after 22 were narrowed down to 11, indicating that an environmental focus could provide a competitive advantage [9]. This study proposes a two-phase sustainable multi-tier supplier selection process for food supply chains (FSCs). To estimate criteria weights in phase one, D-numbers, LBWA, and SWARA are used. In phase two, MARCOS-D is used for supplier ranking. Sensitivity analysis guarantees the dependability of the model. The use of the concept in a case study aims to effectively manage problems with multi-tier supplier selection [10]. For the purpose of integrating blockchain technology into the pharmaceutical supply chain, this article suggests a multi-phase optimization method. It combines fuzzy optimization with QFD and SWARA approaches to overcome obstacles. The fuzzy SWARA technique and Fermatean probabilistic hesitant-fuzzy sets to assess agriculture-food 4.0 supply chain approaches, aiming to enhance decision accuracy amidst uncertainty in the agri-food sector is used to modify barriers that have been identified through research [11 & 12]. Then, methods for removing obstacles are introduced using the House of Quality methodology. The integrated multi-criteria decision-making model combining grey WISP and grey BWM methods for sustainable supplier selection, enhances decision robustness in supply chain management [13 & 14]. The technological integration and decision-making models compare various ranking methods, including AHP, BWM, and fuzzy SWARA, to identify key enablers of lean supply chains. Their study offers insights into optimizing supply chain efficiency through different decision-making techniques [16]. Similarly, [17] propose an integrated model using path analysis, SWARA, and TOPSIS for evaluating green and resilient suppliers. This approach enhances sustainability and resilience in supply chains. Sustainability and performance assessment is useful to explore the competitiveness of the food industry in the digital transformation era, emphasizing the role of digital technologies in boosting industry performance towards Agriculture 4.0 [18 & 19] and also be useful to develop an integrated method for assessing sustainable performance in the Indonesian coffee agro-food industry, aiming to improve both environmental and socio-economic sustainability and their effectiveness in optimizing supply chain operations [21 & 23]. [27] propose an integrated decision-making approach for green supplier selection, focusing on robustness and reliability in green procurement. Comprehensive reviews and methodologies are the vital aspects of planning models in agri-food supply chains, discussing various approaches on green supply chain management, discussing trends, challenges, and future research areas [29]. Risk management and strategic frameworks plays a vital role in an integrated FMEA-SWARA-WASPAS model to assess and manage risks in construction projects under fuzzy environments, providing insights into risk management strategies [31] and a strategic decision framework for green supply chain management, integrating environmental considerations into supply chain strategies [32]. The advanced optimization strategies undergo multi-stage optimization strategy based on fuzzy QFD and fuzzy SWARA for adopting blockchain technology in drug supply chains, aiming to improve traceability and efficiency [35].

2.2 Significance of automation of Agri food supply

The use of AI and ML in agriculture to supply food is a significant problem. Artificial intelligence and machine learning now play a major role in the agricultural food supply chain. Automation can help regulate and manage the agricultural food supply. Less time and labor are needed thanks to contemporary resources. Fewer individuals can complete more work in less time. Real-time surveys are needed for this process. In terms of farming, we have a plethora of tools at our disposal that allow us to determine the crop's purity at any given time. In addition, predictions about the timing and amount of any crop's growth can be made.

2.3 Significance of MCDM methods in Agri food supply

These days, MCDM approaches are highly helpful for optimization. With the use of one or more tools, the vast breadth of MCDM allows for the optimization of expert opinions. These top rankings can be evaluated in order to provide suitable weights and provide guidance to collaborators on how to resolve supply chain issues. Given the vast scope of supply chain management, agri-food and SCM have been associated. There are numerous attempts to connect agri-food and SCM. As everyone is aware, the agri-food sector has also undergone significant modernization. These days, AI and ML are reducing the need for human labor.

Numerous issues plague the sector, such as the need in the agri-food sector for maximum production and greatest profit with little loss. All of these considerations can help to increase the productivity of agri-food production. But we must overcome revolutionary challenges before we can establish peace. These problems will need to be resolved using various models and real politics. Technologies like as SWARA, F-AHP, TOPSIS, Grey GRA, and others have shown to be crucial in contemporary times. This method optimizes profit-making while accounting for agricultural losses.

Different MCDM groups consult with expert groups to determine the appropriate weighting for each challenge. The issue that carries the greatest weighting is ranked top. An excellent MCDM method for converting ranking into weighting is SWARA. This method assigns a total weight to each challenge based on the opinions of experts. Here, the rank has been altered by using the TOPSIS technique to solve the problem. Here, the method that is most suited for the most crucial task is determined by its final rating. Consequently, MCDM seeks to accomplish ranking by maximizing the difficulties and tactics at particular points in time. With this in mind, it also seeks to offer suppliers hierarchical solutions.

2.4 Identification of problems by Literature review

Table 1. Problems and description in Agri-food SCM

Code	Problems	Description	Literature support
P_1	High Initial Investment	Agri-food supply chain management, which requires a large financial investment and is crucial for efficient operations, quality control, and market competitiveness, involves infrastructure, technology, logistics, and trained labor.	Ayşegül, T. U. Ş., & Adali, E. A., 2022, Almutairi, K. et. al., 2023
P_2	Complexity of Integration and adoption	It is necessary to coordinate various stakeholders, technology, policies, and procedures in order to create seamless collaboration and functionality. Careful	Ebrahimpour, M., & Zeinab Farjood Chokami, Z., 2023

		preparation, funding, and flexibility are needed for this.	
P_3	Data Security and Privacy	Protecting confidential information about production, delivery, and consumers while lowering the risk of security breaches, theft, or abuse requires enforcing stringent access controls, robust encryption, and regulatory compliance.	Baierle et al., 2022
P_4	Labor Shortages and Workforce Challenges	Seasonal variations, skill shortages, and changes in the labor force are the causes. Adoption of technology, innovative recruitment strategies, and training programmers are necessary to sustain operational resilience and efficiency.	Qahtan et al., 2023
P_5	Regulatory Compliance	Respecting local, national, and international regulations and standards relevant to food safety, labelling, environmental sustainability, and labor practices is necessary to maintain consumer confidence, lower risks, and maintain access to markets.	Ansari, Z. N., et. al., 2020
P_6	Reliability and Maintenance	Ensuring the continuous operation of buildings, transportation assets, and machinery while optimizing production and decreasing downtime is the responsibility of proactive maintenance plans, spare parts management, and performance monitoring.	Nasiri, A., et. al., 2022
P_7	Access to Markets and Trade Barriers	It includes managing taxes, quotas, import/export regulations, and market dynamics in order to expand market reach, increase competitiveness, and lower risks associated with geopolitical tensions and trade disputes.	Mahdiraji et al., 2022
P_8	Resistance to Change the policy	It involves overcoming organizational inertia, cultural norms, and stakeholder apprehensions through effective communication, education, and incentives in order to create a supportive atmosphere that encourages creativity, efficiency, and flexibility.	Puška, A., & Stojanović, I., 2022
P_9	Sustainability and Environmental Impact	It entails reducing resource use, cutting emissions, and promoting biodiversity conservation across the stages of production, processing, distribution, and consumption in order to foster resilience and responsible stewardship of natural resources for future generations.	(Akcan, S., & Taş, M. A., 2019).
P_{10}	Consumer Awareness and Demand for Transparency	It forces the sector to raise ethical and quality standards by making it mandatory to disclose product sources, production methods, and sustainability strategies in plain language. Additionally, it promotes accountability, commitment, and trust.	Yontar, E., & Derse, O. (2023)
P_{11}	Quality assurance	Every step of the manufacturing, processing, and distribution operations must have stringent standards, testing protocols, and inspection systems in place to ensure uniformity, safety, and compliance with regulatory requirements. Customer confidence and satisfaction rise as a result.	Yazdani, M., et. al., 2022
P_{12}	Seasonal Variability	Seasonal variations in weather patterns frequently have an impact on agricultural productivity by influencing crop yields and livestock productivity. This volatility makes it challenging to maintain a steady supply all year long.	Ulutaş et al., 2022
P_{13}	Logistical Complexity	Careful logistical preparation is necessary to preserve the freshness of perishable agricultural products during long-distance transportation. Inadequate infrastructure, traffic jams, and delays can cause waste and product spoiling.	Almutairi, K. et. al., 2023, Qahtan et al., 2023

2.5 Research Gap

Numerous obstacles have been noted in the field of agri-food supply chain management, with an emphasis on technological modernization and automation. Many different methodologies have been applied in this study on agri-food SCM, and by greatly refining the problems and strategies, the results have been pure. Three methods have been combined in this study to determine the main obstacles and correct the most effective course of action. This study's primary goal is to make corrections based on the advice of specialists from various fields. Providing stakeholders with a policy of lowest waste and maximum profit is the primary priority when it comes to automation these days. Agri-food products incorporate prediction and forecasting to ensure a seamless supply chain. The integration and optimization of digital technologies such as blockchain, IoT, and AI for resilience and efficiency represents a major research gap in agri-food supply chain management. Adoption varies by geography and size, therefore in-depth research on interoperability, scalability, and cost-effectiveness is required. Barriers including the digital divide, data privacy, and inadequate technical infrastructure should also be the subject of research. In Agri-food supply chain there can be used the triangular fuzzy analysis and Delphi fuzzy analytic hierarchy process in future for getting the refine approximation.

3.0 Research Methodology

In Agri-food SCM, opinion is given by experts, based on this opinion, average and normalized value is calculated using Grey-GRA technique. After this the criteria are hierarchized through ranking. This process has happened in three steps. It is the first opinion that is normalized and gets a rank. After getting the rank, all the criteria are converted into weights using SWARA technique. The weight should be arranged in such a way that the weightage distribution value of all criteria is equal to 1. The appropriate strategy has to be obtained by mapping the weights obtained by SWARA and solving them through TOPSIS. Here two steps determine which criteria are on top priority. And in this order top send and third will be the criteria. From top to bottom the ranks are being hierarchized on the basis of opinion by experts. After this it has to be seen which strategy is on top in the ranking. And the second and third also have to be identified. The first teen strategy is considered very good, which is capable of solving all the challenges. The opinion of MCDM has been resolved through two mediums which are Grey-GRA, SWARA, TOPSIS. All these techniques have been explained in the following order [Figure 1 & 2].

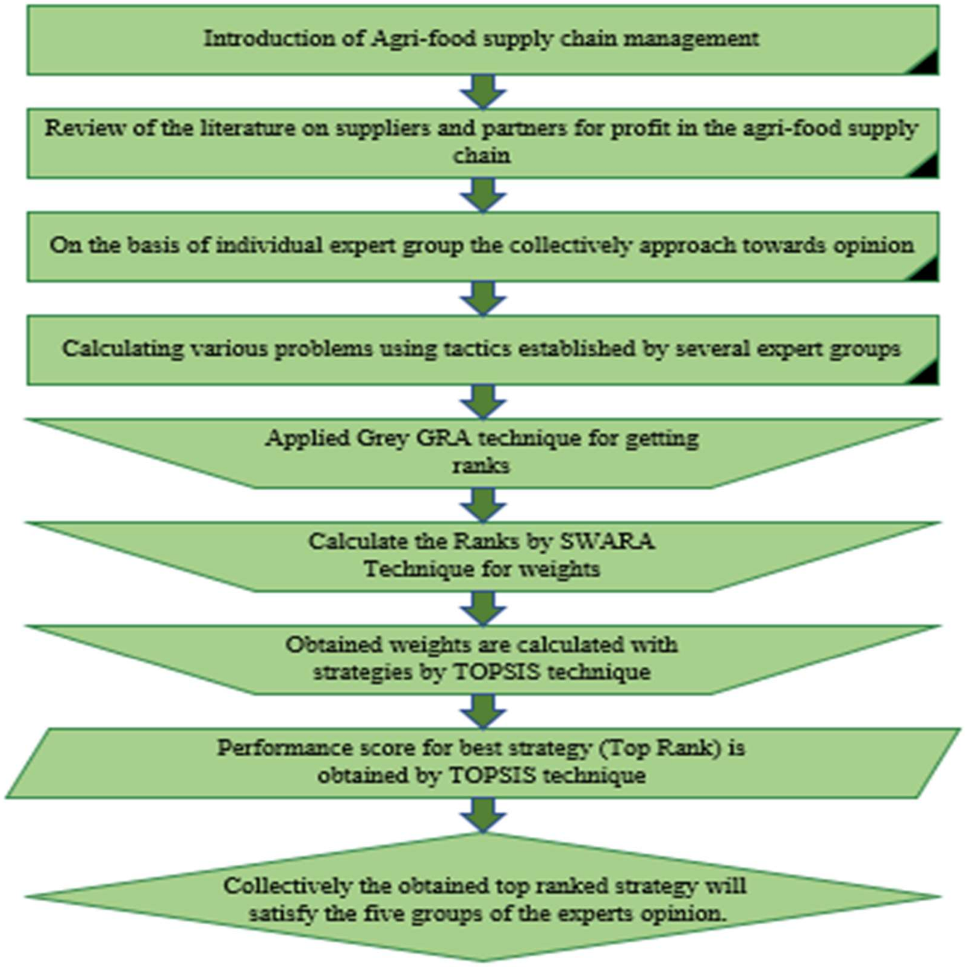

Figure 1. Step by step Research methodology

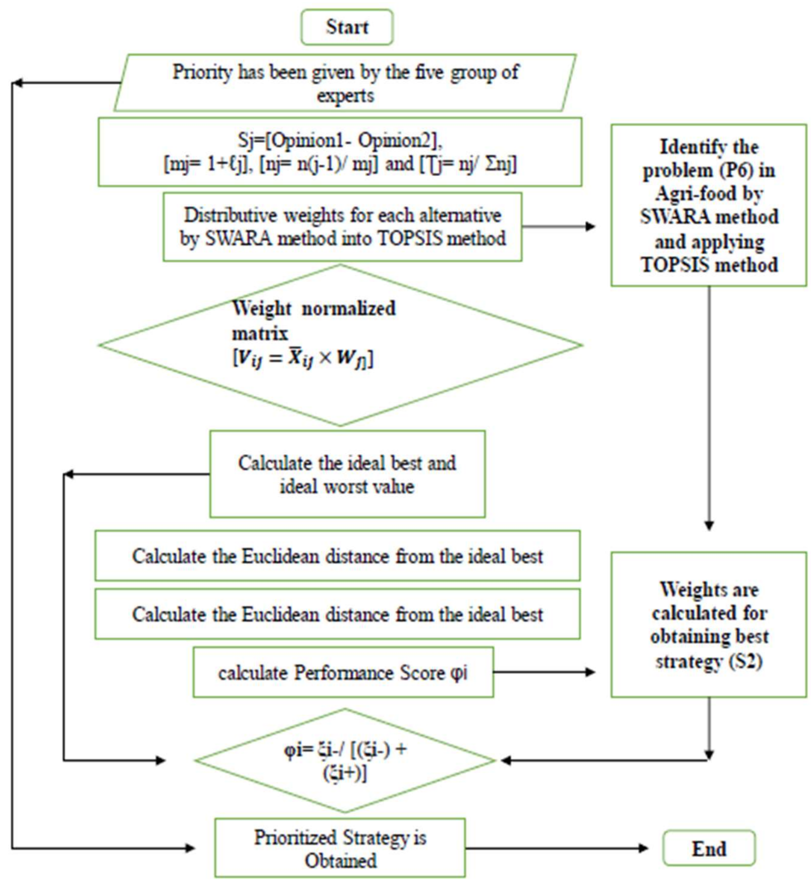

Figure 2. Analysis of top performance score

3.1 Recognition of specialists

Agri-food supply chain management experts must be acknowledged in order to maintain the effectiveness and sustainability of the food system. These experts are knowledgeable in a variety of fields, including distribution, agriculture, and logistics. Their efforts enable the smooth transition of agricultural goods from farm to customer, so enhancing food security and satisfying the changing needs of an expanding world population.

Five different categories of specialists have been included in this study. The issues with agri-food supply chain management have received the appropriate attention from each of the five categories of groups. Five groups of this weight were created, and the average of each group was determined. The Grey-GRA approach has been applied to overcome this problem. These values will be acquired in a manner that will enable them to be shown through ranking in each of the provided challenges. Grey-GRA is an averaging method that creates a hierarchical ranking by taking the average of all the weights provided by a group of experts.

3.2 Profile of specialists

Table 2. Experts field, experience and their affiliation

S. No.	Field	Affiliation	Experience (Years)
1	Industrialists	Strategic planning, risk management and food safety regulations	17
2	Academicians	Quality control, hygiene, and regulatory compliance	14
3	Technology Innovators	IoT devices, blockchain, and data analytics	11
4	Agricultural Economists	Market trends, pricing, and trade policies	19
5	Agricultural Engineers	Designing and implementing infrastructure and equipment for agricultural production, storage,	15

and processing

3.3 Identification of strategies in Agri food supply chain

Despite the advancements in every field in this day and age, the agri-food supply chain is hardly worth discussing. The goal of the research is to identify these issues and provide remedies. Even with automation, many tasks can still be completed by hand rather than automatically, or they can be refined through hybridization. This is how a group of five experts described certain strategies, and the MCDM technique was used to remedy any issues that the experts noted. The adolescent approach, which is employed in the MCDM technique, maps the strategies to the problem in the final TOPSIS and determines which strategy is most effective at solving the difficulties.

Table 3. Strategies

S. No.	Codes	Strategies
1	DF	Dynamic Demand Forecasting
2	IO	Inventory Optimization
3	PM	Predictive Modelling
4	TI	Technology Integration
5	RC	Regulatory Compliance

3.4 Symbols used in different methodologies

Table 4. Symbols Used and descriptions

S. No.	Symbol	Description
1	ρ_{ij}	Prioritization
2	$D_{(seq)}$	Deviation sequence
3	$G_{r(coeff.)}$	Grey Relational coefficient
4	P_i	Problems in SCM
5	ℓ_j	Relative difference
6	m_j	Growth Value
7	n_j	Importance of the index
8	τ_j	Weight of each index
9	X_{ij}	Decision Matrix
10	η_{ij}	Weight Normalized matrix
11	S_i	Strategies in Agri-food supply chain
12	δ_{ij}	Weight Decision matrix
13	υ^+	Positive Ideal
14	υ^-	Negative Ideal
15	ξ_i^+	Euclidian distance from ideal best
16	ξ_i^-	Euclidian distance from ideal worst
17	φ_i	Performance Score

3.5 Problems hierarchize by Grey-GRA method: Based on expert's opinion

It can handle the uncertainties and partial information that come with working in the agricultural domain, the Grey-GRA (Grey Relational Analysis) method is important in the management of the agri-food supply chain. This approach combines GRA and Grey System Theory to examine correlations between variables when the data is ambiguous or only partially understood. By identifying important elements, streamlining procedures, and boosting productivity, Grey-GRA aids in decision-making in agri-food supply chains where variables like weather, market demand, and resource availability are unpredictable. By offering insights into dynamic interactions and enabling adaptive measures to manage risks and uncertainties, it improves the resilience of supply chains.

Table 5. Parameter

Symbolical corresponding parameter		
S.N.	**Linguistics notation in SWARA numbers**	**Scale**
1	No impact (N)	[1, 1]
2	Very low impact (VL)	[1, 2]
3	Low impact (L)	[2, 3]
4	High impact (H)	[3, 4]
5	Very high impact (VH)	[4, 5]

Step 1: The priority has been given by the five group of experts in weightages.
Step 2: Normalization has been found out with the help of prioritization [Equation 1]

$$\rho_{ij} = \frac{p_{r(\max)} - p_{r(\mathrm{i})}}{p_{r(\max)} - p_{r(\min)}} \tag{1}$$

Step 3: Deviation sequence has been obtained with the help of [Equation 2].

$$D_{(seq)} = 1 - \rho_{ij} \tag{2}$$

Step 4: Grey relational coefficient has been obtained by the equation-3.

$$G_{r(coeff.)} = \frac{[0 + (0.5 * 1)]}{[D_{(seq)} + (0.5 * 1)]} \tag{3}$$

Step 5: Grade of each prioritized value given by experts has been converted with the help of equation-4.

$$Grade = \sum_{i=1}^{n} G_{r(coeff.)} \tag{4}$$

Step 6: On the basis of grades [Equation 4] the rank is calculated and applied in the second method i.e., SWARA technique.

Table 6. Normalized value

Normalization				
Group of Industrialists	**Group of Academicians**	**Group of Technology Innovators**	**Group of Agricultural Economists**	**Group of Agricultural Engineers**
0.5625	0.2308	0.0000	0.7500	0.2000
0.0000	0.3077	0.0556	0.0833	0.4667
0.1875	0.4615	0.5000	0.4167	0.3333
0.7500	0.2308	0.3333	0.0000	0.5333
1.0000	0.1538	0.2222	0.2500	0.6000
0.8750	0.7692	1.0000	0.8333	0.2000
0.4375	0.5385	0.0556	0.6667	0.7333
0.8750	0.3846	0.2222	0.4167	1.0000
0.8125	0.4615	0.6667	0.5833	0.0000
0.5625	0.6923	0.9444	0.9167	0.2667
0.3750	0.7692	0.7778	1.0000	0.7333
0.6250	1.0000	0.8333	0.4167	0.4667
0.6875	0.0000	0.4444	1.0000	0.6000

Table 7. Deviation sequence of Normalized value

Deviation Sequence

Group of Industrialists	Group of Academicians	Group of Technology Innovators	Group of Agricultural Economists	Group of Agricultural Engineers
0.4375	0.7692	1.0000	0.2500	0.8000
1.0000	0.6923	0.9444	0.9167	0.5333
0.8125	0.5385	0.5000	0.5833	0.6667
0.2500	0.7692	0.6667	1.0000	0.4667
0.0000	0.8462	0.7778	0.7500	0.4000
0.1250	0.2308	0.0000	0.1667	0.8000
0.5625	0.4615	0.9444	0.3333	0.2667
0.1250	0.6154	0.7778	0.5833	0.0000
0.1875	0.5385	0.3333	0.4167	1.0000
0.4375	0.3077	0.0556	0.0833	0.7333
0.6250	0.2308	0.2222	0.0000	0.2667
0.3750	0.0000	0.1667	0.5833	0.5333
0.3125	1.0000	0.5556	0.0000	0.4000

Table 8. Grey rational Coefficient from Deviation Sequence

Grey Relational Coefficient				
Group of Industrialists	**Group of Academicians**	**Group of Technology Innovators**	**Group of Agricultural Economists**	**Group of Agricultural Engineers**
0.533333	0.393939	0.333333	0.666667	0.384615
0.333333	0.419355	0.346154	0.352941	0.483871
0.380952	0.481481	0.500000	0.461538	0.428571
0.666667	0.393939	0.428571	0.333333	0.517241
1.000000	0.371429	0.391304	0.400000	0.555556
0.800000	0.684211	1.000000	0.750000	0.384615
0.470588	0.520000	0.346154	0.600000	0.652174
0.800000	0.448276	0.391304	0.461538	1.000000
0.727273	0.481481	0.600000	0.545455	0.333333
0.533333	0.619048	0.900000	0.857143	0.405405
0.444444	0.684211	0.692308	1.000000	0.652174
0.571429	1.000000	0.750000	0.461538	0.483871
0.615385	0.333333	0.473684	1.000000	0.555556

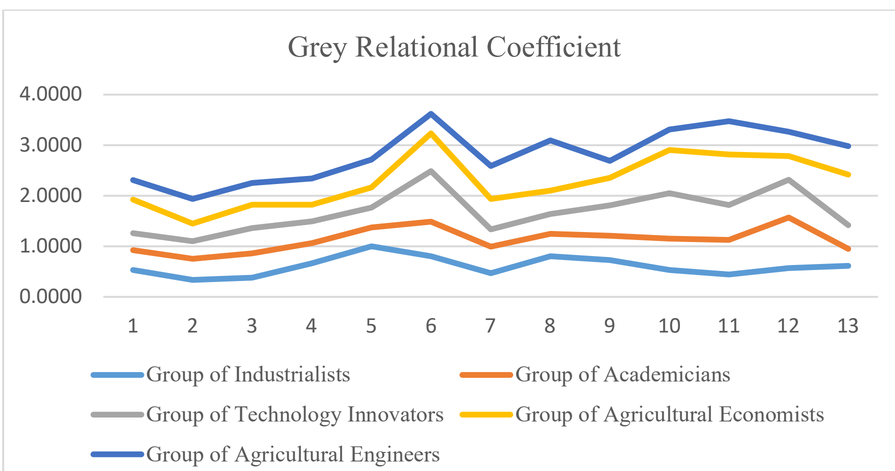

Figure 3. Grey Relational Coefficient

Table 9. Grade and Rank of alternatives

Code	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}
Grade	0.4624	0.3871	0.4505	0.4680	0.5437	0.7238	0.5178	0.6202	0.5375	0.6630	0.6946	0.6534	0.5956
Rank	11	13	12	10	7	1	9	5	8	3	2	4	6

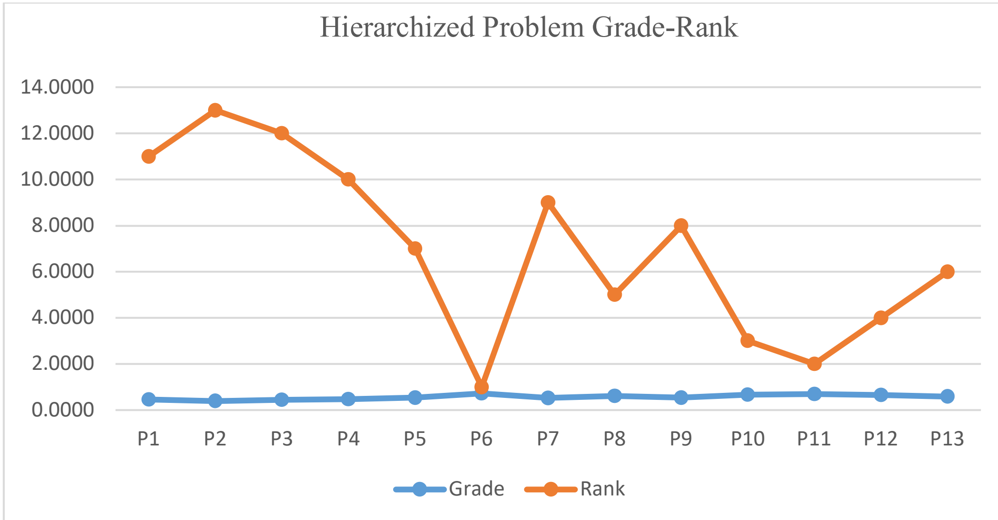

Figure 4. Hierarchized problem grade rank

3.6 Problems hierarchize by SWARA method

SWARA provides a methodical approach to ranking elements including distribution networks, storage facilities, and modes of transportation according to their significance and influence. Stakeholders may efficiently evaluate the relative weight of various factors and make well-informed decisions about risk management, process optimization, and resource allocation by utilizing SWARA. By allowing for a thorough examination of variables including affordability, food safety, sustainability, and regulatory compliance, this approach improves the resilience and overall performance of agri-food supply chains.

There are five groups in this study, with four specialists in each group. Thus, the averages of four distinct groups like academicians, agri-food experts, industrialists, and suppliers have been calculated [16 & 17]. Compared to other procedures (AHP, F-AHP, GRA Grey), the SWARA technique is a more straightforward and easy method of comparison [18]. Experts are essential in the SWARA technique because they are able to assign weights based on their expertise with various challenges. [Table 1]. A scale ranging from 1 to 9 has been used to assign each expert's viewpoint.

Step 1. Expert opinions of each index were obtained [Table-13].

Step 2. This hierarchized value of each challenge will be calculated for getting weighted values [Table-14].

Step 3. Determine the relative variance in perspectives between each successive index

$$\ell_2 = [Opinion\ P2 - Opinion\ P3] \tag{5}$$

Step 4. The growth value of n_j is calculated by [Equation 6]

$$\begin{Bmatrix} m_j = (1 + l_j) \\ n_j = \dfrac{n_j - 1}{m_j} \end{Bmatrix} \tag{6}$$

Step 5. From [Equation 2] gives m_j and n_j is calculated.

Step 6. n_j is employed to determine the weight of each index τ_j [Equation 7]. [Table 14].

$$\tau_j = \frac{n_j}{\sum_{j=1}^{j=13} n_j} \tag{7}$$

Table 10. Distributive weights for each alternative by SWARA method

Experts	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}
ω_j	0.0933	0.0888	0.0808	0.0702	0.0540	0.0900	0.0750	0.0883	0.0706	0.0673	0.0747	0.0830	0.0639

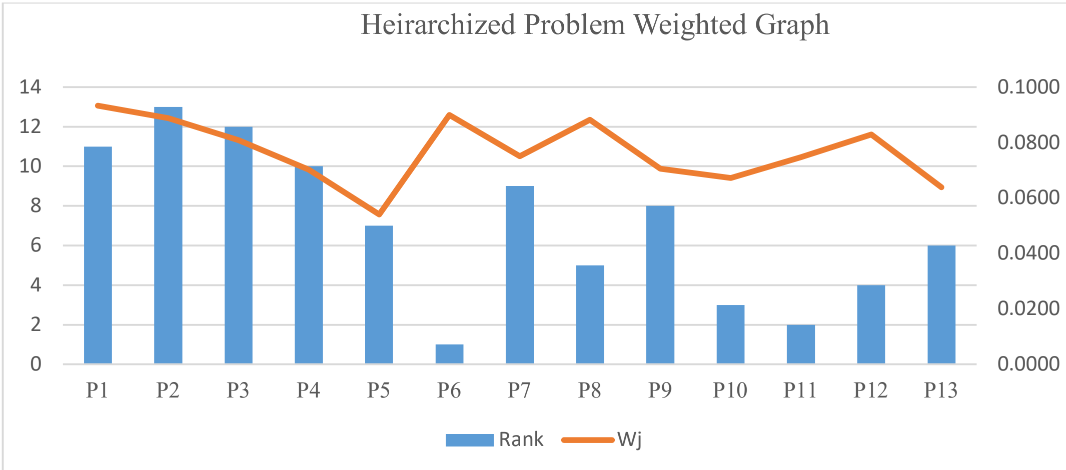

Figure 5. Hierarchized problem weighted graph

3.7 Problems and strategies hierarchize by TOPSIS method

In the context of agri-food supply chains, where a multitude of factors impact profitability, sustainability, and efficiency, TOPSIS offers an organized method for sorting through options and determining which ones are best. Stakeholders can use TOPSIS to evaluate the effectiveness of various supply chain components, including distribution channels, storage facilities, and transportation routes, depending on a variety of factors like cost, dependability, food safety, and environmental impact. This enables decision-makers to recognize the supply chain's advantages and disadvantages and to decide how best to enhance it.

Additionally, TOPSIS makes sensitivity analysis easier, allowing stakeholders to comprehend how different scenarios or adjustments to criteria weights affect the results of decisions. This capacity is especially helpful in the dynamic and unpredictable world of agri-food supply chains, where variables like the weather, consumer demand, and legal requirements are often changing.

Step 1: Calculate Normalized Matrix [Table 16]: As per the preference given by all experts the following table contains the normalized weight by the [Equation 8]. The [Equation 9 & 10] converts the preferences into weights. Get the decision matrix as follows:

$$X_{ij} = \begin{vmatrix} x_{11} & \dots & x_{1n} \\ \dots & \dots & \dots \\ x_{m1} & \dots & x_{mn} \end{vmatrix} \tag{8}$$

Step 2: Compute normalized decision matrix for i = 1… m, j = 1 … n

Calculate Weight Normalized Matrix [Table 17]. The weight normalized is obtained by the normalized value of each weight opted in row & column. The aim is to keep the weighted value against the preferences of 20 experts.

$$\bar{\eta}_{ij} = \begin{vmatrix} \eta_{11} & \dots & \eta_{1n} \\ \dots & \dots & \dots \\ \eta_{m1} & \dots & \eta_{mn} \end{vmatrix} \tag{9}$$

$$\bar{\eta}_{ij} = \frac{\eta_{ij}}{\sqrt{\sum_{i=1}^{n} \eta_{ij}^2}} \tag{10}$$

Table 11. Normalized decision matrix

STGY	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}
S1	0.0273	0.0372	0.0301	0.0333	0.0353	0.0320	0.0512	0.0410	0.0450	0.0275	0.0213	0.0294	0.0230
S2	0.0449	0.0465	0.0256	0.0323	0.0185	0.0306	0.0394	0.0449	0.0358	0.0288	0.0417	0.0437	0.0316
S3	0.0586	0.0374	0.0428	0.0413	0.0277	0.0456	0.0224	0.0391	0.0277	0.0203	0.0345	0.0324	0.0405

S4	0.0313	0.0506	0.0306	0.0252	0.0212	0.0567	0.0192	0.0396	0.0236	0.0348	0.0317	0.0225	0.0162
S5	0.0391	0.0197	0.0468	0.0212	0.0105	0.0292	0.0242	0.0316	0.0188	0.0362	0.0115	0.0137	0.0331

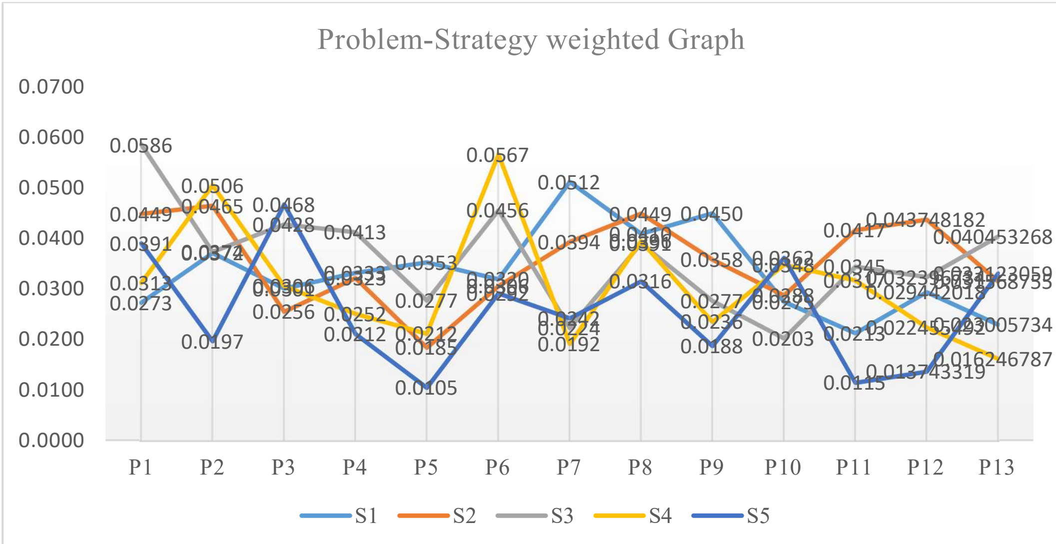

Figure 6. Problem strategy weight graph

Step 3: Compute weighted decision matrix:
For Calculating the ideal best and ideal worst value first choose minimum and maximum value from each column S_i- & S_i+ respectively. Then the Euclidian distance from the ideal best (**μ_i+**) and Euclidian distance from the ideal worst (**μ_i-**) has been calculated in the following step.

$$\delta_{ij} = \overline{\eta_{ij}} \times \boldsymbol{\lambda}_{\mathbf{ij}} = \begin{bmatrix} \delta_{11} & \dots & \delta_{1n} \\ \dots & \dots & \dots \\ \delta_{m1} & \dots & \delta_{mn} \end{bmatrix} \tag{11}$$

Step 4: Get the positive ideal (υ^+) and the negative ideal (υ^-) solutions
Calculate the Euclidean distance from the ideal best by the [Equation 12] [Table 12].

$$\begin{Bmatrix} \upsilon^+ = (\delta_1^+, \delta_2^+, \dots\dots\dots\dots\dots \delta_n^+) \\ \upsilon^- = (\delta_1^-, \delta_2^-, \dots\dots\dots\dots\dots \delta_n^-) \end{Bmatrix} \tag{12}$$

Step 5: Compute the separation measures ξ_i+ and ξ_i- (i= 1 … m)
Calculate the Euclidean distance from the ideal best and ideal worst by [Equation 13 & 14].

$$\xi_i^+ = \left[\sum_{j=1}^{m} \left(\delta_{ij} - \delta_j^+ \right)^2 \right]^{\frac{1}{2}} \tag{13}$$

$$\xi_i^- = \left[\sum_{j=1}^{m} \left(\delta_{ij} - \delta_j^- \right)^2 \right]^{\frac{1}{2}} \tag{14}$$

Step 6: Calculate the proximity to the ideal solution for each alternative (i = 1…m) and rank hierarchy for calculating Performance Score (φ_i) the Euclidean distance from the ideal best and Euclidean distance from the ideal worst has been used in the following [Equation 15].

$$\varphi_i = \frac{\xi_i^-}{\xi_i^+ + \xi_i^-} \tag{15}$$

4.0 Case Study

In the agri-food industry XYZ Company transformed their supply chain operations to increase revenue strategically. Company XYZ reduced waste and improved quality control by implementing digital transformation and integrating blockchain and IoT technology to provide product traceability and transparency from farm to table. They established solid alliances with nearby farmers, guaranteeing a consistent flow of raw materials and advancing environmentally friendly farming practices. In order to optimize inventory management, save holding costs, and avoid stockouts, advanced analytics were used. Sustainability was a major priority, with eco-friendly operations drawing in ecologically sensitive customers to boost brand loyalty. Furthermore, XYZ made use of data analytics to comprehend and address customer preferences, which raised customer happiness and boosted revenue. The agri-food business witnessed a notable 20% increase in earnings as a consequence of these strategic initiatives, demonstrating the significant influence of creative supply chain management.

Table 12. Performance Score

Strategies	Ideal Best ξ_i^+	Ideal Worst ξ_i^-	Performance Score φ_i	Rank
S_1	0.8811	0.0574	0.0612	**4**
S_2	0.0047	0.0453	0.9051	**1**
S_3	0.8532	0.0453	0.0504	**5**
S_4	0.9617	0.0658	0.0640	**3**
S_5	1.0007	0.0851	0.0784	**2**

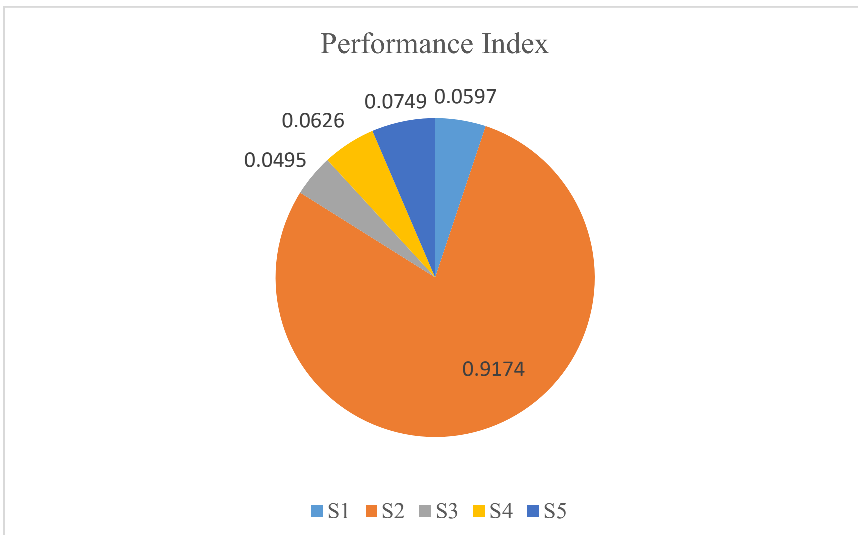

Figure 7. Performance Score

5.0 Result Analysis

This provides the crucial analysis for decision making through GRA Grey, SWARA & TOPSIS techniques. The step-by-step approaches conclude the selection procedure for best strategy among all the collaborators [Figure 2]. All the approaches validate the outcome of the result. In this study the three approaches of MCDM refines and provide the appropriate analysis.

Table 13. Group-wise hierarchized opinion

Problems	Group of Industrialists	Group of Academicians	Group of Technology Innovators	Group of Agricultural Economists	Group of Agricultural Engineers
P_1	5	3	1	9	2
P_2	1	5	2	2	6
P_3	2	7	8	4	5
P_4	9	4	6	1	8
P_5	13	2	4	3	9
P_6	11	11	13	10	3
P_7	4	9	3	8	11

P_8	12	6	5	6	13
P_9	10	8	9	7	1
P_{10}	6	10	12	11	4
P_{11}	3	12	10	12	12
P_{12}	7	13	11	5	7
P_{13}	8	1	7	13	10

Table 14. Weights obtained by SWARA for each challenge

Challenges	Rank	Opinion %	ℓ_i	m_i	n_i	τ_j
P_1	11	0.55		1	1	0.0933
P_2	13	0.65	0.05	1.05	0.9524	0.0888
P_3	12	0.60	0.10	1.10	0.8658	0.0808
P_4	10	0.50	0.15	1.15	0.7529	0.0702
P_5	7	0.35	0.30	1.30	0.5791	0.0540
P_6	1	0.05	-0.40	0.60	0.9652	0.0900
P_7	9	0.45	0.20	1.20	0.8043	0.0750
P_8	5	0.25	-0.15	0.85	0.9463	0.0883
P_9	8	0.40	0.25	1.25	0.7570	0.0706
P_{10}	3	0.15	0.05	1.05	0.7210	0.0673
P_{11}	2	0.10	-0.10	0.90	0.8011	0.0747
P_{12}	4	0.20	-0.10	0.90	0.8901	0.0830
P_{13}	6	0.30	0.30	1.30	0.6847	0.0639
			Total			**1.0000**

In SWARA technique the problem coded P_6 indicates the rank 1 [Table 14]. The rank score of all 13 problem is as follows: $P_6 > P_{11} > P_{10} > P_{12} > P_8 > P_{13} > P_5 > P_9 > P_7 > P_4 > P_1 > P_3 > P_2$. This shows that the top three problems are P_6, P_{11}, P_{10}. For the next phase the identification of strategies is calculated by TOPSIS method (Saaty, 2008) by using the (1-9) scale [Table 5]. The obtained hierarchized rank of problems used in TOPSIS technique. TOPSIS mapping provides the best strategy [Table 18]. In the sequence of the strategies S2 > S5 > S4 > S1 > S3, the best is identified S2 (Score 1). The individual group is analyzed by the SWARA technique and weights are obtained [Table 15]. In the various sets of strategies S_2 shows the robustness and rigidness. While other parameters remain near the main result when makes fluctuation in values. Overall, it remains in the same sequence S2 > S5 > S4 > S1 > S3.

Table 15. Computed values for individual group of experts

Codes	Group 1	Group 2	Group 3	Group 4	Group 5
P_1	0.0461	0.0588	0.0454	0.0528	0.0569
P_2	0.0485	0.0653	0.0649	0.0587	0.0542
P_3	0.0746	0.0568	0.0590	0.0510	0.0638
P_4	0.0933	0.0516	0.0536	0.0567	0.0671
P_5	0.0848	0.0939	0.0975	0.0872	0.0516
P_6	0.0628	0.0854	0.0650	0.0793	0.0860
P_7	0.1047	0.0742	0.0722	0.0721	0.0956
P_8	0.0952	0.0825	0.0903	0.0759	0.0598
P_9	0.0793	0.0916	0.1062	0.0948	0.0703
P_{10}	0.0690	0.1018	0.0966	0.0998	0.1172
P_{11}	0.0862	0.1072	0.1017	0.0739	0.0937
P_{12}	0.0907	0.0670	0.0847	0.1232	0.1103
P_{13}	0.0648	0.0638	0.0628	0.0747	0.0735
Total	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**

5.1 Discussion

Collectively the opinion of individual group and collaborated results shows that there are top three problems identified P_6, P_{11}, P_{10}. In this sequence the mainly focus on “Reliability and Maintenance”, “Quality assurance” and “Consumer Awareness and Demand for Transparency” [35]. So that this phenomenon is impartial to set the best strategy which is identified by the performance score of TOPSIS technique. The best strategy S_2 “Inventory Optimization”, S_5 “Regulatory Compliance” and S_4 “Technology Integration”. In this case the collaborators will always suggest the best performance score i.e., S_2. This is the most significant strategy for the identified 13 problem [21].

Table 16. Normalized Matrix

W_j	0.0933	0.0888	0.0808	0.0702	0.0540	0.0900	0.0750	0.0883	0.0706	0.0673	0.0747	0.0830	0.0639
STGY	**P_1**	**P_2**	**P_3**	**P_4**	**P_5**	**P_6**	**P_7**	**P_8**	**P_9**	**P_{10}**	**P_{11}**	**P_{12}**	**P_{13}**
S1	1.5643	2.3654	2.5491	3.6969	4.9587	2.5852	4.9631	3.8264	4.1397	3.7845	2.2584	3.3321	2.7264
S2	2.5698	2.9584	2.1654	3.5847	2.5931	2.4752	3.8137	4.1937	3.2937	3.9612	4.4158	4.9512	3.7412
S3	3.3548	2.3784	3.6251	4.5869	3.8974	3.6914	2.1659	3.6482	2.5468	2.7921	3.6548	3.6665	4.7941
S4	1.7894	3.2154	2.5914	2.7951	2.9835	4.5823	1.8596	3.6918	2.1649	4.7932	3.3632	2.5414	1.9254
S5	2.2365	1.2548	3.9584	2.3548	1.4789	2.3625	2.3485	2.9487	1.7235	4.9854	1.2212	1.5554	3.9254

Table 17. Weighted Normalized matrix

STGY	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}
S1	0.0273	0.0372	0.0301	0.0333	0.0353	0.0320	0.0512	0.0410	0.0450	0.0275	0.0237	0.0363	0.0218
S2	0.0449	0.0465	0.0256	0.0323	0.0185	0.0306	0.0394	0.0449	0.0358	0.0288	0.0463	0.0540	0.0300
S3	0.0586	0.0374	0.0428	0.0413	0.0277	0.0456	0.0224	0.0391	0.0277	0.0203	0.0383	0.0400	0.0384
S4	0.0313	0.0506	0.0306	0.0252	0.0212	0.0567	0.0192	0.0396	0.0236	0.0348	0.0353	0.0277	0.0154
S5	0.0391	0.0197	0.0468	0.0212	0.0105	0.0292	0.0242	0.0316	0.0188	0.0362	0.0128	0.0170	0.0315

5.2 Variation of Weight Set

The performance score is derived from the TOPSIS results. As a result, several sets of weight variations have been found. These sets demonstrate the degree of sensitivity deviation. The performance score was obtained using the obtained weight sets and weight variation. The sets of preferences for the various strategies are displayed in the following table. The degree to which the outcomes of the various sets of methods vary will be reflected in these scores. Additionally, the sets of strategies will determine the rank-wise repetition of which sequence. In order to validate the stability of the strategy sequencing.

Table 18. Variation of weight

STGY/PROBLEMS	S1	S2	S3	S4	S5	Ranking
P_1	0.05966	0.91738	0.04946	0.06260	0.07490	S2 > S5 > S4 > S1 > S3
P_2	0.05991	0.87834	0.05133	0.06745	0.07965	S2 > S5 > S4 > S1 > S3
P_3	0.05883	0.88186	0.05602	0.06953	0.08555	S2 > S5 > S4 > S1 > S3
P_4	0.06169	0.86870	0.05611	0.07183	0.08650	S2 > S5 > S4 > S1 > S3
P_5	0.06138	0.92366	0.05087	0.06646	0.08094	S2 > S5 > S4 > S1 > S3
P_6	0.06139	0.86798	0.05475	0.07019	0.08354	S2 > S5 > S4 > S1 > S3
P_7	0.05999	0.88408	0.05681	0.07050	0.08448	S2 > S5 > S4 > S1 > S3

P_8	0.05384	0.93111	0.05418	0.06313	0.07522	S2 > S5 > S4 > S3 > S1
P_9	0.06321	0.87188	0.05972	0.07140	0.08971	S5 > S2 > S4 > S1 > S3
P_{10}	0.05713	0.86433	0.05460	0.06814	0.08551	S2 > S5 > S4 > S1 > S3
P_{11}	0.05880	0.87841	0.05352	0.06976	0.08621	S2 > S5 > S4 > S1 > S3
P_{12}	0.05937	0.86367	0.05387	0.06859	0.08411	S2 > S5 > S4 > S1 > S3
P_{13}	0.06310	0.88956	0.05706	0.06960	0.08445	S2 > S5 > S4 > S1 > S3

In the [Table 18] it is clear that the ranking is mostly sequenced in S2 > S5 > S4 > S1 > S3. There are some fluctuations in sequencing. The percentage of the strategy S1, S2, S3, S5 remains 7.69% in 8th and 9th result. The table is also representing the tendency of strategy S4 which shows robustness (100%) as it is fixed and do not become change in sequence.

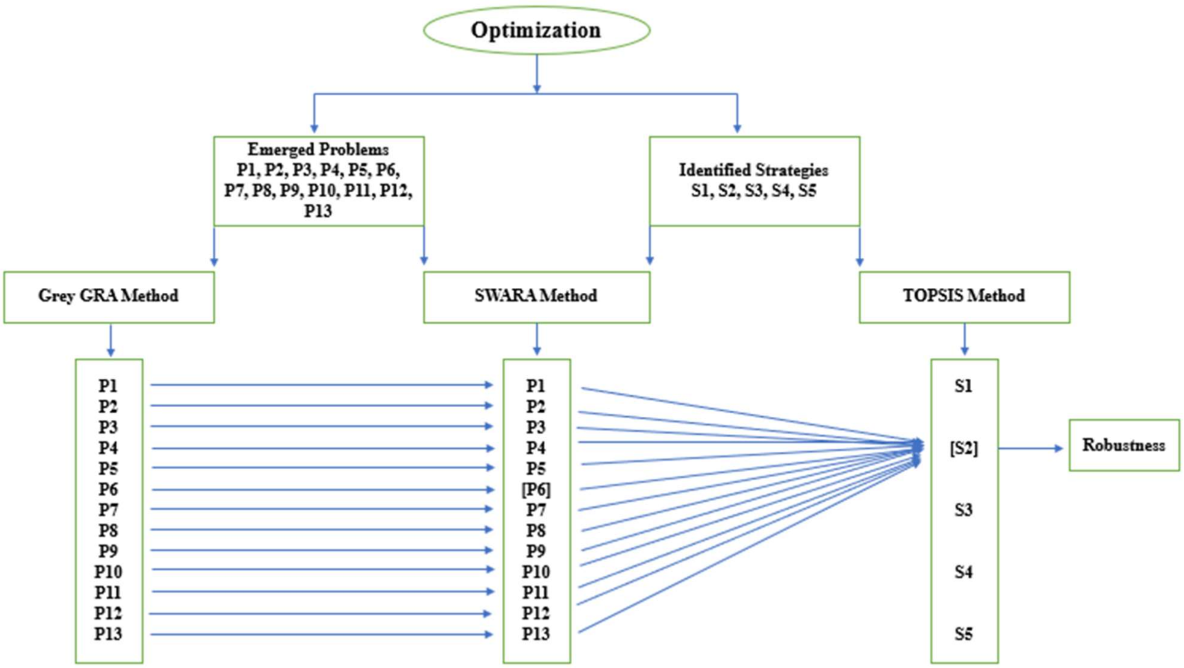

Figure 8. Input techniques

5.3 Sensitivity analysis

In the following table the 13-sets and the problems are mapped. The Set 1 is ideal and shows robustness. Other sets are having some different figures by fluctuating in opinions of experts. [Table18 & 19]. Strategies S2 shows maximum importance while S3 minimum. So that all the group of experts reach to the same prioritization [S2 > S5 > S4 > S1 > S3]. This results the robustness of the S2 & S3. [Table 18 & 19] [Figure 7].

Table 19. Sensitivity analysis

SETS	Set1	Set2	Set3	Set4	Set5	Set6	Set7	Set8	Set9	Set10	Set11	Set12	Set13
P_1	0.0933	0.0799	0.0509	0.0694	0.1022	0.0613	0.0700	0.0596	0.0385	0.0449	0.0668	0.0639	0.0540
P_2	0.0888	0.0666	0.0636	0.0631	0.0973	0.0645	0.0609	0.0662	0.0962	0.0817	0.0607	0.0710	0.0600
P_3	0.0808	0.0701	0.0578	0.0526	0.0847	0.0679	0.0580	0.0697	0.0663	0.0584	0.0552	0.0546	0.0461
P_4	0.0702	0.0638	0.0609	0.0701	0.0806	0.0755	0.0645	0.0774	0.0829	0.0648	0.0480	0.0643	0.0923
P_5	0.0540	0.0554	0.0761	0.0779	0.0948	0.0604	0.0678	0.0737	0.0754	0.0683	0.0800	0.0612	0.0839
P_6	0.0900	0.0584	0.0801	0.0557	0.0790	0.0549	0.0798	0.0983	0.0793	0.0546	0.0728	0.0583	0.0799
P_7	0.0750	0.0614	0.0728	0.0619	0.0753	0.0578	0.0760	0.0936	0.0721	0.0520	0.0606	0.0530	0.0726
P_8	0.0883	0.0819	0.0857	0.0687	0.0717	0.0525	0.0950	0.0694	0.0901	0.1040	0.0674	0.1060	0.0605

P9	0.0706	0.0964	0.1008	0.1057	0.0623	0.1051	0.1056	0.0578	0.0949	0.1156	0.1123	0.1116	0.0673
P10	0.0673	0.0918	0.0960	0.1007	0.0656	0.1001	0.0918	0.0642	0.0999	0.0963	0.0976	0.0970	0.0961
P11	0.0747	0.1020	0.0640	0.1119	0.0691	0.1177	0.1020	0.0988	0.0689	0.1014	0.1085	0.0882	0.1068
P12	0.0830	0.1073	0.1163	0.0973	0.0601	0.1121	0.0658	0.1040	0.0725	0.0922	0.1033	0.1038	0.1124
P13	0.0639	0.0650	0.0751	0.0649	0.0572	0.0701	0.0627	0.0671	0.0631	0.0658	0.0667	0.0670	0.0681
Total	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**

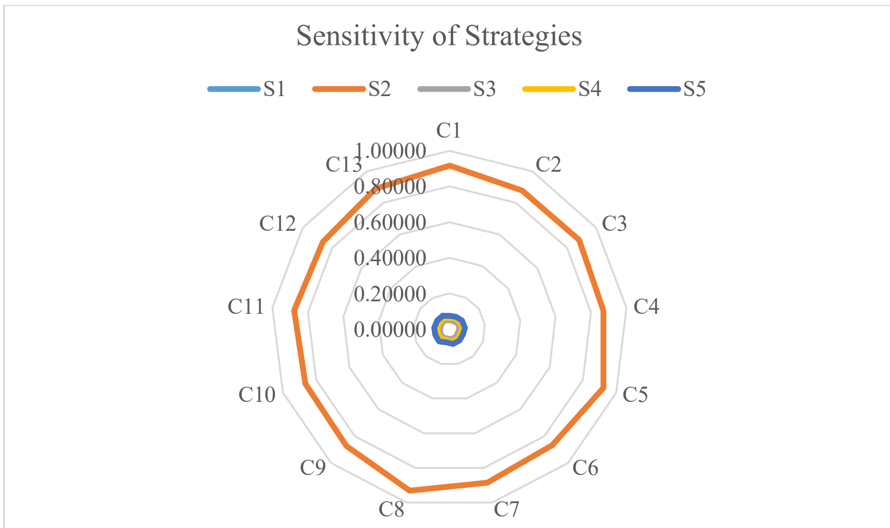

Figure 9. Sensitivity analysis in variation of weights of strategies

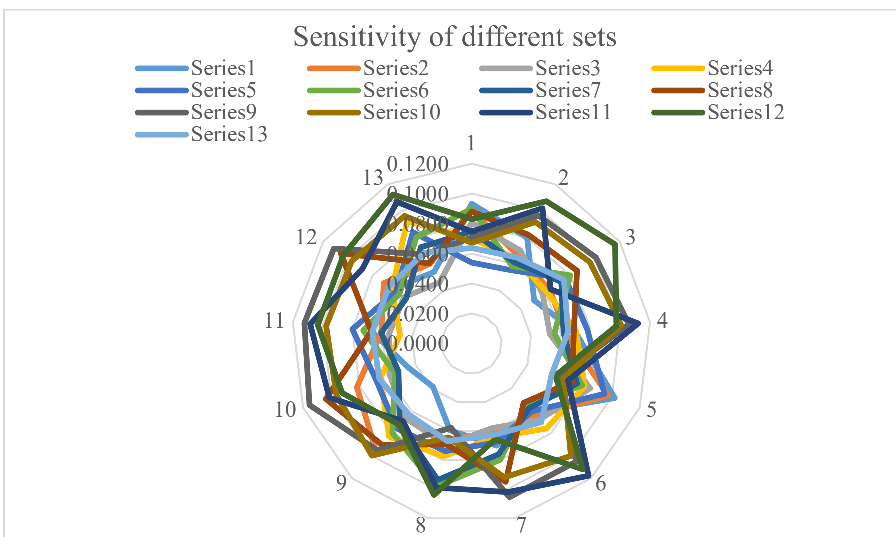

Figure 10: Sensitivity of different sets of criteria

6.0 Conclusion

Criteria weights are calculated by using SWARA, ensuring the total weight equals one. Strategies are prioritized using TOPSIS based on these weights. The process involves three steps: normalizing opinions, ranking criteria, and mapping weights to select effective strategies. The process refines the result more by these techniques. Techniques used include Grey-GRA for normalization, SWARA for weight calculation, and TOPSIS for performance score and strategy selection. These methods collectively form a multi-criteria decision-making (MCDM) approach, ensuring systematic prioritization and effective resolution of supply chain challenges. The use of Grey-GRA, SWARA, and TOPSIS techniques in agri-food supply chain management (SCM) demonstrates a structured approach to prioritizing criteria and selecting strategies. The analysis confirms that Strategy S2 holds the highest importance, followed by S5, S4, S1, and S3. The robustness of S2 is particularly notable, suggesting it is highly effective in addressing the challenges in agri-food SCM. The robustness of S4 remains 100% while S2, S5, S1, S3 remains 7.69%. This outcome concludes that the sensitivity of strategies [Figure 8] and the sensitivity of the alternatives distributed among all the different experts (sets) show collaborative approach [Figure 9]. This multi-criteria decision-making (MCDM) process ensures a consensus among experts and validates the prioritization methodology. The result as a conclusion reflects among the sensitivity of strategies S1, S2, S3, S4 and S5 the only S4 remains same considered as center while S2 consist of the top prioritization among all the strategies. S2 directs in different metrices of thirteen problems which occur in agri-food supply chain management. Among all the collaborators, enablers and suppliers the traceability and real time visibility play a vital role in agri-food supply chain but the applications become more efficient while the AI and ML together tackles to find the various problem by setting some strategies against it. Really the automize optimization in agri-food supply chain management gets crucial advantage.

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