Article history:
Received 19 April 2026
Revised 22 June 2026
Accepted 05 July 2026
Initial Publish 28 July 2026
Published online 01 January 2027

Journal of Resource Management and Decision Engineering

Volume 6, Issue 1, pp 1-14

Presenting a LARG Supply Chain Model with a Hybrid Approach in the Poultry Industry in Northern Iran

Kaveh. Kafili Kasmaei[1], Arshad. Farahmandian[1*], Homa. Doroudi[1], Nabiollah. Mohammadi[1]

[1] Department of Management, Za.C., Islamic Azad University, Zanjan, Iran

*** Corresponding author email address**: 4280924015@iau.ir

Article Info

Article type:
Original Research

How to cite this article:
Kafili Kasmaei, K., Farahmandian, A., Doroudi, H., & Mohammadi, N. (2027). Presenting a LARG Supply Chain Model with a Hybrid Approach in the Poultry Industry in Northern Iran. *Journal of Resource Management and Decision Engineering*, *6*(1), 1-14.
https://doi.org/10.61838/kman.jrmde.390

ABSTRACT

The aim of the present study is to present a LARG supply chain model with a hybrid approach in the poultry industry in northern Iran. In terms of purpose, the present study is applied, and in terms of data nature, it was conducted using a mixed-methods approach (qualitative–quantitative). The qualitative section was carried out using a multiple fuzzy Delphi analysis approach, both deductively through a systematic review of the theoretical literature and inductively through semi-structured interviews with experts. The participants in the qualitative section included 20 university faculty members and senior managers of poultry industries, who were selected through non-probability theoretical sampling. Interpretive Structural Modeling (ISM) was used to analyze the data. The qualitative findings showed that the final indicators were classified into four main paradigms of the LARG supply chain, namely lean, agile, resilient, and green. To calculate the final weight of each indicator, the fuzzy Analytic Network Process (fuzzy ANP) method was used, and the results showed that just-in-time production, information technology, and continuous improvement obtained the highest final weights among the LARG supply chain indicators, respectively. The DEMATEL results indicate that, in the poultry industry, the lean paradigm has the highest importance with a weight of 35%, reflecting the industry's focus on cost reduction and efficiency improvement. The agile and resilient paradigms ranked next, whereas the green paradigm has received comparatively less attention in this industry.

Keywords: *LARG supply chain, fuzzy DEMATEL, ANP, ISM*

1. Introduction

Supply chain management has become one of the most decisive areas of strategic and operational decision-making in contemporary industries because firms are no longer evaluated only by their internal efficiency, but also by the responsiveness, adaptability, sustainability, and continuity of the networks through which raw materials, information, products, and services flow. In industries with high demand volatility, short product life cycles, biological risks, perishability, and strong dependence on logistics coordination, supply chain design is not merely a technical concern but a fundamental determinant of competitiveness and survival. The poultry industry is one such sector, because it is directly connected with food security, public health, agricultural production, livestock inputs, cold-chain logistics, market demand fluctuations, and environmental concerns. In this context, supply chain performance depends on the ability of firms to reduce waste and cost, respond rapidly to demand changes, withstand disruptions, and minimize environmental damage. Therefore, an integrated supply chain model that simultaneously considers efficiency, agility, resilience, and environmental responsibility is particularly relevant for the poultry industry.

The LARG supply chain framework, which integrates Lean, Agile, Resilient, and Green paradigms, has emerged as a comprehensive approach for developing supply chains that are efficient, responsive, disruption-resistant, and environmentally sustainable. The lean paradigm emphasizes waste elimination, cost reduction, process discipline, just-in-time production, and continuous improvement. The agile paradigm focuses on flexibility, speed, information sharing, responsiveness, and the capacity to adapt to changing customer and market requirements. The resilient paradigm addresses the ability of the supply chain to anticipate, absorb, recover from, and learn after disruptions. The green paradigm emphasizes environmentally responsible purchasing, production, logistics, design, recycling, and compliance with environmental standards. Early studies on LARG supply chain management conceptualized these four paradigms as complementary rather than isolated approaches and argued that supply chain competitiveness requires the coordinated integration of operational efficiency, market responsiveness, risk preparedness, and environmental sustainability (Azevedo et al., 2011; Carvalho & Cruz-Machado, 2011).

The relevance of LARG supply chain management has increased because supply chains are increasingly exposed to multidimensional pressures. These pressures include cost competition, unpredictable demand, supplier unreliability, climate-related risks, resource scarcity, regulatory expectations, and the need for sustainable development. The traditional view that supply chains can be optimized only through cost reduction is no longer sufficient. A supply chain that is lean but not resilient may be efficient under normal conditions but vulnerable during disruption. A supply chain that is agile but not lean may respond rapidly but at excessive cost. A supply chain that is resilient but not green may survive shocks but contribute to environmental degradation. Similarly, a green supply chain without agility and resilience may fail to meet dynamic market requirements. Therefore, the central logic of LARG is integration: each paradigm compensates for the limitations of the others while contributing to a broader model of sustainable supply chain performance (Cabral et al., 2011; Espadinha-Cruz et al., 2013; Shams & Salimi Zaviyeh, 2021).

The lean dimension of LARG supply chain management is rooted in the elimination of non-value-added activities and the continuous improvement of operational processes. Lean practices such as just-in-time production, waste reduction, pull production systems, production lead-time reduction, and continuous improvement can increase productivity and reduce unnecessary inventory and process inefficiencies. In supply chains with perishable products such as poultry, lean thinking is especially important because delays, excess inventory, and inefficient handling can directly increase waste and economic loss. Studies have emphasized that lean supply chain assessment requires attention to maturity, process consistency, supplier coordination, and performance measurement rather than isolated implementation of individual tools (Soares et al., 2021). Moreover, lean planning in the context of Industry 4.0 suggests that digital technologies, information integration, and multidimensional operations management can strengthen the ability of lean systems to function in complex environments (Reyes et al., 2021). Continuous improvement practices such as Kaizen also reinforce the lean paradigm by encouraging systematic incremental improvement and employee participation in process optimization (Rusdiana & Soediantono, 2022).

The agile dimension is essential when supply chains operate under uncertain demand, variable market conditions, and changing customer expectations. Agility refers to the ability of the supply chain to respond quickly and effectively to changes in demand, supply, technology, and environmental conditions. In the poultry industry, agility is important because market demand may fluctuate due to seasonality, price changes, public health concerns, consumer preferences, and disruptions in feed, transportation, or distribution. Research on agile supply chain design has shown that identifying critical agility factors and understanding their interrelationships is necessary for effective supply chain responsiveness (Piya et al., 2020). In the poultry sector, key agility variables have been identified as influential factors in improving supply chain sustainability, indicating that agility is not merely a speed-oriented capability but also a contributor to broader sustainable performance (Yunita et al., 2022). Information technology, flexible operations, quick responsiveness, process reengineering, and customer relationship management are therefore among the most important mechanisms through which agility can be operationalized in a LARG supply chain.

The resilient dimension of the LARG framework has become increasingly important due to the growing frequency and severity of supply chain disruptions. Resilience refers to the ability of a supply chain to prepare for disruptions, reduce vulnerability, maintain continuity during crises, recover after disturbances, and learn from previous events. The COVID pandemic, geopolitical instability, disease outbreaks, transportation bottlenecks, and input shortages have shown that supply chains cannot rely solely on efficiency-based designs. For the poultry industry, resilience is particularly crucial because disruptions in feed supply, disease control, transportation, labor availability, and cold-chain distribution can rapidly affect production continuity and food availability. A multi-period, multi-modal stochastic supply chain model developed for the poultry industry under pandemic conditions illustrates the complexity of planning poultry supply chains in uncertain environments and highlights the importance of risk-sensitive design (Wang et al., 2021). Similarly, research on LARG supply chain risks has shown that identifying risk categories and developing a structured framework for risk recognition are necessary prerequisites for resilient supply chain management (Gharghachian et al., 2022).

The green dimension of LARG supply chain management reflects the increasing importance of environmental responsibility in production and distribution systems. Green supply chain practices include environmentally responsible purchasing, green logistics, green design, reuse, recycling, waste management, and environmental certification. In the poultry industry, environmental issues may arise from feed sourcing, energy consumption, water use, waste generation, packaging, transportation emissions, and biological by-products. Therefore, green supply chain practices can contribute to both environmental performance and social legitimacy. A diagnostic instrument proposed for assessing environmental management in LARG supply chains indicates that supplier evaluation and environmental criteria should be incorporated into supply chain assessment rather than treated as peripheral concerns (Sousa et al., 2020). In addition, sustainability performance evaluation and scenario planning in the LARG supply chain demonstrate that environmental criteria should be integrated into strategic supply chain assessment, especially when long-term sustainability and uncertainty are considered (Izadiyar et al., 2021).

The poultry industry has a special position in food security and agricultural economics. Poultry production is associated with the supply of affordable animal protein, employment, rural and regional economic development, and national food supply stability. Therefore, improving poultry supply chain performance is not only an organizational concern but also a broader economic and social priority. Studies on the efficiency and effectiveness of livestock and poultry production have emphasized the importance of this sector in achieving food security across provinces, showing that poultry production should be evaluated in relation to productivity, regional capacity, and supply stability (Ghomsheh et al., 2022). Given the sensitivity of poultry products to time, temperature, disease, and logistics conditions, the industry requires a supply chain model that can simultaneously reduce operational inefficiency, respond to market changes, protect against disruptions, and support sustainable production. This makes the LARG framework particularly suitable for poultry supply chain modeling.

Previous research has applied the LARG framework in different industrial contexts and has shown its usefulness for supply chain evaluation, strategic alignment, and performance improvement. In the automotive industry, the identification of lean, agile, resilient, and green implementation dimensions has shown that LARG can serve as a practical framework for diagnosing supply chain capabilities across industrial systems (Aisyah et al., 2021). In the cement industry, the evaluation of competitive strategies based on gap analysis demonstrated that LARG supply chain management can be used to identify strategic deficiencies and prioritize improvement actions (Jamali & Karimi Asl, 2018). More recent reviews of LARG supply chain management in engineering, business, and management fields have highlighted the increasing diversity of LARG applications and the need for context-specific models that reflect the structural characteristics of each industry (Khanzadi et al., 2024). These studies suggest that although LARG is conceptually general, its indicators, causal relationships, and implementation priorities may differ across industries.

In addition to conceptual development, recent studies have increasingly focused on modeling techniques, decision-making methods, and performance evaluation tools for LARG supply chains. Meta-synthesis research has identified key success factors for implementing LARG supply chains, indicating that effective implementation depends on a structured understanding of organizational, technological, operational, and environmental factors (Nasiri Dehaj &

Morovati Sharifabadi, 2021). System dynamics has also been used to develop an effective LARG supply chain management model, showing that dynamic interactions among variables must be considered when evaluating long-term supply chain behavior (Khanzadi et al., 2023). Hierarchical DEMATEL has been applied to model causal relationships among LARG supply chain indicators, demonstrating the value of causal mapping in understanding which indicators influence others and which are more dependent (Mohammadi et al., 2023). These methodological developments confirm that LARG supply chain research requires integrated analytical approaches capable of capturing both weighting priorities and causal structures.

The increasing role of digitalization and advanced manufacturing has further strengthened the relevance of integrated LARG models. Industry 4.0 technologies, big data analytics, virtual supply chain systems, and advanced manufacturing capabilities can enhance visibility, responsiveness, coordination, and sustainability in supply chain networks. Research has shown that big data analytics can mediate the effects of LARG practices on sustainable supply chains, indicating that information processing capability is a key mechanism through which LARG practices generate performance outcomes (Raut et al., 2021). Industry 4.0 adoption and advanced manufacturing capabilities also support sustainable development by improving operational control, resource efficiency, and technological adaptability (Bag et al., 2021). Similarly, the construction of virtual supply chains using enterprise e-catalogues highlights the importance of digital information infrastructures for supply chain coordination and integration (Matsuda et al., 2020). These findings are particularly relevant for the poultry industry, where rapid information exchange, traceability, inventory control, and coordination between producers, suppliers, distributors, and customers are critical.

Decision-making methods are also central to LARG supply chain modeling because managers must prioritize indicators, evaluate suppliers, and allocate resources under uncertainty. Multiple-criteria decision-making approaches provide systematic tools for ranking alternatives and assessing complex criteria. The opportunity losses-based polar coordinate distance approach has been introduced as a novel multiple-criteria decision-making method, and its later application to LARG supplier performance evaluation demonstrates its relevance for evaluating suppliers in complex LARG contexts (Mohammadi Zanjirani & Sheikh, 2025; Sheikh & Senfi, 2024). These developments show that LARG supply chain management requires not only conceptual clarity but also quantitative tools for ranking, prioritization, and performance evaluation. In particular, fuzzy methods are appropriate because expert judgments about supply chain indicators are often expressed in linguistic, uncertain, and imprecise terms.

Despite the growing body of research on LARG supply chains, several gaps remain. First, many existing studies focus on manufacturing or general industrial contexts, while fewer studies have developed sector-specific LARG models for the poultry industry. Second, much of the literature emphasizes individual paradigms or limited combinations of indicators, whereas the poultry sector requires a simultaneous consideration of lean efficiency, agile responsiveness, resilient continuity, and green sustainability. Third, many studies provide conceptual frameworks or ranking models but do not fully integrate qualitative expert validation, fuzzy prioritization, causal analysis, and hierarchical structural modeling. Fourth, the northern region of Iran, with its specific poultry production capacities, supply chain conditions, climatic characteristics, logistics requirements, and market conditions, requires a localized model that reflects the realities of the industry. Therefore, a hybrid methodological approach can provide a more comprehensive understanding of LARG supply chain indicators by combining expert-based identification, fuzzy Delphi validation, fuzzy DEMATEL causal analysis, fuzzy ANP weighting, and ISM-based hierarchical modeling.

Accordingly, the aim of the present study was to present a hybrid LARG supply chain model for the poultry industry in northern Iran by identifying, validating, weighting, and structurally modeling the lean, agile, resilient, and green indicators of the supply chain.

2. Methods and Materials

In terms of purpose, the present study is applied, and the method used in this research is a mixed-methods design. In applied research, the results derived from existing knowledge and technology are used and developed for practical utilization in possible or specific contexts so that, if successful, they can lead to practical application. In addition, the sampling technique used at this stage of the present study was snowball sampling. Snowball sampling is a method in which sample units, while providing information about themselves, also provide the researcher with information about other units in the population.

In this study, expert opinions were used to identify and validate the indicators of the LARG supply chain in the poultry industry. The experts included university faculty members and senior managers of poultry industries who had sufficient experience and expertise in this field.

The expert population in this section consisted of 20 individuals, including 8 faculty members and 12 senior managers of poultry industries in northern Iran, who were selected through purposive sampling. The criteria for selecting the experts were as follows:

• A minimum of 10 years of work experience in the field of supply chain management or the poultry industry

• Holding a master's or doctoral degree in related fields

• Managerial experience at senior organizational levels

In the present study, the conceptual model of the research was first extracted from the theoretical foundations. Then, according to the research questions, the fuzzy Delphi technique was used to confirm and finalize the model. A fuzzy inference system includes a set of fuzzy membership functions as inputs or outputs and a set of fuzzy rules as the rule engine. The input consists of some vague and imprecise linguistic concepts related to a specific event, while the output includes either a fuzzy set or a crisp set of specific characteristics.

3. Findings and Results

In the first Delphi round, an open-ended questionnaire was provided to the experts so that they could express their views regarding the important indicators of the LARG supply chain in the poultry industry. Based on the review of the theoretical literature and the results obtained from qualitative analysis, a set of indicators and components was identified and submitted to the experts. The experts evaluated these indicators and, when necessary, suggested new indicators or deleted or modified some of the existing indicators. After collecting the experts' opinions, the final indicators were classified into the four main paradigms of the LARG supply chain, namely lean, agile, resilient, and green.

Table 1

Identified Indicators of the LARG Supply Chain in the Poultry Industry

Paradigm	Code	Indicator	Description
Lean	L1	Just-in-Time Production (JIT)	Inventory reduction and demand-based production
Lean	L2	Waste Reduction (RS)	Elimination of non-value-added activities
Lean	L3	Pull Production Line (TT)	Production based on customer orders
Lean	L4	Continuous Improvement (VIM)	Kaizen and continuous process optimization
Lean	L5	Production Lead-Time Reduction (PL)	Reduction of the production cycle time
Agile	A1	Information Technology (IT)	Use of integrated systems
Agile	A2	Flexibility (F)	Ability to respond quickly to changes
Agile	A3	Quick Responsiveness (QR)	Reduction of customer response time
Agile	A4	Process Reengineering (RR)	Innovation in business processes
Agile	A5	Customer Relationship Management (CRM)	Effective and sustainable communication with customers
Resilient	R1	Multiple Supplier Diversity (MSD)	Having multiple sources of supply
Resilient	R2	Supply Chain Security (SS)	Management of risks and disruptions
Resilient	R3	Recovery and Learning Capability (RLR)	Ability to recover rapidly after a crisis
Resilient	R4	Product Variety (DV)	Offering diverse products
Resilient	R5	Planning Preparedness (PRP)	Preventive planning for crises
Resilient	R6	Distribution System Flexibility (DTF)	Adaptability of the distribution system
Green	G1	Green Purchasing (PS)	Purchasing environmentally friendly raw materials
Green	G2	Green Logistics (GL)	Sustainable transportation and warehousing
Green	G3	Green Design (GD)	Designing environmentally compatible products
Green	G4	End-of-Use Reuse and Recycling (EUR)	Waste management and recycling
Green	G5	Environmental Certifications (ISO)	ISO 14001 environmental standards

To calculate the final weight of each indicator, the fuzzy Analytic Network Process (fuzzy ANP) method was used. This method consists of three main stages.

First, the unweighted supermatrix was formed based on experts' pairwise comparisons and indicated the relationships among all indicators.

Second, the weighted supermatrix was obtained by normalizing the unweighted supermatrix using the weights of the main paradigms.

Third, the limit supermatrix was calculated by raising the weighted supermatrix to powers until convergence was achieved. The limit supermatrix indicates the final and stable weights of each indicator.

Table 2

Final Weights of the LARG Supply Chain Indicators

Rank	Code	Indicator	Final Weight	Paradigm
1	L1	Just-in-Time Production (JIT)	0.0892	Lean
2	A1	Information Technology (IT)	0.0847	Agile
3	L4	Continuous Improvement (VIM)	0.0789	Lean
4	R1	Multiple Supplier Diversity (MSD)	0.0756	Resilient
5	A3	Quick Responsiveness (QR)	0.0723	Agile
6	L2	Waste Reduction (RS)	0.0698	Lean
7	A5	Customer Relationship Management (CRM)	0.0671	Agile
8	L3	Pull Production Line (TT)	0.0654	Lean
9	R3	Recovery and Learning Capability (RLR)	0.0628	Resilient
10	A2	Flexibility (F)	0.0602	Agile
11–28	...	...	...	...

The analysis of the first fuzzy Delphi round showed that 26 indicators out of the 28 initial indicators were confirmed by the experts. Two indicators were eliminated because their mean scores were lower than 3 on a five-point Likert scale. In addition, three new indicators were suggested by the experts and added to the list.

The descriptive statistics of the first round showed an overall mean of 4.23, a standard deviation of 0.87, and a coefficient of variation of 20.5%.

To examine the degree of consensus among the experts, Kendall's coefficient of concordance, known as Kendall's W, was used. This test determines whether experts agree in ranking the indicators. The results of the first round showed that Kendall's W was 0.468, with a chi-square statistic of 126.972, 19 degrees of freedom, and a significance level of 0.000. The value of W = 0.468 indicates a moderate level of agreement among the experts. Since Sig. = 0.000 < 0.05, the difference between the mean ranks was statistically significant. Therefore, the results indicated that a second Delphi round was required.

In the second fuzzy Delphi round, the results of the first round, including the mean, standard deviation, and the opinions of other experts, were provided to each expert individually, and they were asked to revise their opinions. In this round, indicators with mean scores lower than 3 were eliminated, newly suggested indicators were added, and the experts were given the opportunity to revise their opinions according to the collective view of the expert panel.

Table 3

Summary of Fuzzy Delphi and Kendall's W Results

Indicator	First Round	Second Round	Change / Interpretation
Number of experts (N)	20	20	Stable
Overall mean	4.23	4.51	Increased by 6.6%
Standard deviation	0.87	0.64	Decreased by 26.4%
Kendall's coefficient of concordance (W)	0.468	0.687	Increased by 46.8%
Chi-square statistic	126.972	185.374	Increased
Degrees of freedom (df)	19	19	Stable
Significance level (Sig.)	0.000	0.000	Stable and statistically significant

The interpretation of the second-round results showed that the increase in Kendall's W from 0.468 to 0.687 indicated a considerable improvement in expert consensus. Moreover, the reduction in the standard deviation from 0.87 to 0.64 indicated convergence among expert opinions. Considering that W > 0.6, the Delphi process could be stopped.

In the second section of the analysis, fuzzy DEMATEL and fuzzy ANP were integrated as FDANP. In this section, the combination of the fuzzy Decision Making Trial and Evaluation Laboratory technique and the fuzzy Analytic Network Process was used to determine the final weights of the indicators and to analyze the causal relationships among them.

The fuzzy DEMATEL technique is a tool for analyzing causal relationships among criteria and identifying influencing and influenced factors. In the present study, the fuzzy version of this technique was used.

In the first step, the fuzzy direct-relation matrix was formed. At this stage, the experts evaluated the direct effect of each indicator on the other indicators. The linguistic influence scale used in this study included five levels: no influence, very low influence, low influence, moderate influence, and high influence. These linguistic terms were respectively represented by the triangular fuzzy numbers (0, 0, 0.25), (0, 0.25, 0.50), (0.25, 0.50, 0.75), (0.50, 0.75, 1), and (0.75, 1, 1).

In the second step, the normalized total-relation matrix was calculated. After collecting the opinions of the 20 experts, the fuzzy direct-relation matrix was normalized using the following equation:

$$X_{ij} = \frac{A_{ij}}{r}$$

where:

$$r = \max_{i} \sum_{j=1}^{n} u_{ij}$$

In the third step, the fuzzy total-relation matrix was calculated using the following equation:

$$T = X(I - X)^{-1}$$

In this equation, Idenotes the identity matrix.

In the fourth step, the causal diagram was drawn using two indices. The first index was $D + R$, which indicates the overall importance of the indicator and is represented on the horizontal axis. The second index was $D - R$, which indicates the type of effect and is represented on the vertical axis.

If $D - R > 0$, the indicator is classified as a causal or influencing factor.

If $D - R < 0$, the indicator is classified as an effect or influenced factor.

Figure 1

Causal Diagram of the LARG Supply Chain Paradigms

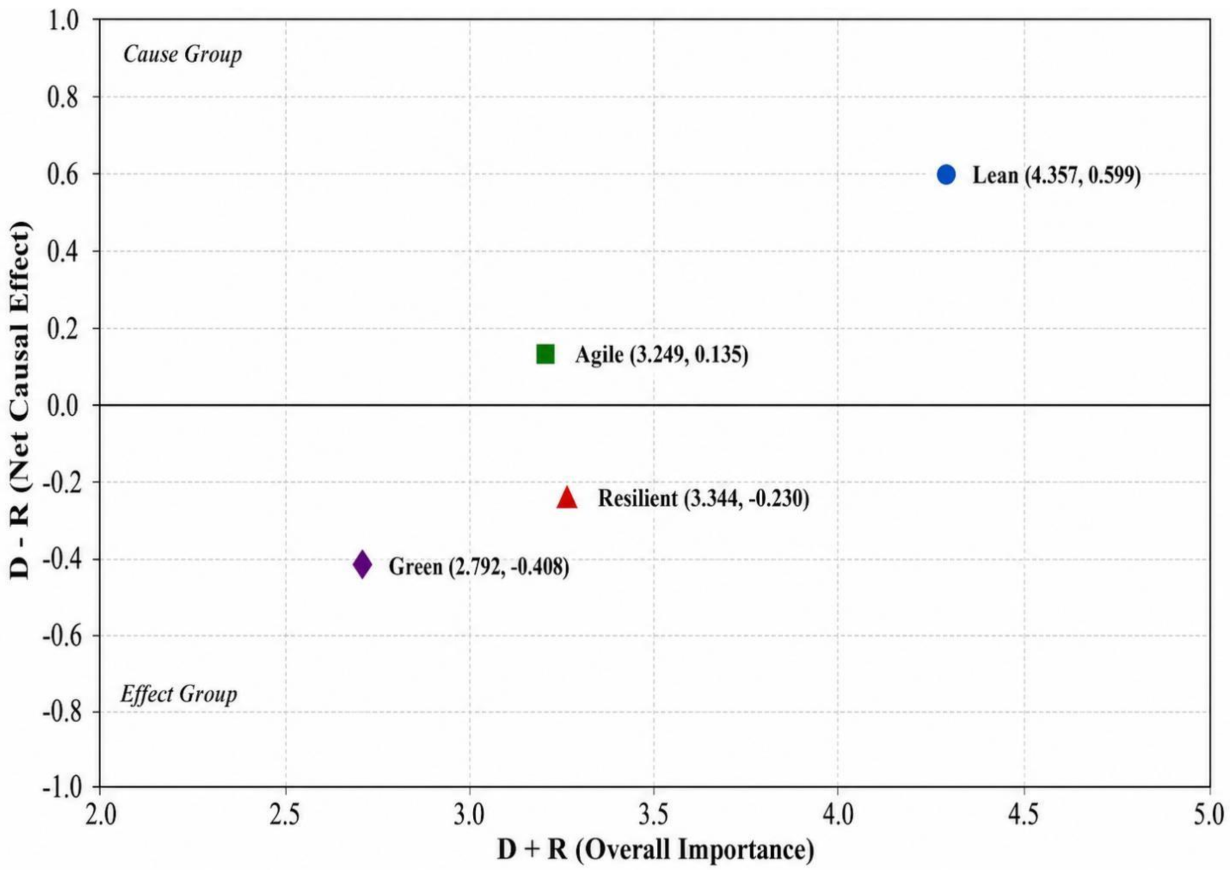


Table 4

Integrated Fuzzy DEMATEL, FDANP, and ISM Results

Analysis Section	Dimension / Level	D	R	D + R	D − R	Weight / Percentage	Type / Explanation
DEMATEL causal coordinates	Lean	2.478	1.879	4.357	0.599	—	Causal
DEMATEL causal coordinates	Agile	1.692	1.557	3.249	0.135	—	Causal
DEMATEL causal coordinates	Resilient	1.557	1.787	3.344	−0.230	—	Effect
DEMATEL causal coordinates	Green	1.192	1.600	2.792	−0.408	—	Effect
FDANP final paradigm weight	Lean	—	—	—	—	0.350 / 35%	Fuzzy weight: (0.31, 0.35, 0.39); Rank 1
FDANP final paradigm weight	Agile	—	—	—	—	0.290 / 29%	Fuzzy weight: (0.25, 0.29, 0.33); Rank 2
FDANP final paradigm weight	Resilient	—	—	—	—	0.233 / 23.3%	Fuzzy weight: (0.20, 0.23, 0.27); Rank 3
FDANP final paradigm weight	Green	—	—	—	—	0.127 / 12.7%	Fuzzy weight: (0.10, 0.13, 0.17); Rank 4
ISM level partitioning	Level 1	—	—	—	—	1 indicator	Sustainable performance; final objective
ISM level partitioning	Level 2	—	—	—	—	10 indicators	G1–G5, R4–R6, A4–A5; influenced indicators
ISM level partitioning	Level 3	—	—	—	—	6 indicators	A1–A3, R1–R3; intermediate indicators
ISM level partitioning	Level 4	—	—	—	—	5 indicators	L1–L5; foundational lean indicators

The interpretation of the causal diagram showed that the lean and agile paradigms were located in the causal group and influenced the other paradigms.

The resilient and green paradigms were located in the effect group and were more strongly influenced by the other paradigms.

The lean paradigm had the highest overall importance, with $D + R = 4.357$.

In the next stage, fuzzy DEMATEL was integrated with fuzzy ANP. At this stage, the DEMATEL total-relation matrix was used to form the ANP supermatrix.

In the fifth step, the initial supermatrix was formed. The normalized DEMATEL total-relation matrix was used as the initial ANP supermatrix.

In the sixth step, the weighted supermatrix was calculated. For weighting, the weights of the main paradigms obtained through pairwise comparisons were used.

In the seventh step, the limit supermatrix was calculated. By raising the weighted supermatrix to powers, the final stable weights of each indicator were obtained.

The results showed that, in the poultry industry, the lean paradigm had the highest importance with a weight of 35%. This finding indicates that the poultry industry is primarily focused on cost reduction and efficiency improvement. The agile and resilient paradigms ranked next, whereas the green paradigm has still received comparatively less attention in this industry.

Interpretive Structural Modeling (ISM) was also used in this study. Interpretive Structural Modeling is a method for identifying and analyzing relationships among variables and developing a hierarchical model of these relationships.

The ISM procedure was implemented in several stages.

In the first stage, the variables were identified. The variables of this study consisted of the 28 indicators of the LARG supply chain, which had been identified in the previous stages.

In the second stage, internal relationships were determined through the Structural Self-Interaction Matrix (SSIM). At this stage, the experts were asked to determine the relationships among the indicators. Four symbols were used: V indicated that indicator $i$influences indicator j; A indicated that indicator $j$influences indicator i; X indicated that indicators $i$and $j$influence each other; and O indicated that there is no relationship between indicators $i$and j.

A sample of the SSIM showed that L1 had direct influence relationships with L2, L3, A1, A2, and A3; a mutual relationship with L4; and was influenced by L5. Similarly, L2 had influence relationships with L3, L4, A1, and A2; a mutual relationship with A3; and was influenced by L5. L3 had influence relationships with L4, A1, and A3; a mutual relationship with A2; and no relationship with L5. Because of the large size of the 28 × 28 matrix, only a partial sample was reported.

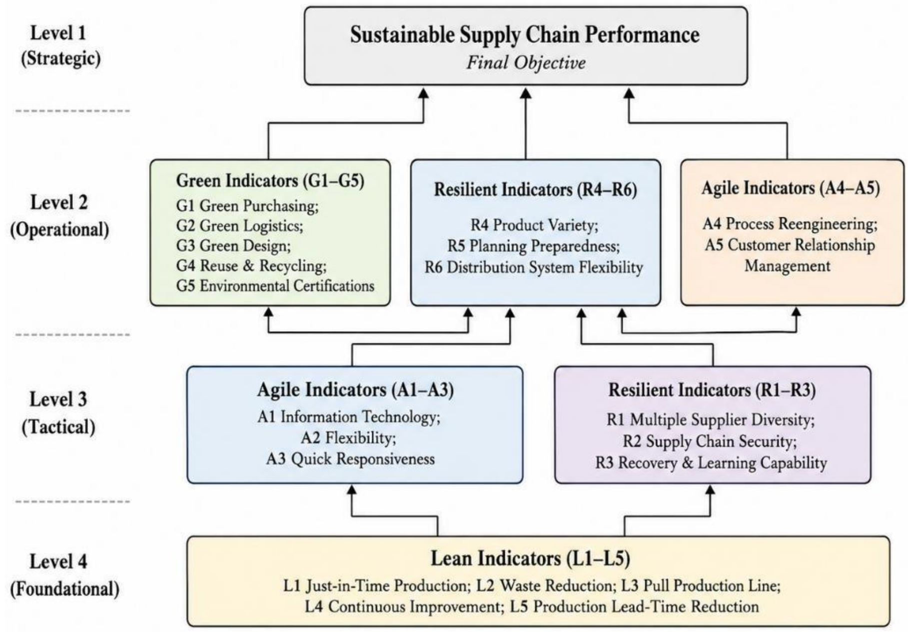
In the third stage, the initial reachability matrix was formed. The SSIM was converted into an initial reachability matrix with binary values of 0 and 1.

The conversion rules were as follows: if $SSIM(i,j) = V$, then $RM(i,j) = 1$and $RM(j,i) = 0$. If $SSIM(i,j) = A$, then $RM(i,j) = 0$and $RM(j,i) = 1$. If $SSIM(i,j) = X$, then $RM(i,j) = 1$and $RM(j,i) = 1$. If $SSIM(i,j) = O$, then $RM(i,j) = 0$and $RM(j,i) = 0$.

In the fourth stage, consistency and the final reachability matrix were examined. The reachability matrix was checked for transitivity. This means that if indicator $i$influences indicator j, and indicator $j$influences indicator k, then indicator $i$must also influence indicator k. Indirect relationships were marked with an asterisk.

Figure 2

Final Interpretive Structural Modeling (ISM) Model



The interpretation of the ISM model showed that Level 4, as the foundational level, included the lean supply chain indicators. These indicators were positioned at the lowest level and served as the basis of the model. This means that the successful implementation of the LARG supply chain in the poultry industry should begin with a focus on lean indicators.

Level 3, as the tactical level, indicated that after establishing the lean indicators, agile and resilient indicators can be implemented.

Level 2, as the operational level, included green indicators and some agile and resilient indicators.

Level 1, as the strategic level, positioned sustainable supply chain performance as the final objective at the highest level.

4. Discussion and Conclusion

The present study aimed to develop a hybrid LARG supply chain model for the poultry industry in northern Iran by identifying, validating, weighting, and structurally modeling the indicators of lean, agile, resilient, and green supply chain paradigms. The findings showed that the final set of indicators was organized into four major paradigms, namely lean, agile, resilient, and green. The fuzzy Delphi results confirmed the validity of most of the initially extracted indicators, as 26 out of the 28 initial indicators were approved by the expert panel, two indicators were removed due to insufficient mean scores, and three new indicators were added based on expert judgment. This outcome indicates that the theoretical foundation of the LARG framework is largely applicable to the poultry industry, but it also requires contextual refinement according to industry-specific conditions. The increase in the overall mean from 4.23 in the first round to 4.51 in the second round, together with the decrease in standard deviation from 0.87 to 0.64, shows that expert opinions became more convergent after feedback was provided. Moreover, Kendall's coefficient of concordance increased from 0.468 to 0.687, indicating a clear improvement in consensus and confirming the adequacy of the second Delphi round. This result supports the idea that LARG supply chain implementation requires systematic expert-based validation, because the relative importance of indicators may differ across industries and operational environments (Khanzadi et al., 2024; Nasiri Dehaj & Morovati Sharifabadi, 2021).

The results of the fuzzy ANP analysis showed that Just-in-Time Production (JIT), Information Technology (IT), Continuous Improvement (VIM), Multiple Supplier Diversity (MSD), and Quick Responsiveness (QR) obtained the highest final weights among the LARG supply chain indicators. The first rank of JIT indicates that inventory control, demand-based production, and reduction of unnecessary stock are highly important in the poultry industry. This finding is theoretically consistent with the lean supply chain paradigm, which emphasizes the elimination of waste, reduction of inventory, and improvement of process efficiency. In poultry supply chains, the importance of JIT can be explained by the perishable nature of poultry products, the high cost of storage, and the need to synchronize production, processing, and distribution. Similar studies have emphasized that lean supply chain practices improve operational performance by reducing non-value-added activities and strengthening process discipline (Azevedo et al., 2011; Carvalho & Cruz-Machado, 2011). The finding is also consistent with studies that highlight the importance of lean maturity, continuous improvement, and operational planning in achieving higher supply chain performance (Reyes et al., 2021; Soares et al., 2021). Therefore, the high weight of JIT in the present study suggests that poultry supply chain managers should first focus on reducing inefficiencies in production and inventory flows.

The second-ranked indicator was Information Technology (IT), which reflects the central role of digital integration, data exchange, monitoring, and coordination in LARG supply chain management. In the poultry industry, information technology can support demand forecasting, inventory visibility, supplier coordination, customer responsiveness, cold-chain control, and risk monitoring. This result aligns with the increasing emphasis on digitalized and data-driven supply chain management. Previous studies have shown that big data analytics strengthens the effect of LARG practices on sustainable supply chain performance by improving information processing capability and decision-making quality (Raut et al., 2021). Similarly, research on virtual supply chains has shown that digital platforms and enterprise e-catalogues can improve coordination among supply chain actors (Matsuda et al., 2020). The importance of IT also corresponds with the broader argument that Industry 4.0 adoption and advanced manufacturing capabilities can enhance sustainable development by supporting flexibility, visibility, and efficient resource utilization (Bag et al., 2021). Therefore, the high priority of IT in this study indicates that digital infrastructure is not only an agile capability but also a cross-cutting enabler of lean efficiency, resilience, and green management.

Continuous Improvement (VIM) was ranked third, showing that incremental process optimization remains a core requirement for the successful implementation of the LARG model. This result is consistent with the logic of Kaizen and lean management, according to which organizations can improve performance through ongoing small-scale improvements, employee involvement, process standardization, and systematic problem solving. In the poultry industry, continuous improvement can contribute to reduced production errors, improved feed conversion processes, better quality control, lower waste, and enhanced logistics performance. This finding is supported by studies that identify continuous improvement as a key managerial practice in lean systems and as an important mechanism for sustaining operational excellence (Rusdiana & Soediantono, 2022; Soares et al., 2021). Moreover, because poultry supply chains are exposed to recurring operational pressures, continuous improvement can help firms gradually improve their ability to manage cost, quality, and responsiveness. The priority of this indicator suggests that the LARG model should not be understood as a static framework but as a dynamic improvement-oriented system.

The fourth-ranked indicator was Multiple Supplier Diversity (MSD), which belongs to the resilient paradigm. This finding demonstrates that supplier diversification is a major requirement for maintaining continuity in the poultry supply chain. Poultry production depends on various inputs, including feed, veterinary services, chicks, packaging materials, transportation services, and cold-chain facilities. Dependence on a limited number of suppliers can expose firms to serious disruption risks, especially under conditions such as disease outbreaks, transportation restrictions, price shocks, or input shortages. The importance of supplier diversity is consistent with the resilience literature, which emphasizes redundancy, risk dispersion, and recovery capability as essential supply chain features. Studies on LARG supply chain risks have shown that identifying and managing risk sources is a prerequisite for resilient supply chain implementation (Gharghachian et al., 2022). Likewise, research on poultry supply chains during the COVID pandemic has demonstrated that uncertainty, disruptions, and multi-period planning challenges require robust supply chain structures (Wang et al., 2021). Therefore, the high weight of MSD indicates that resilience in the poultry industry should begin with reducing dependency on single-source supply relationships.

Quick Responsiveness (QR), which ranked fifth, confirms the importance of agility in the poultry supply chain. Because poultry products are sensitive to time, freshness, and customer demand fluctuations, responsiveness is essential for maintaining market competitiveness. Rapid response capability enables firms to adjust production volume, distribution routes, customer service processes, and inventory decisions according to market changes. This finding is consistent with studies that identify agility as a key requirement for supply chains operating in uncertain and dynamic environments (Piya et al., 2020). It also aligns with research on poultry supply chain sustainability, which found that key agility variables can improve the sustainability and competitiveness of poultry supply chains (Yunita et al., 2022). Therefore, in the context of the present study, quick responsiveness can be considered a bridge between operational performance and customer-oriented competitiveness.

The DEMATEL results showed that the lean and agile paradigms were located in the causal group, while the resilient and green paradigms were located in the effect group. The lean paradigm had the highest overall importance, with (D + R = 4.357), and the highest net causal effect, with (D - R = 0.599). This means that lean practices not only have high importance but also influence other paradigms. In practical terms, reducing waste, improving production flow, implementing JIT, and developing continuous improvement can create the operational foundation needed for agility, resilience, and green performance. This finding is consistent with earlier conceptualizations of LARG supply chains, which argue that lean practices are often foundational because they discipline processes and remove inefficiencies that would otherwise weaken agility and sustainability (Cabral et al., 2011; Carvalho & Cruz-Machado, 2011). It also supports previous models of LARG supply chain management that describe the paradigms as interdependent rather than independent dimensions (Khanzadi et al., 2023; Shams & Salimi Zaviyeh, 2021). Therefore, the causal dominance of the lean paradigm in this study suggests that poultry firms should not attempt to implement complex agility, resilience, or green initiatives before establishing basic process efficiency.

The agile paradigm was also classified as causal, although its net causal effect was lower than that of the lean paradigm. This indicates that agility influences other paradigms, particularly by improving responsiveness, information sharing, flexibility, and customer coordination. Agile capabilities can strengthen resilience by enabling rapid reaction to disruption and can support green practices by improving coordination and reducing unnecessary movement, delay, or overproduction. This finding is consistent with research indicating that agility factors are interconnected and can shape the performance of other supply chain capabilities (Piya et al., 2020). It also aligns with the evidence from the Indonesian poultry supply chain, where agility variables were found to play an important role in improving supply chain sustainability (Yunita et al., 2022). Accordingly, agility in the poultry industry should be viewed not only as a market response mechanism but also as a structural capability that supports broader LARG implementation.

The resilient and green paradigms were placed in the effect group, indicating that they are more influenced by lean and agile practices than they are influencing factors. The resilient paradigm obtained a final paradigm weight of 23.3%, ranking third after lean and agile. This result suggests that although resilience is highly important for poultry supply chains, its development depends partly on the prior establishment of efficient and flexible processes. For example, supplier diversity, supply chain security, recovery capability, planning preparedness, product variety, and distribution flexibility are more effective when the basic production and information systems are already stable. This finding is consistent with studies that have emphasized the causal complexity of LARG indicators and the need to identify influential and dependent factors through structured decision-making methods (Mohammadi et al., 2023). It also corresponds with studies on LARG supplier evaluation, which suggest that supplier-related decisions require systematic weighting and multi-criteria assessment because resilience is embedded in supplier performance and network design (Mohammadi Zanjirani & Sheikh, 2025; Sheikh & Senfi, 2024).

The green paradigm had the lowest final weight, equal to 12.7%, and was also classified as an effect paradigm. This finding indicates that environmental practices have received comparatively less attention in the poultry industry than lean, agile, and resilient practices. This result may reflect the current priorities of the industry, where cost reduction, production efficiency, market responsiveness, and supply continuity are often considered more urgent than environmental concerns. However, the lower priority of the green paradigm should not be interpreted as a lack of importance. Rather, it suggests that green practices may depend on the maturity of other supply chain capabilities. For instance, green purchasing, green logistics, green design, recycling, and environmental certifications require stable suppliers, reliable information systems, efficient processes, and managerial commitment. Previous research has emphasized that environmental management should be integrated into LARG supplier assessment and supply chain diagnostics (Sousa et al., 2020). Studies on sustainability performance evaluation in LARG supply chains also show that green criteria are essential for long-term strategic performance and scenario planning (Izadiyar et al., 2021). Therefore, the weak position of the green paradigm in this study reveals a critical developmental gap in the poultry supply chain.

The ISM results provided a hierarchical interpretation of the relationships among the indicators. Lean indicators were positioned at Level 4 as the foundational level, indicating that they form the base of the LARG supply chain model. Agile and resilient indicators such as IT, flexibility, quick responsiveness, supplier diversity, supply chain security, and recovery capability were located at the tactical level. Green indicators and some advanced agile and resilient indicators were positioned at the operational level, while sustainable supply chain performance was placed at the strategic level as the final objective. This hierarchical structure is consistent with the theoretical logic that sustainable performance is achieved through the progressive development of operational foundations, tactical capabilities, and advanced implementation mechanisms (Azevedo et al., 2011; Espadinha-Cruz et al., 2013). It is also consistent with prior studies showing that LARG models require integrated structural design and cannot be reduced to a list of independent indicators (Khanzadi et al., 2024; Nasiri Dehaj & Morovati Sharifabadi, 2021). In the poultry industry, this means that managers should first establish lean efficiency, then develop agility and resilience, and finally integrate green practices into the broader pursuit of sustainable performance.

Overall, the findings indicate that the LARG supply chain model for the poultry industry in northern Iran is strongly driven by lean and agile capabilities, while resilience and green practices represent dependent but strategically important outcomes of supply chain maturity. This pattern is understandable given the economic and operational characteristics of the poultry industry, where perishability, cost pressure, logistics sensitivity, and market fluctuations require firms to focus first on efficiency and responsiveness. At the same time, the results show that long-term competitiveness cannot be achieved through lean and agile practices alone. Resilience is necessary for continuity under disruption, and green practices are necessary for environmental legitimacy and sustainable development. This interpretation is supported by previous studies showing that LARG supply chain management is most effective when the four paradigms are integrated and when decision-making tools are used to prioritize their relationships and implementation pathways (Aisyah et al., 2021; Jamali & Karimi Asl, 2018; Raut et al., 2021). Therefore, the proposed hybrid model provides both a diagnostic and practical framework for improving poultry supply chain performance.

The present study had several limitations. First, the study relied on expert judgments, and although the fuzzy Delphi method improved consensus, the findings may still reflect the perceptions and experiences of the selected experts. Second, the study was conducted in the poultry industry of northern Iran; therefore, the results may not be directly generalizable to other regions or other agricultural and food industries. Third, the model focused on identified indicators and their structural relationships, but it did not test the model using longitudinal operational performance data. Fourth, although fuzzy DEMATEL, fuzzy ANP, and ISM provided a strong hybrid analytical framework, the complexity of these methods may limit their direct use by practitioners without technical support.

Future studies are suggested to test the proposed model quantitatively using larger samples from poultry firms, suppliers, distributors, and customers. Researchers may also compare the LARG model across different regions, agricultural industries, or food supply chains to examine whether the hierarchy and causal relationships remain stable. Longitudinal studies are recommended to investigate how improvements in lean, agile, resilient, and green indicators affect actual supply chain performance over time. Future research can also integrate digital transformation variables, sustainability reporting criteria, environmental performance indicators, and financial performance outcomes into the model. In addition, comparative studies may examine whether different decision-making methods produce similar or different priority rankings for LARG indicators.

From a practical perspective, managers in the poultry industry should begin LARG implementation by strengthening lean indicators such as just-in-time production, waste reduction, pull-based production, continuous improvement, and production lead-time reduction. After establishing these foundational capabilities, firms should invest in information technology, flexibility, quick responsiveness, supplier diversity, and recovery capability. Managers should also avoid treating green practices as secondary or symbolic activities; instead, green purchasing, green logistics, recycling, green design, and environmental certification should be gradually integrated into the operational system. The proposed model can help managers prioritize improvement programs, allocate resources more effectively, evaluate supplier performance, reduce disruption vulnerability, and move toward sustainable supply chain performance.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

Acknowledgments

We would like to express our gratitude to all individuals helped us to do the project.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

References

Aisyah, S., Purba, H. H., Jaqin, C., Amelia, Z. R., & Adiyatna, H. (2021). Identification of Implementation Lean, Agile, Resilient and Green (LARG) Approach in Indonesia Automotive Industry. *Journal Européen des Systèmes Automatisés*, *54*(2), 317-324. https://doi.org/10.18280/jesa.540214

Azevedo, S. G., Carvalho, H., & Cruz-Machado, V. (2011). A Proposal of LARG Supply Chain Management Practices and a Performance Measurement System. *International Journal of e-Education, e-Business, e-Management and e-Learning*, *1*(1), 7. https://doi.org/10.7763/IJEEEE 2011.V1.2

Bag, S., Gupta, S., & Kumar, S. (2021). Industry 4.0 Adoption and 10R Advance Manufacturing Capabilities for Sustainable Development. *International Journal of Production Economics*, *231*, 107844. https://doi.org/10.1016/j.ijpe.2020.107844

Cabral, I., Espadinha-Cruz, P., Grilo, A., Puga-Leal, R., & Cruz-Machado, V. (2011). Decision-Making Models for Interoperable Lean, Agile, Resilient and Green Supply Chains. Proceedings of the International Symposium on the Analytic Hierarchy Process,

Carvalho, H., & Cruz-Machado, V. (2011). Integrating Lean, Agile, Resilience and Green Paradigms in Supply Chain Management (LARG-SCM). In *Supply chain management* (pp. 28-47). https://doi.org/10.5772/14592

Espadinha-Cruz, P., Cabral, I., & Grilo, A. (2013). LARG Interoperable Supply Chains: From Cooperation Analysis to Design. Intelligent Decision Technologies: Proceedings of the 5th KES International Conference on Intelligent Decision Technologies (KES-IDT 2013),

Gharghachian, M., Adeli, O., Safa, M., & Pourfakharan, M. (2022). Presenting a Framework for Identifying LARG Supply Chain Risks. *Environmental Science and Technology*, *24*(4), 1-15.

Ghomsheh, A. M., Hosseini Yekani, S. M., & Hosseini Yekani, S. A. (2022). Calculating the Efficiency and Effectiveness of Livestock and Poultry Production with the Aim of Achieving Food Security in the Provinces of the Country. *Agricultural Economics*, *30*(119), 1-32.

Izadiyar, M., Tolouei Ashfali, A., & Mehri, Z. (2021). Presenting a Sustainability Performance Evaluation Model for Scenario Planning in the LARG Supply Chain. *Management Futures Studies Quarterly*, *31*(124).

Jamali, G., & Karimi Asl, E. (2018). Evaluation of Competitive Strategies of LARG Supply Chain Management Based on Gap Analysis in the Cement Industry. *Research in Production and Operations Management*, *9*(1), 29-54.

Khanzadi, F., Radfar, R., & Pilevari, N. (2024). A Review of Lean, Agile, Resilient, and Green (LARG) Supply Chain Management in Engineering, Business and Management Areas. *Decision Science Letters*, *13*(2), 287-306. https://doi.org/10.5267/j.dsl.2024.3.002

Khanzadi, F., Radfar, R., & Pilevari, N. S. (2023). Developing an Effective LARG Supply Chain Management Model Using a System Dynamics Approach. *Industrial Management Studies*, *21*(68), 153-196.

Matsuda, M., Nishi, T., Hasegawa, M., & Terunuma, T. (2020). Construction of a Virtual Supply Chain Using Enterprise E-Catalogues. *Procedia CIRP*, *93*, 688-693. https://doi.org/10.1016/j.procir.2020.04.093

Mohammadi, K., Zanjirchi, S. M., & Mohammadi, L. (2023). Presenting a Model of Causal Relationships Among LARG Supply Chain Indicators Using the Hierarchical DEMATEL Method. *Management Science and Information Technology*, *9*(3), 431-468.

Mohammadi Zanjirani, D., & Sheikh, R. (2025). Performance Evaluation of LARG Suppliers Using the Opportunity Losses-Based Polar Coordinate Distance Technique (OPLO-POCOD). *Research in Production and Operations Management*, *16*(1), 49-70.

Nasiri Dehaj, E., & Morovati Sharifabadi, A. (2021). Presenting a Model of Key Success Factors in Implementing the LARG Supply Chain Using a Meta-Synthesis Approach. *Organizational Resource Management Researches*, *11*(2), 165-186.

Piya, S., Shamsuzzoha, A., Khadem, M., & Al-Hinai, N. (2020). Identification of Critical Factors and Their Interrelationships to Design Agile Supply Chain: Special Focus to Oil and Gas Industries. *Global Journal of Flexible Systems Management*, *21*(3), 263-281. https://doi.org/10.1007/s40171-020-00247-5

Raut, R. D., Mangla, S. K., Narwane, V. S., Dora, M., & Liu, M. (2021). Big Data Analytics as a Mediator in Lean, Agile, Resilient, and Green (LARG) Practices Effects on Sustainable Supply Chains. *Transportation Research Part E: Logistics and Transportation Review*, *145*, 102170. https://doi.org/10.1016/j.tre.2020.102170

Reyes, J., Mula, J., & Diaz-Madronero, M. (2021). Development of a Conceptual Model for Lean Supply Chain Planning in Industry 4.0: Multidimensional Analysis for Operations Management. *Production Planning & Control*, 1-16. https://doi.org/10.1080/09537287.2021.1993373

Rusdiana, I. W., & Soediantono, D. (2022). Kaizen and Implementation Suggestion in the Defense Industry: A Literature Review. *Journal of Industrial Engineering & Management Research*, *3*(3), 35-52.

Shams, S., & Salimi Zaviyeh, S. G. (2021). A Review of LARG Supply Chain Management: Analysis of LARG Supply Chain Management Models. *Iranian Rubber Industry*, *26*(103), 79-87.

Sheikh, R., & Senfi, S. (2024). A Novel Opportunity Losses-Based Polar Coordinate Distance (OPLO-POCOD) Approach to Multiple Criteria Decision-Making. *Journal of Mathematics*, *2024*(1), 43-62. https://doi.org/10.1155/2024/8845886

Soares, G. P., Tortorella, G., Bouzon, M., & Tavana, M. (2021). A Fuzzy Maturity Based Method for Lean Supply Chain Management Assessment. *International Journal of Lean Six Sigma*. https://doi.org/10.1108/IJLSS-08-2020-0123

Sousa, J. C. D., Alves, M. B., Leocadio, L., & Rossato, J. (2020). Environmental Management of LARG Supply Chain: A Diagnostic Instrument Proposed for Assessing Suppliers. *BBR: Brazilian Business Review*, *16*, 537-554. https://doi.org/10.15728/bbr.2019.16.6.1

Wang, J., Yazdekhasti, A., Zhang, L., & Ma, J. (2021). A Multi-Period Multi-Modal Stochastic Supply Chain Model Under COVID Pandemic: A Poultry Industry Case Study in Mississippi. *Transportation Research Part E: Logistics and Transportation Review*, *154*(1), 102463. https://doi.org/10.1016/j.tre.2021.102463

Yunita, I., Hasibuan, S., & Thaheer, H. (2022). Identification of Key Agility Variables to Improve Poultry Supply Chain Sustainability: Indonesian Case. *Industria: Jurnal Teknologi dan Manajemen Agroindustri*, *11*(2), 117-127. https://doi.org/10.21776/ub.industria.2022.011.02.3