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A hybrid decision-making framework for a supplier selection problem based on lean, agile, resilience, and green criteria: a case study of a pharmaceutical industry

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Abstract
Due to the outbreak of COVID-19 around the globe in the last few years, the need for pharmaceutical supply chains is felt more than before. However, increasing uncertainties along with unpredictable demand for products led to disruptions in supply chains when receiving requests from retailers. These disruptions not only affected the economic aspect of supply chains but also caused shortages in hospitals and medical centers. Therefore, it has become significant for companies to select their suppliers to avoid disruptions in the case of the severity of infections. To address this issue in practice, this paper has been conducted based on a case study to address the role of lean, agile, resilience, and green (LARG) criteria in selecting the supplier in a pharmaceutical supply chain and compare the results obtained before and after the prevalence of COVID-19. The main purpose of this study is to determine and evaluate different indicators within the LARG concept to avoid disruptions when selecting suppliers. Besides, the significance of these criteria before and after the pandemic condition is addressed. Due to addressing multiple aspects of the problem, a hybrid fuzzy multi-attribute decision-making (MADM) approach is adopted for this elaboration when the four LARG criteria are integrated with eighteen supplier selection sub-criteria. To calculate the impact of each criterion (or sub-criteria), a fuzzy best–worst method (BWM) along with an additive ratio assessment (ARAS) is employed to propose a supplier ranking for a distributor of a pharmaceutical supply chain. The developed model is novel as LARG criteria in the context of supplier selection have not been studied to address the disruptions in the pharmaceutical supply chain. This is significant because it gives insight to both retailers and suppliers to emphasize the correct criteria, especially in the pandemic or related disrupting conditions. The results demonstrated that quality, collaboration, safety stock, and environmental criteria weigh the highest before the pandemic, while just-in-time delivery, lead time, safety stock, and environmental criteria weigh the highest after the pandemic. This study demonstrates that developing a supplier selection approach that meets the demand in a short time and recommends suppliers to hold surplus inventory helps the healthcare systems better respond to the market needs.

Keywords Supplier selection · LARG supply chain · Pharmaceutical supply chains · Fuzzy multi-attribute decision-making

Extended author information available on the last page of the article

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1 Introduction

Increasing demand for high-quality healthcare services leads governments to invest in healthcare systems more than before. According to the report published in 2019 by the World Health Organization, total health expenditure has grown at a higher pace than before. This report indicates that the growth rate of health expenditures in developing countries is around %6 which is higher than in developed countries with %4. In addition, global medicine expenditures have significantly increased by approximately %30 and reached around $1.4 trillion per year in 2020 (WHO, 2019). On the other hand, pharmaceutical companies are obliged by the governments to identify and evaluate reliable suppliers to increase the quality of healthcare services while decreasing the corresponding costs and delivery time. This obligation has made the processes of these supply chains more complex. Dramatic changes in these complex environments have triggered companies to make adjustments to satisfy customer needs (Ciccullo et al., 2018).

In 1990, the Toyota production system successfully created a new approach called 'lean' for companies to be more competitive in their markets. The lean paradigm aims to minimize the total cost and maximize efficiency by eliminating waste from the different parts of supply chains. By removing activities that are non-value added and unnecessary for customers, it attempts to enhance the end customers' satisfaction. As a result, the lean paradigm has been applied in many supply chains as an efficient way to improve their profitability (Taddeo et al., 2019).

Alongside mass consumption, variations in customers' behaviors force companies to adjust their paradigms in today's volatile markets. To address this situation, the concept of agility can be used as the mainstream to overcome rapid market changes and improve profitability. Agility is related to the flexibility and responsiveness of companies to variations in the product volume ordered (Toker & Görener, 2023). This demands appropriate inventory levels to fulfill customer needs. Accordingly, supply chain members from retailers to suppliers need to align themselves with customers and collaborate to reach an acceptable stage of agility. An agile supply chain seeks to increase cooperation among its actors to respond quickly to market changes (Wu et al., 2017).

Nowadays, in order to gain a competitive advantage in a complicated atmosphere, successful holding companies need to pay more attention to their Suppliers (Asghari Zadeh et al., 2011; Safari et al., 2012; Haghighi et al., 2016). By increasing supply chain complexity, agile and lean paradigms have been widely used by companies to survive in competitive markets. However, using these paradigms may not be sufficient in such an uncertain and competitive environment. Disruptive events, such as the COVID outbreak in 2019, bushfires across Australia in 2019, the US-China trade war in 2018–2019, Hurricane Florence in 2018, the Japanese tsunami in 2011, the Indonesian earthquake in 2004, and the SARS outbreak in 2003, have had irreparable impacts on supply chains. Disruptions can increase the supply chain's vulnerability by causing significant impacts on the flow of materials/products, highlighting the importance of the resilience paradigm. According to the paper proposed by Gong et al. (2014), supply chains with resilience capabilities can back to their prior state or exploit the change as a new opportunity after being disrupted. In addition, Blackhurst et al. (2011) found that implementing a set of criteria, enablers, and actions related to this paradigm in the supply chain design phase can help supply chains to better react to disruptions.

The COVID-19 outbreak significantly changed the supply and demand equilibrium in the markets. Shocks and challenges on supply chains disrupt the materials and products

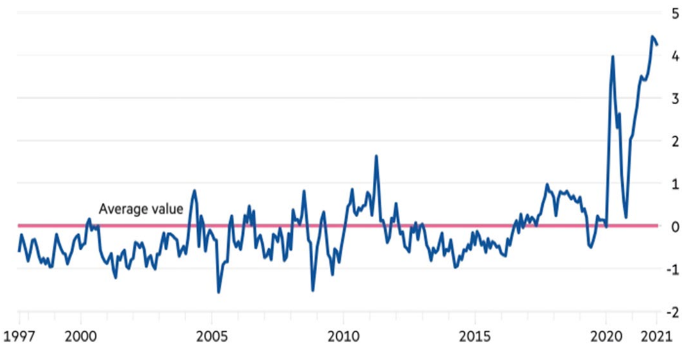


Fig. 1 Changes in the global supply chain pressure index and its standard deviations from the average value between 1997 and 2021 (www.statista.com)

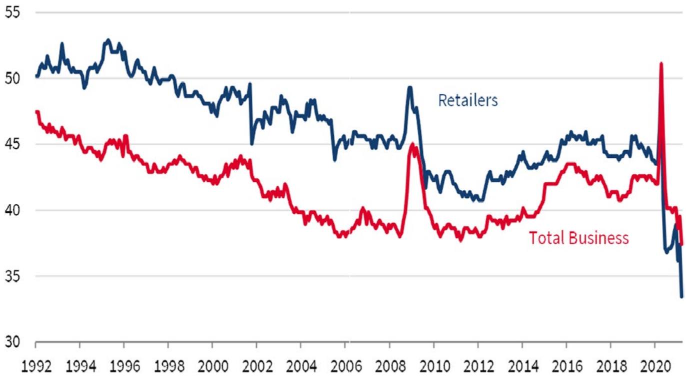


Fig. 2 Changes in the inventory-in-hand of retailers and businesses between 1992 and 2020 (www.statista.com)

flow during the pandemic. Based on a survey conducted by the Federal Reserve Bank of New York, the number of supply chain disruptions had drastically increased during COVID-19. The global supply chain pressure index which shows the resilience of supply chains when facing unexpected circumstances such as pandemics increased considerably and deviated from the average value (See Fig. 1). In another survey conducted by the U.S. Census Bureau, the inventory-in-hand of retailers and businesses, in general, has fallen considerably during the COVID-19 outbreak which emphasizes the changed supply–demand equilibrium. Therefore, shortages in retailers' inventory systems were inevitable (See Fig. 2).

Increasing pressure originating from customers' expectations and later enacted by governmental rules and regulations about environmental issues has forced companies to take action in implementing green initiatives in their supply chains. The green paradigm aims to protect the environment at every stage of the supply chain such as purchasing green materials from suppliers, green product/process design, green manufacturing, and green delivery (Sepehri et al., 2021). By adding reverse logistics to the green supply chains, the companies' responsibilities to address environmental issues will be continued until products are recycled or disposed of. The benefits of the green paradigm not only include the environmental issues but also economic aspects. For example, applying the green paradigm can economically benefit the supply chains by maximizing customer satisfaction, and improving the green image, and the reputation of the business (Kang et al., 2019). To address the mentioned green paradigm, Abbasi and Choukolaei (2023) developed a systematic review of green supply chain network design when the focus is on carbon emission policy.

Based on the four aforementioned paradigms including lean, agile, resilience, and green (LARG) in the supply chains, Azevedo et al. (2011) proposed an integrated model including these four paradigms simultaneously. In recent years, some researchers have started to work on integrated principles of the LARG paradigm to analyze their impacts on supply chains. For example, Ciccullo et al. (2018) revealed how implementing lean and agile paradigms can affect supply chain sustainability. They concluded that lean and agile approaches can have a supporting and competing role in the sustainability of supply chains. Also, Luthra et al. (2016) proposed a conceptual model that investigates green and resilience paradigms in the automobile industry. Despite some differences and similarities, these paradigms have complementary roles in reaching competitiveness.

Supplier selection is one of the challenging tasks in supply chain management and can have a high impact on the performance of supply chains because supplying part of the supply chain is one of the most costly processes. Besides, almost all the resources are provided by the suppliers such as capabilities, materials, and information which can lead to enhancing the supply chain's performance (Wetzstein et al., 2016). The mentioned resources can significantly affect the final products resulting in customer satisfaction and increasing the competitiveness of a supply chain in the global market. Key performance indicators (KPIs) can be adapted to measure this impact. This influence can be more significant in manufacturing companies, where the costs related to purchasing raw materials from the suppliers consist of 50–70% of the production costs. Therefore, poor decisions related to supplier selection can result in ineffective management of cost, time, and quality factors in supply chains (Qin et al., 2017).

Supplier selection problems integrated with LARG criteria can also be used for other applications such as helping manufacturers in recycling and reusing products in reverse supply chains (Tavana et al., 2021). Selecting a robust supplier with minimum possibility of disruptions can be achieved using a decision support framework. The developed tool can help managers overcome imprecise information resources within the supply chain (Sahu et al., 2022). When sustainability criteria are also taken into account, other criteria such as the green quality of items become important when selecting a supplier. Besides, advanced technologies can be utilized to place smart orders which helps both suppliers and retailers to minimize the amount of waste (Alimohammadlou & Khoshsepehr, 2022; Haghighi et al., 2016).

During the pandemic outbreak, the significance of selecting the best suppliers increased. Research conducted on the manufacturing sector of Nigeria, Orji et al. (2021) showed that there is an interrelationship between pandemic-related strategies and multi-criteria decision-making for selecting the optimal suppliers. In addition, uncertainties due to pandemic conditions caused severe disruptions in supply chains, and different methodologies such as the fuzzy weighted intersection (FWI) approach (Chen et al., 2021) and fuzzy best–worst method (FBWM) (Ilyas et al., 2021) are utilized to solve the problem of uncertainties.

Despite the mentioned significance of implementing the LARG paradigms in practice, a few research works have concentrated on supplier selection problems in the corresponding literature. Moreover, pharmaceutical supply chains are confronting high demands in medicine due to the outbreak of COVID-19 (Govindan et al., 2020). This study aims to fill this gap by addressing the following two research questions:

- **RQ1** How LARG paradigms can be quantified in the era of COVID-19 when the risk of disruption is increased due to unexpected changes?
- **RQ2** What criteria are the most significant for supplier selection in the era of COVID-19 and to what extent can be considered?

Supplier selection is the concept that is elaborated in this study based on LARG paradigms to enhance the efficiency of supplying medicine by pharmaceutical distributors (Tavana et al., 2017). Considering the COVID-19 pandemic and its subsequent impact on pharmaceutical supply chains, this study is done a case study using a real-world case study comparing the before and after pandemic situations. In this regard, the novel hybrid fuzzy best–worst method (BWM) and fuzzy additive ratio assessment (ARAS) are utilized to select and evaluate the suppliers for a pharmaceutical distributor in a healthcare supply chain.

The remaining sections of this study are elaborated as follows. A review of the literature review is proposed in Sect. 2 separating lean, agile, resilience, and green paradigms for solving supplier selection problems. The general research methodology is proposed in Sect. 3 by elaborating on the fuzzy BWM and ARAS approaches. Implementation of the results in practice is summarized in Sect. 4 when a real-world database of the case study is applied for the LARG supplier selection. Section 5 discusses the criteria weights and proposes the supplier selection. Eventually, Sect. 6 wraps up the findings and provides some insights for future research on this subject.

2 Literature review

A huge number of research works have investigated the supplier selection problem, but the focus of this study is one concentrated on LARG paradigms. Thereafter, making benefit from the help of a committee of academic and industrial experts in the pharmaceutical supply chain, the most desirable criteria are obtained (Gupta & Barua, 2018). Besides, a critical review of supplier selection problems has been proposed. This section mainly reviews the most recent research works on supplier selection problems which have focused on LARG paradigms individually or concurrently. Some of the most relevant papers that are published in the last 8 years are reviewed and the older papers are neglected.

In a paper proposed by Kannan et al. (2014), a framework using the fuzzy TOPSIS approach is developed to select green suppliers based on a case study of an electronic company in Brazil. Thereafter, product and organizational-related criteria of suppliers have been indicated as lean and agile characteristics, respectively, in the paper proposed by Abdollahi et al. (2015). In this research, a supplier portfolio is developed based on the mentioned concepts, and the problem is solved using analytical network process (ANP) and data envelopment analysis (DEA) to determine the weight of each criterion and rank the suppliers, respectively. Three phases of a supplier selection methodology including pre-selection, selection, and aggregation are adopted to recognize the significance of new supplier recognition decisions (Rezaei et al., 2016). Conjunctive screening and the best–worst method (BWM) are adopted in this paper for pre-selecting and selecting the suppliers and the results are implemented in food industries.

The relationship between lean, resilience, and green criteria in supplier selection problems is studied by Ruiz-Benitez et al. (2017) who analyzed the impact of these criteria on the environmental performance of the supply chain. The aerospace sector was selected as the case study of this research and a combination of importance-performance analysis (IPA) and interpretive structural modeling (ISM) techniques are applied to determine the relationship between practices and performance measures. In another paper presented by El Mokadem (2017), lean and agile criteria are considered to study what is the impact of manufacturing strategies on supplier selection. Two solution approaches include principal component factor analysis (PCFA) and simple regression analysis (SRA) to validate the structure of supplier selection criteria and test the research hypotheses. Amindoust (2018) elaborated a joint sustainable and resilient supplier selection framework to help procurement managers avoid disruptions in purchasing items. A fuzzy-set theory is utilized to handle the problem of uncertainty in selecting the suppliers. Thereafter, a modular fuzzy interface system (FIS) approach is employed to create the affinity indices of suppliers concerning sustainability and resilience criteria. The results are an assurance region data envelopment analysis (AR-DEA) method to determine the weight of each indicator in evaluating the suppliers.

In another research, Abdullah et al. (2019) utilize the PROMETHEE approach which employs lots of preference functions to select green suppliers. They made use of seven economic and environmental criteria and four green suppliers were selected by five decision-makers when the data were collected using a five-point Likert scale. Another application of FBWM has been addressed in a paper proposed by Gan et al. (2019) who aimed to reduce the supplier selection risks and avoid supply chain disruptions. This method is combined with fuzzy modular TOPSIS in random environments for group decision-making (GMo-RTOPSIS). Thereafter, the feasibility and validity of the mentioned methods are proved using illustrative examples. Resilient supplier selection was again addressed by Davoudabadi et al. (2019) who conducted the research based on collecting the judgment of decision-makers and converting them into interval-valued intuitionistic fuzzy (IVIF) numbers. In this research, the weight of each criterion is determined based on an entropy index. A complex proportional assessment (COPRAS) approach has been adopted to rank the suppliers and the weights are aggregated using WASPAS method. Proposing a business intelligence (BI) framework was the novelty of a paper proposed by Pramanik et al. (2020) who determined a resilient supplier selection approach. This paper analyzed the corresponding datasets to elaborate meaningful information, relevant knowledge, and visualization. Selecting the best suppliers and building a resilient supply chain management platform are aimed in the mentioned paper and the authors adopted integration of the fuzzy analytic hierarchy process (FAHP) and fuzzy additive ratio assessment method (FARAM) to obtain the optimal values in a multi-criteria decision-making model. Fuzzy entropy is utilized to determine the fuzzy weights and mitigate the uncertainty of the problem.

Lean and agile strategic perspectives are employed together in a paper proposed by Li et al. (2020), and the textile industry sector of China is considered as the case study. Based on the decision-making trial and evaluation laboratory tool, the most effective criteria are selected and the relationship between these criteria is also addressed. In this regard, the decision-making trial and evaluating laboratory (DEMATEL) approach is adopted to select the optimal suppliers. Developing resilience and green criteria in supplier selection problems simultaneously were adopted by Xiong et al. (2020) who adopted the integration of BWM, Weighted Aggregated Sum-Product Assessment (WASPAS), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). This combination of problems had been rarely studied in this elaboration, and this paper proposed a novel hybrid solution approach to address both resilience and greenness objectives. In a research project conducted in a healthcare company, lean Six Sigma (LSS) strategies including 5S, stakeholder analysis, and standard operating procedure are employed by Tay and Aw (2021) for a supplier selection problem. This study aims to reduce lead time using the define-measure-analyze-improve-control (DMAIC) approach. Studying supplier selection problems in the era of Industry 4.0 has been another problem proposed by Çalık (2021). Group decision-making using AHP and TOPSIS approaches is proposed in this paper to select the best green supplier based on industry 4.0 components. The judgment of different experts can be quantified using Pythagorean fuzzy numbers. Besides, this paper is structured based on a case study of agricultural tools and machinery companies.

Another case study in the palm oil industry in Malaysia has been conducted by Fallahpour et al. (2021) using 30 criteria in three cases general, green, and resilient supplier selection. Suppliers' performance evaluation is studied in this paper using a hybrid methodology including fuzzy DEMATEL, Fuzzy Best–Worst Method (FBWM), fuzzy analytical network process (FANP), and FIS. In another paper proposed by Baki (2022), a green supplier selection problem is studied while the integration of structural equation modeling (SEM) and FARAS methods and the effectiveness of this combination are evaluated by collective decision-making. Similar to this research, a questionnaire is designed with eight criteria and 27 sub-criteria for classical, green, and social supplier selection problems to select among six potential suppliers.

Hybrid fuzzy methods including FDEMATEL, FBWM, FANP, and Fuzzy Vlse Kriterijumsk Optimizacija Kompromisno Resenje (FVIKOR) are adopted by Alamroshan et al., (2022) who attempted to study a supplier selection problem.

Overcoming challenges such as pandemics is a huge problem for supply chains when selecting suppliers. One of the solutions is proposed by Abbasi et al. (2022c) who defined numerous performance indicators to assess the sustainability of supplier selection. Weighting and normalizing these indicators helped them to quantify the trade-offs between economic and environmental aspects. Recovery networks which are applied for integrating the activities associated with product return are other parts of supply chains that are affected by pandemic conditions. In this regard, a multi-objective mixed-integer linear programming is developed by Abbasi et al. (2021) and Abbasi et al. (2022a) when assigning a separate objective function for economic, social, and environmental aspects of recovery networks to highlight the impact of COVID-19 on the total flow of products in the network. Mitigating the emissions along with optimizing the costs associated with supply chain network design is another subject which is proposed by Abbasi et al. (2022b). Measuring attractiveness through a categorical-based evaluation technique (MACBETH) is the methodology used by Pamucar et al. (2022) to address the uncertainty, vagueness, and incomplete information for decision-making problems when selecting suppliers within a supply chain. In another study proposed by Kocabey Çiftçi (2023), the factors affecting supplier performance are analyzed using fuzzy cognitive maps. The results obtained from this study indicate that some factors such as total production capacity and quality level of products play a crucial role in selecting the suppliers for a supply chain network during the pandemic era. Mohaghar et al. (2011), Mohaghar and Ghasemi (2011a), and Mohaghar and Ghasemi (2011b) also evaluated the quality of supplier relationships as an important factor affecting supply chain performance and cooperative strategy. The DEMATEL approach was also developed by Sahu et al. (2022) for supplier selection in construction projects. This study demonstrated that lead time is the most significant aspect, while product range and customer relationship also play important roles in selecting suppliers in a construction project.

In a study conducted by Abbasi et al. (2023), a closed-loop supply chain network is studied in which hygiene costs are added as a consequence of COVID-19 conditions. Besides, the possibility of increasing potential job opportunities during pandemic conditions is considered in the mathematical model. Then, a weighted Tchebycheff method (WTM) scalarization is employed to solve the mathematical model. Another closed-loop supply chain network was also developed by Abbasi and Erdebilli (2023) to address the environmental challenges associated with pandemic conditions in terms of carbon regulatory rules. Tavakoli et al. (2023) developed a Markovian-based fuzzy decision-making approach to select suppliers based on sustainability and resilience criteria. Then, the model is formulated based on pandemic conditions when solving the developed model based on the integration of the Markov transition matrix (MTM) and FBWM. In another study developed by Carissimi et al. (2023), the interaction between resilience and greenness in supplier selection processes is discussed in a review process. A summary of the mentioned studies is proposed in Table 1.

2.1 Research gap analysis

The COVID-19 pandemic has had an influence on many industries' operations in many ways. Decision-makers not only have to deal with the natural complexity of supply chains but also have to deal with new disruptions during the COVID-19 pandemic. Despite the many studies on the models and factors influencing supply chains, there are a few studies to address the changes in supply chain decision-makers in four paradigms: lean, agile, resilient, and green during the COVID-19 outbreak. Thus, this study is an attempt to understand the disruptions such as COVID-19's influence on the supply chain decision-makers' perspective in solving supplier selection problems. Apart from the specific consideration regarding COVID-19's impact on the proposed model, this study proposes a novel model that can be modified to assist decision-makers in selecting the most appropriate suppliers during other disruptions.

Based on the comprehensive literature review, many studies have addressed supplier selection problems using MCDM methods. Due to the time pressure on a large while during long-lasting disasters such as COVID-19, making quick decisions and well-coordinated responses is required. Since the BWM proposed by Rezaei (2015) has received a wide and fast-growing attraction in the literature, this method has been used in this study. More importantly, shorter times of pairwise comparisons and the high efficiency of this method make it a suitable MCDM tool for decision-makers in disasters; while in a method like AHP, the number of comparisons is much more (Ghasemi et al., 2018).

Furthermore, due to the required simplicity of methodology as well as ease of understanding for supply chain decision-makers, the ARAS method is used to evaluate and select suitable suppliers for a distributor of a pharmaceutical supply chain. Fuzzy logic is also adopted to address the uncertainty of the environment and the vagueness of human preferences in the decision process. In this paper, an integrated fuzzy ARAS and fuzzy BWM are proposed which is a novel hybrid model for solving supplier selection problems.

One of the main contributions of this study to the corresponding literature is that the mentioned problem and methodology are not proposed simultaneously. Moreover, the issue of disruption that affects the performance of pharmaceutical supply chains is another novelty of this study and is addressed using a multi-attribute decision-making approach. The main contribution of this study is to compare the importance of different criteria before and after the pandemic era. Among LARG criteria, the criteria related to quick response

Table 1 Lean, agile, resilience, and green criteria for supplier selection

Author(s)	Lean (C1)	Agile (C2)	Resilience (C3)	Green (C4)	Methodology
Kannan et al. (2014)				✓	FTOPSIS
Abdollahi et al. (2015)	✓	✓			ANP, DEA
Razavi et al. (2016)	✓	✓			SEM
Rezaei et al. (2016)				✓	BWM
El Mokadem (2017)	✓	✓			PCFA-SRA
Ruiz-Benitez et al. (2017)	✓		✓	✓	IPA, ISM
Jamalian et al. (2018)	✓			✓	CCA
Amindoust (2018)			✓	✓	FIS, AR-DEA
Davoudabadi et al. (2019)			✓		IVIF, COPRAS, WASPAS
Abdullah et al. (2019)				✓	PROMETHEE
Gan et al. (2019)			✓		FBWM, GMo-RTOPSIS
Li et al. (2020)	✓	✓			DEMATEL
Pramanik et al. (2020)			✓		FAHP, FARAS
Xiong et al. (2020)			✓	✓	BWM, WASPAS, TOPSIS
Tay and Aw (2021)	✓				DMAIC
Çalık (2021)				✓	AHP, TOPSIS
Fallahpour et al. (2021)			✓	✓	FDEMATEL, FBWM, FANP, FIS
Baki (2022)				✓	FES, FARAS
Alamroshan et al. (2022)		✓		✓	FDEMATEL, FBWM, FANP, FVIKOR
Pamucar et al. (2022)	✓		✓	✓	MACBETH
Çiftçi (2023)	✓	✓			Fuzzy Cognitive Maps
Sahu et al. (2022)	✓			✓	DEMATEL
Abbasi et al. (2023)				✓	WTM
Tavakoli et al. (2023)			✓	✓	MTM, FBWM
This research	✓	✓	✓	✓	FBWM; FARAS

to the orders (e.g., just-in-time delivery) and the criteria concerning accessibility of products when placing orders (safety stock) become more important. This idea is novel because most of the recent studies have not focused on this type of comparison. The elaboration of this comparison can also be used in other industries when comparing different criteria in normal and disrupting conditions.

Also, considering all lean, agile, resilient, and green criteria for supplier selection has rarely been addressed in the literature on supplier selection problems. Thus, this study contributes to the corresponding literature by discussing all these instances and proposing a newly developed hybrid solution methodology.

3 Hybrid fuzzy MADM methodology

Developing a framework that helps healthcare supply chains when confronting a disruption is significant, especially during the COVID-19 outbreak. Besides, increasing the number of suppliers not only stimulates competitiveness but also increases the complexity of supplier selection problems in pharmaceutical industries. To address these challenges, this study proposes a new methodology to optimize the supplier selection process by integrating LARG paradigms and employing them in a pharmaceutical supply chain. The snowball method is adopted by inviting a panel of experts from academia and industry to evaluate criteria and select the ones that are most related to the scope of this elaboration. Thereafter, the importance of the final criteria list is evaluated using the fuzzy best–worst method. Eventually, the fuzzy ARAS approach is applied to evaluate and select the best suppliers for a single distributor in a pharmaceutical supply chain. The criteria used to evaluate supplier performance include all the criteria outlined in the corresponding literature in a comprehensive way to highlight all possible aspects of LARG practices. A schematic view of the proposed method is illustrated in Fig. 3 which demonstrates the different steps of the proposed method.

According to Fig. 3, an initial list of criteria is proposed which is filtered and validated after expert consultation. After deriving the final list of LARG criteria, questionnaires are designed to determine the significance of each criterion when adopting BWM. Whenever the questionnaire is incompatible with the finalized criteria, the questions are revised and the process is repeated. Afterward, the LARG criteria are ranked and suppliers are prioritized accordingly. Later, the process of supplier selection and the selected criteria are differentiated for the time before and after the pandemic. The fuzzy ARAS method is used for this validation.

A defuzzification of fuzzy numbers is required in order to compare and rank the fuzzy numbers. The triangular-type membership function $\mu_{\tilde{A}}(x)$ is shown in Fig. 4.

Considering $\tilde{A} = \left(a_l, a_m, a_u\right)$ as a fuzzy number, the defuzzification process of this elaboration can be demonstrated as follows (Chakraborty et al., 2021).

$$X = a_m + \frac{a_u - a_l}{4} \tag{1}$$

$$\mathrm{DF}_{ij} = \frac{\left[\left(a_u - a_l\right) - \left(a_m - a_l\right)\right]}{3} + a_l \tag{2}$$

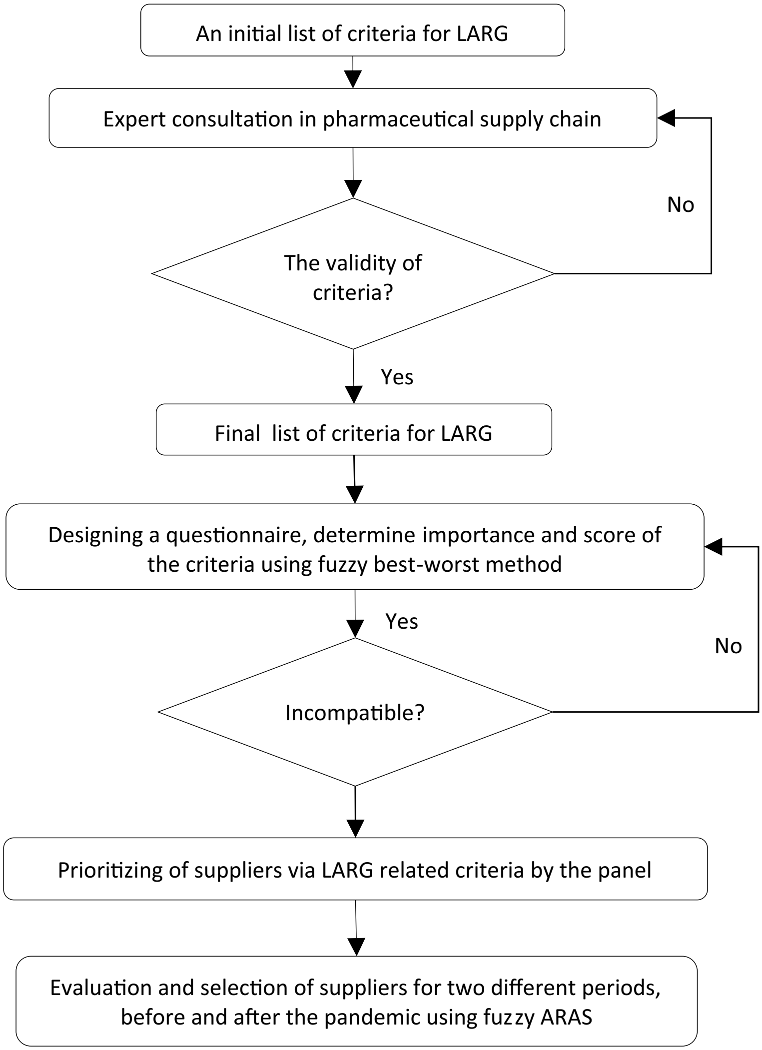
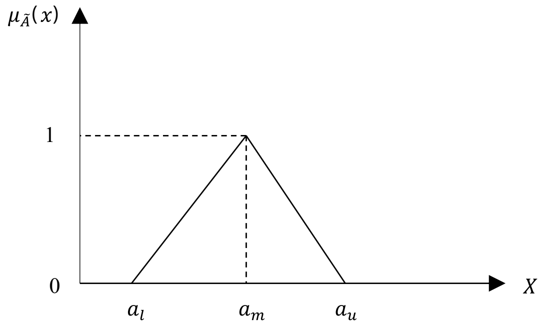


Fig. 3 Research methodology

Fig. 4 Triangular-type membership function $\mu_{\tilde{A}}(x)$



$$X_m^1 = \frac{a_l + a_m + a_u}{3}, X_m^2 = \frac{a_l + 2a_m + a_u}{4}, X_m^3 = \frac{a_l + 4a_m + a_u}{6}$$
$$\text{Crisp number} = Z^* = \max\left(X_{\max}^1, X_{\max}^2, X_{\max}^3\right). \tag{3}$$

3.1 Fuzzy BWM

BWM is a novel weighting method, initially developed by Rezaei (2015), which proposes more efficient and reliable results than the traditional AHP method and has been used more frequently in the literature in previous years. One of the significant advantages of BWM over AHP is the shorter time for creating a pairwise comparison matrix with higher accuracy in general. The uncertainties of real-world problems, specifically in the MCDM problems that deal with human judgments and linguistics, require considering the uncertainty logic such as fuzzy logic for solving these problems. Therefore, considering the advantages of the BWM and the existing uncertainty environment, the fuzzy BWM approach has been used in this paper to calculate the significance of the criteria. The integrated fuzzy BWM introduced by Guo and Zhao (2017) is elaborated in six phases as follows.

Step 1. Propose a list of criteria: Using $\{c_1, c_2, c_3, \dots, c_n\}$ a list of criteria from literature subsequently filtered by the opinions of industry and academia experts is formed (Pamucar et al., 2022).

Step 2. Determine the significance of each criterion: A panel of experts in the pharmaceutical company determines the significance of each criterion.

Step 3. Determine best (most significant) criteria: According to Eq. (1), fuzzy numbers are converted to crisp numbers. Then, the best criteria comprise all other criteria which can be expressed as follows (Alamroshan et al., 2022).

$$\widetilde{C_B} = \left(\widetilde{C_{B1}}, \widetilde{C_{B2}}, \dots, \widetilde{C_{Bn}}\right) \tag{4}$$

where a_{Bj} represent the fuzzy preference of the most significant criteria identified in the previous phase which prefers criterion B over criterion j, $j = 1, 2 \dots, n$ while we have $\widetilde{C_{BB}} = (1, 1, 1)$.

Step 4. Determine worst (least significant) criteria: A comparison between different criteria and the least significant criteria can be listed by the fuzzy values in Table 2.

$$\widetilde{C_W} = \left(\widetilde{C_{1W}}, \widetilde{C_{2W}}, \dots, \widetilde{C_{nW}}\right) \tag{5}$$

Table 2 Transformation of rules of linguistic terms to fuzzy numbers

Linguistic variables	Fuzzy number
Equally important (EI)	$(1, 1, 1)$
Weakly important (WI)	$\left(\frac{2}{3}, 1, \frac{3}{2}\right)$
Fairly important (FI)	$\left(1, \frac{3}{2}, 2\right)$
Very important (VI)	$\left(\frac{3}{2}, 2, \frac{5}{2}\right)$
Absolutely important (AI)	$\left(\frac{5}{2}, 3, \frac{7}{2}\right)$

where a_{iW} represent the fuzzy preference of the most significant criteria identified in the previous phase which prefers criterion j over criterion B, $j = 1, 2, \dots, n$ while we have $\widetilde{C_{WW}} = (1, 1, 1)$

Step 5. Calculating optimal fuzzy weights: Optimal fuzzy weights are determined to minimize the absolute maximize gap which is indicated as $\left|\frac{\widetilde{W_B}}{\widetilde{W_j}} - \widetilde{a_{Bj}}\right|$ and $\left|\frac{\widetilde{W_j}}{\widetilde{W_w}} - \widetilde{a_{jw}}\right|$.

In the abovementioned formulas, $\widetilde{W_B}$, $\widetilde{W_w}$, and $\widetilde{a_{jw}}$ are triangle fuzzy numbers.

Assuming that weights are non-negative and the sum of the weights is equal to one, the fuzzy best–worst method is utilized to measure the optimal fuzzy weights as follows (Guo & Zhao, 2017).

$$\min \max \left\{ \left|\frac{\widetilde{W_B}}{\widetilde{W_j}} - \widetilde{a_{Bj}}\right|, \left|\frac{\widetilde{W_j}}{\widetilde{W_w}} - \widetilde{a_{jw}}\right| \right\}$$

$$\text{Subject to} \quad \begin{cases} \sum_{j=1}^{n} R\left(\widetilde{W_j}\right) = 1 \\ l_j^w \le m_j^w \le u_j^w \\ l_j^w \ge 0 \\ j = 1, 2, \dots, n \end{cases} \tag{6}$$

where $\widetilde{W_B} = \left(l_B^w, m_B^w, u_B^w\right)$, $\widetilde{W_j} = \left(l_j^w, m_j^w, u_j^w\right)$, $\widetilde{W_w} = \left(l_w^w, m_w^w, u_w^w\right)$, $\widetilde{a_{Bj}} = \left(l_{Bj}^w, m_{Bj}^w, u_{Bj}^w\right)$, $\widetilde{a_{jw}} = \left(l_{jw}^w, m_{jw}^w, u_{jw}^w\right)$. Assuming $\varepsilon = (K^*, K^*, K^*)$ where $l^\varepsilon \le m^\varepsilon \le u^\varepsilon$ and $K^* \le l^\varepsilon$, equations can be modified as follows.

$$\min \varepsilon$$

$$\text{Subject to} \quad \begin{cases} \left|\frac{\widetilde{W_B}}{\widetilde{W_j}} - \widetilde{a_{Bj}}\right| \le \varepsilon \\ \left|\frac{\widetilde{W_j}}{\widetilde{W_w}} - \widetilde{a_{jw}}\right| \le \varepsilon \\ \sum_{j=1}^{n} R\left(\widetilde{W_j}\right) = 1 \\ l_j^w \le m_j^w \le u_j^w \\ l_j^w \ge 0 \\ j = 1, 2, \dots, n \end{cases} \tag{7}$$

Let $\varepsilon = (K^*, K^*, K^*)$, where $l^\varepsilon \le m^\varepsilon \le u^\varepsilon$ and $K^* \le l^\varepsilon$, the whole model can be finalized as follows.

$$\min \varepsilon$$
$$\text{Subject to}$$
$$\begin{cases} \left| \frac{(l_B^w, m_B^w, u_B^w)}{\left(l_j^w, m_j^w, u_j^w\right)} - \left(l_{Bj}^w, m_{Bj}^w, u_{Bj}^w\right) \right| \le (K^*, K^*, K^*) \\ \left| \frac{\left(l_j^w, m_j^w, u_j^w\right)}{(l_w^w, m_w^w, u_w^w)} - \left(l_{jw}^w, m_{jw}^w, u_{jw}^w\right) \right| \le (K^*, K^*, K^*) \\ \sum_{j=1}^{n} R\left(\widetilde{W}_j\right) = 1 \\ l_j^w \le m_j^w \le u_j^w \\ l_j^w \ge 0 \\ j = 1, 2, \ldots, n \end{cases} \tag{8}$$

As a result, the model determines the optimal weight of the fuzzy concept.

Step 6. Calculate the consistency index (CI): The CI is calculated to evaluate the consistency of pairwise comparison that illustrates the reliability of the model (Rezaei, 2015). The results of CI calculations are summarized in Table 3.

3.2 Fuzzy ARAS

A fuzzy ARAS approach is adopted in this paper to prioritize the suppliers based on the paper proposed by Zavadskas and Turskis (2010). The fuzzy ARAS is a methodology for solving multi-criteria decision-making (MCDM) problems and the following steps are elaborated in this regard.

Step 1. Fuzzy decision matrix development: Using linguistic variables and related fuzzy values in Table 3, the experts evaluate the preferences of alternatives (x) concerning the corresponding criteria (C_i). In this regard, the final decision matrix is developed according to the opinions of experts as follows (Pramanik et al., 2020).

$$\tilde{X} = \begin{bmatrix} \widetilde{x_{01}} & \cdots & \widetilde{x_{0j}} & \cdots & \widetilde{x_{0n}} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \widetilde{x_{i1}} & \cdots & \widetilde{x_{ij}} & \cdots & \widetilde{x_{in}} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \widetilde{x_{m1}} & \cdots & \widetilde{x_{mj}} & \cdots & \widetilde{x_{mn}} \end{bmatrix}, \quad i = 0, 1, \ldots, m, \quad j = 0, 1, \ldots, n \tag{9}$$

where m stands for the number of options, n shows the corresponding criteria, and $\widetilde{x_{ij}}$ illustrates a fuzzy value as the performance value of ith alternative in terms of jth criteria.

Step 2. Optimal performance evaluation: The optimal value for the performance criterion is determined in this step as follows.

Table 3 Consistency index (CI)

Linguistic variables	EI	WI	FI	VI	AI
U_{bw}	1	1.5	2	2.5	3.5
CI	3	3.80	4.56	5.59	6.69

$$X_{0j} = \min x_{ij}, \quad j \in \Omega_{\min} \tag{10}$$

$$X_{0j} = \max x_{ij}, \quad j \in \Omega_{\max} \tag{11}$$

where X_{0j} represents the value of optimal performance for jth criteria, $\Omega_{\max}$ illustrates a set of benefit criteria, and $\Omega_{\min}$ denotes a set of cost criteria.

Step 3. Normalized fuzzy decision matrix: The normalized fuzzy decision matrix is determined in Eq. (12), while Eqs. (13) and (14) are stated as normalized benefit and cost criteria, respectively (Baki, 2022).

$$\overline{X} = \begin{bmatrix} \overline{x_{01}} & \cdots & \overline{x_{0j}} & \cdots & \overline{x_{0n}} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \overline{x_{i1}} & \cdots & \overline{x_{ij}} & \cdots & \overline{x_{in}} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \overline{x_{m1}} & \cdots & \overline{x_{mj}} & \cdots & \overline{x_{mn}} \end{bmatrix}, \quad i = 0, 1, \dots, m, \quad j = 0, 1, \dots, n \tag{12}$$

$$\overline{x_{ij}} = \frac{\widetilde{x_{ij}}}{\sum_{i=0}^{m} \widetilde{x_{ij}}} \tag{13}$$

$$\overline{x_{ij}} = \frac{\frac{1}{\widetilde{x_{ij}}}}{\sum_{i=0}^{m} \frac{1}{\widetilde{x_{ij}}}} \tag{14}$$

Step 4. Weighted normalized fuzzy decision matrix: The normalized fuzzy decision matrix in step 3 can be weighted using the following equation.

$$x_{ij}^{*} = \overline{x_{ij}}.\widetilde{w_j}, \quad i = 0, 1, \dots, m, \quad j = 0, 1, \dots, n \tag{15}$$

where $\widetilde{w_j}$ indicate the weight of j th criterion, and x_{ij}^{*} indicate the weighted normalized value of the j th criterion.

Step 5. Overall performance index: The overall performance index can be calculated as follows.

$$S_i = \sum_{j=1}^{n} x_{ij}^{*}, \quad i = 0, 1, \dots, m \tag{16}$$

Step 6: Utilization degree: The utilization degree of each alternative can be calculated using the following equation.

$$\hat{Q} = \frac{S_i}{S_0}, \quad i = 0, 1, \dots, m \tag{17}$$

where S_i represents the overall performance index for each alternative, and S_0 represents the optimal criterion value of the best decision option.

4 Case study

The availability of public healthcare services is vital for any community. After the outbreak of COVID-19, healthcare systems have confronted numerous challenges that not only affect the performance of healthcare supply chains but also increase the responsibilities of practitioners to satisfy both customers and stakeholders. The Medicine shortage led healthcare service providers to produce the highest amount of medical products as the demand was drastically increasing.

In this section, a real-world case study is proposed to solve the problem of selecting the best suppliers that can address the demand in this outbreak. An Iranian pharmaceutical distributor that produces and distributes medicine among retailers is studied as a part of a large supply chain. In this regard, the mentioned company had to deal with the problem of low capabilities and high portions of raw materials imported from foreign suppliers, while international sanctions have increased the risk of disruption in pharmaceutical supply chains (Nasrollahi & Razmi, 2021). This situation resulted in a crisis in providing sufficient medical care for the patients in Iran.

The studied company works with seven suppliers and tends to improve the suppliers' performance by establishing a holistic framework to evaluate the suppliers and prioritize which medicines should be supplied by each supplier. In this study, two cases (before and after the COVID-19 outbreak) are studied (November 22, 2019–January 4, 2020, as point "B" and March 15, 2020–May 10, 2020, as point "A"). The dataset is collected directly from the pharmaceutical distributor, and the results are compared in the next section.

5 Results

In order to prioritize the suppliers $\left(S_1, S_2, \dots, S_7\right)$, the most relevant criteria are obtained by asking experts in academia and practice. The selected criteria are illustrated in Fig. 5.

Thereafter, a panel of experts including chief managers of the pharmaceutical distributor company analyzed the selected criteria, and the significance of each criterion was calculated by adopting a BWM methodology. LINGO software is used to solve the mathematical model and propose weights for different criteria. LINGO is a tool that is used for building and solving optimization problems by integrating different packages including a set of fast built-in solvers.

5.1 Calculating the criteria weights using the BWM method

The fuzzy BWM approach is employed to determine the importance of the final list of criteria for the two periods. The implementation process of this method at the pharmaceutical company is elaborated using the following steps.

Step 1. The best and worst criteria and sub-criteria are determined by the experts' panel using a preference for overall criteria and sub-criteria.

Step 2. The preference for each criterion including the best and worst ones is determined based on the linguistic variables for preference and the corresponding triangular fuzzy number preferences which are shown in Table 3. Experts examined the preference ratio of the best criteria to other main criteria and also compared them with the worst

Fig. 5 Criteria and sub-criteria for lean, agile, resilience, and green factors

Table 4 Criteria and sub-criteria preferences for Expert 1

Best		Worst		BO/WO	Criteria comparison										CRs	
B	A	B	A		B	A	B	A	B	A	B	A			B	A
					C1		C2		C3		C1					
C1	C2	C4	C4	BO	EI	WI	WI	EI	FI	WI	AI	AI			0.12	0.12
				WO	AI	FI	FI	AI	FI	WI	EI	EI				
					C11		C12		C13		C14					
C11	C12	C14	C11	BO	EI	AI	FI	EI	FI	WI	AI	VI			0.12	0.12
				WO	AI	EI	VI	AI	FI	VI	EI	WI				
					C21		C22		C23		C24		C25			
C22	C21	C25	C25	BO	FI	EI	EI	WI	FI	FI	WI	WI	AI	AI	0.12	0.12
				WO	VI	AI	AI	FI	FI	VI	VI	FI	EI	EI		
					C31		C32		C33		C34					
C33	C34	C32	C31	BO	WI	AI	AI	FI	EI	FI	FI	EI			0.12	0.12
				WO	FI	EI	EI	FI	AI	WI	WI	AI				
					C51		C52		C53		C54		C55			
C41	C41	C42	C45	BO	EI	EI	AI	WI	FI	FI	WI	WI	WI	AI	0.12	0.12
				WO	AI	AI	EI	VI	FI	WI	FI	FI	VI	VI		

criteria. For instance, preference criteria for expert 1 are shown in Table 4 for all sub-criteria which is estimated for points A and B and for two periods.

Step 3. According to experts' preferences, optimal fuzzy weights of each criterion and sub-criteria are shown in Table 4 along with the results of local and global weights for two periods. Table 4 demonstrates the final weight of supplier preference criteria for two periods before and after the outbreak of COVID-19. As a result, the weights corresponding to the lean criterion are 29.1%; and for agile, resilience, and green criteria are 26.7%, 22.8%, and 21.3%, respectively. The weights of the mentioned criteria have been changed after the COVID-19 outbreak to 31.2% for resilience, 28.6% for agility, 21.3% for lean, and 19.1% for green criteria.

The obtained results show that the significance of resilience and agile pharmaceutical supply chain has increased after the pandemic, while the importance of developing a lean and green supply chain is mitigated. It happened because of the increasing demand for healthcare services at the beginning of the pandemic and led the practitioners to pay more attention to the resiliency and agility of supply chains to provide medical services at the time of need and as fast as possible. The significance of each criterion along with its sub-criteria is demonstrated in Table 5.

An illustrative comparative analysis for calculated weights before and after the pandemic is illustrated in Fig. 6 for the main criteria and Fig. 7 for the sub-criteria. The final weights of the sub-criteria of lean, agile, resilience, and green are summarized in Fig. 7 for two periods before and after the COVID-19 outbreak.

Table 5 LARG criteria and sub-criteria final weights

Criteria	Weight		Sub-criteria	Weight			
				Local		Global	
	B	A		B	A	B	A
C1	0.266	0.213	C11	0.317	0.164	0.085	0.035
			C12	0.243	0.397	0.065	0.084
			C13	0.240	0.268	0.064	0.057
			C14	0.200	0.173	0.053	0.037
C2	0.291	0.286	C21	0.218	0.253	0.063	0.072
			C22	0.244	0.163	0.071	0.046
			C23	0.174	0.249	0.051	0.071
			C24	0.219	0.202	0.064	0.058
			C25	0.145	0.133	0.042	0.038
C3	0.204	0.312	C31	0.268	0.209	0.055	0.065
			C32	0.219	0.194	0.045	0.061
			C33	0.247	0.207	0.050	0.064
			C34	0.267	0.389	0.055	0.121
C4	0.237	0.191	C41	0.245	0.211	0.058	0.040
			C42	0.144	0.158	0.034	0.030
			C43	0.244	0.239	0.058	0.046
			C44	0.219	0.231	0.052	0.044
			C45	0.148	0.161	0.035	0.031

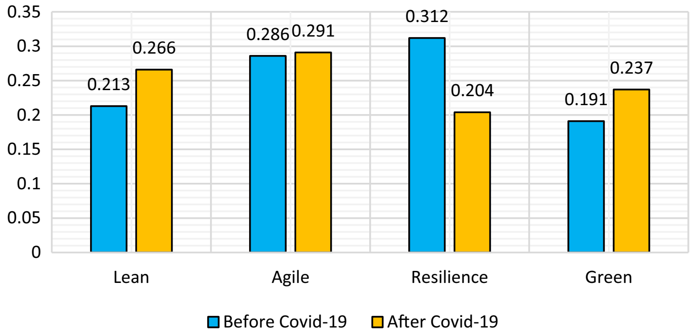


Fig. 6 Expert's views on the lean, agile, resilience, and green criteria before and after the COVID-19 outbreak

5.2 Supplier selection using the fuzzy ARAS method

A fuzzy ARAS approach is adopted to select the suppliers based on the following steps and the results are summarized in Table 6.

Step 1. Given the significance of each criterion, experts employed the linguistic variables illustrated in Table 3 to prioritize the supplier selection process. Considering experts' opinions along with the geometry average method, the final decision matrix can be excluded. Finally, the final supplier ranking is calculated using the fuzzy ARAS approach.

Step 2. The results summarized in Table 6 are normalized using Eq. (15).

Step 3. A normalized fuzzy decision matrix is obtained based on the calculated weights by the BWM approach which is previously shown in Tables 3, 4, 5 and 6.

Step 4. The overall performance index and utility degree for each supplier can be obtained using Eq. (16).

Based on the expert's opinions and the calculated weights of the criteria in the two periods, the supplier selection process is prioritized using the ARAS approach. Based on the final supplier ranking summarized in Table 6, the suppliers S1, S2, S6, S7, S5, and S4 are selected, respectively, before the COVID-19 outbreak, while the suppliers S1, S7, S2, S5, S6, S4, S3 are selected, respectively, after the COVID-19 outbreak. Supplier prioritization results are summarized in Fig. 8.

This study demonstrated that the criteria for selecting the suppliers in a pharmaceutical supply chain have been changed. Five paradigms including lean, agile, resilience, and green criteria are elaborated on in this study. Pharmaceutical supply chains' focus has been shifted from lean and green paradigms to resilience and agile criteria. Also, the sub-criteria of just-in-time delivery in the lean paradigm, lean time in the agile paradigm, and surplus inventory in the resilience paradigm have been increased by %63, %43, % and 46, respectively. However, changes in the significance of green criteria are less considerable. For instance, green image as one of the important criteria of the green paradigm has only experienced %10 changes.

Based on the results of this study, large-scale disasters can significantly influence the strategic decisions of supply chains. In the short term, unpredictable factors such as demand dramatic toleration and medicine shortages have a significant influence on supply chain decision-makers' preferences.

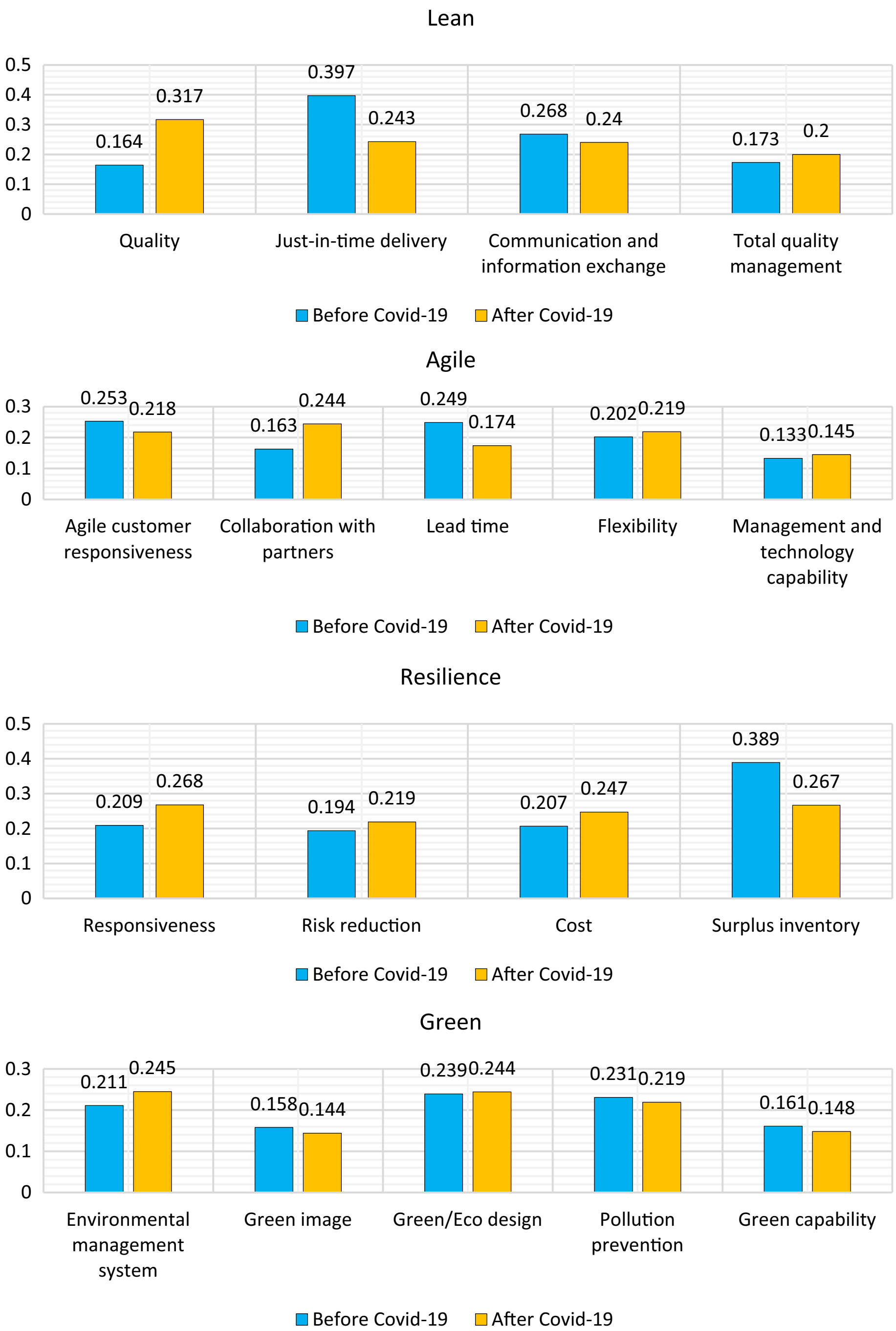


Fig. 7 Expert's preferences toward the lean, agile, resilience, and green sub-criteria before and after the COVID-19 outbreak

Table 6 Result of fuzzy ARAS method for supplier selection and evaluation

Suppliers	S_{il}		S_{im}		S_{iu}		S_i		R_i		Ranking	
	A	B	A	B	A	B	A	B	A	B	A	B
S0	0.105	0.107	0.124	0.124	0.145	0.145	0.125	0.126	1	1	1	1
S1	0.088	0.093	0.109	0.112	0.132	0.134	0.110	0.113	0.881	0.901	1	1
S2	0.087	0.089	0.106	0.106	0.127	0.127	0.107	0.108	0.857	0.859	2	3
S3	0.073	0.071	0.092	0.088	0.113	0.108	0.093	0.090	0.746	0.714	7	7
S4	0.074	0.078	0.094	0.096	0.116	0.118	0.095	0.098	0.763	0.780	6	6
S5	0.079	0.082	0.099	0.101	0.122	0.123	0.100	0.102	0.803	0.812	5	4
S6	0.082	0.083	0.100	0.101	0.122	0.121	0.102	0.102	0.815	0.812	3	5
S7	0.078	0.083	0.098	0.103	0.122	0.125	0.100	0.104	0.798	0.829	4	2

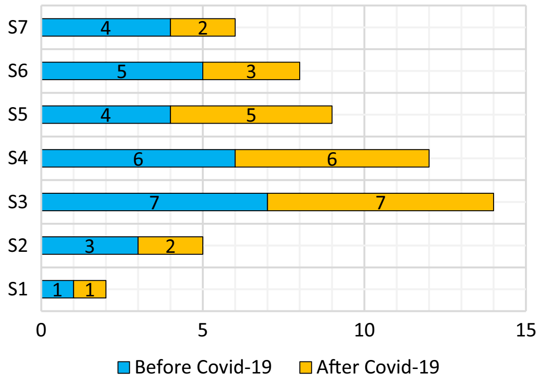


Fig. 8 Supplier selection preference before and after COVID-19

5.3 Managerial implications

The increasing attention paid by governments and consumers to the resilient and sustainable behavior of supply chains affects the managers' choice of producing and selling strategies. Besides, the COVID-19 situation changed different processes of industries, especially pharmaceutical supply chains that confronted a huge increase in demand and shortages in providing the retailers. This situation can also be extended to other disruptive circumstances such as natural disasters in which the urgent need for medicine and food is increased.

Incorporating LARG practices helps practitioners not only develop resiliency and sustainability within the supply chain but also think about leanness and agility of processes which leads to quick responses and harmonization among suppliers and retailers. It can also drive customer satisfaction by developing profitability in turbulent markets during disasters. By employing LARG systematically, manufacturers might expect a decrease in manufacturing and remanufacturing waste, suppliers can develop just-in-time and resiliency in the delivery of items, and retailers can reduce the lead time and improve the service quality.

The impreciseness of information can be determined by the developed approach in this study due to adopting fuzzy set theory. It can help quantify the subjective views of retailers when measuring the performance of suppliers under LARG criteria. The combination of FBWM and FARAS methods connects knowledge-based theory with the LARG perspective which can be used for satisfying business requirements, business sophistication (Bazargan et al., 2017; Razavi et al., 2012), competitions, customer satisfaction, and building trust between different parties of a supply chain. Companies can adopt this technique to develop service excellence, societal performance, and sustainability considering the governmental and non-governmental rules. To do so, the managers should increase their knowledge about LARG practices to keep the personnel motivated in following these criteria. It can also help these managers to move beyond benchmarking activities by eliminating imprecise information.

6 Concluding remarks

Supplier selection and prioritizing the suppliers have always been a challenging issue for supply chain practitioners. Due to the outbreak of COVID-19 in the last 2 years, the supplier selection problem has become more significant, especially in pharmaceutical industries. A combination of lean, agile, resilient, and green (LARG) approaches can be employed for supplier selection in large-scale problems in the case of unpredicted circumstances such as pandemics. Despite the investigations in LARG paradigms, a comprehensive model on large-scale disruptions in crises such as COVID-19 has never been utilized.

To address this challenge during the COVID-19 outbreak, this study elaborated a LARG supplier selection model while each LARG criteria is divided into different sub-criteria, and a specific weight is assigned to each criterion and sub-criteria. The supplier ranking approach in the pharmaceutical supply chain provides a comparative analysis of the ranked suppliers before and after the outbreak of COVID-19. Also, discussing a supplier selection problem in the era of the pandemic is a vital subject that is discussed by other researchers (Ilyas et al., 2021; Orji & Ojadi, 2021) in terms of cost, protected equipment, and prediction of customer demand using information technology.

This study proposes a novel framework to improve supply chain performance in the case of disruptions. As far as our knowledge, this study is the first attempt to employ LARG paradigms for solving supplier selection problems. Another contribution of this study to the corresponding literature is applying a novel hybrid fuzzy MADM approach including fuzzy ARAS and fuzzy BWM models. In this regard, the final ranking of the suppliers concerning the final weights for both situations is determined before and after the COVID-19 outbreak, while lean and green criteria have become less important.

The results show that the supplier selection scheme changed after the outbreak of COVID-19 and the significance of resilience and agility has increased. The results of this study support the outcome of the papers proposed by Ayati et al. (2020) and Butt (2021), in which the demand is met in a short-term schedule, and the suppliers are forced to produce more pharmaceutical products and provide the distributors with surplus inventory and quick response to the market needs.

One of the limitations of this study is defining LARG criteria based on what has already been done in previous works; however, addressing the problem in practice requires other criteria that might be overlooked due to model restrictions. Uncertainty in the model that causes disruptions in the supply chain might be addressed using fuzzy theory which might not be the case for all supply chains. The type of uncertainty in some supply chains might follow a stochastic pattern that can be modeled. In addition, the weights of LARG criteria are compared between two time periods and do not highlight the possibility of other types of disruptions that occur due to the shortage of products in warehouses or machine breakdowns during the manufacturing process.

For further research in this direction, it is recommended to compare different types of uncertainty. For instance, determining how the weight of each criterion can be changed under different uncertainty situations can be a novel idea for further elaboration. Research methodologies can also be compared to demonstrate how the weights can be changed when different approaches are adopted. For instance, DEMATEL and AHP are the methods that have been more commonly used in comparison with other methods. Besides, comparing the results obtained from these methods can be a validation of this study. Also, the use of emerging technologies such as the Internet of Things (IoT) helps to improve the LARG supply chain (Karimi et al., 2022; Mohaghar et al., 2021; Mohammadzadeh et al., 2018; Nasrollahi et al., 2022; Zadtootaghaj et al., 2019; Zarei et al., 2016, 2017), which can be analyzed in future research.

The results can help pharmaceutical supply chain practitioners make optimal decisions considering LARG paradigms in the case that effective responses to unexpected changes are required. Although this paper provides useful insights in practice, it has its limitations too. This study has been conducted based on a case study, and the general applicability of the approach is questioned. Moreover, the interactions between criteria and sub-criteria are not evaluated. Therefore, it is recommended to evaluate the suppliers in a more detailed way in future. Also, using multi-objective problems can demonstrate the aim of supply chains to be optimized, especially in the case of disruptions. Another novelty for future research works can be considering the uncertainties in supply chains which can be an effective way of controlling disruptions.

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Declarations

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Consent to publish All the authors agreed to submit the manuscript with affiliations of institutes mentioned in the manuscript and also agreed to submit in environment, development, and sustainability.

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