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SOFT COMPUTING IN DECISION MAKING AND IN MODELING IN ECONOMICS

A goal programming-based fuzzy best–worst method for the viable supplier selection problem: a case study

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Abstract

Since the COVID-19 outbreak has led to drastic changes in the business environment, researchers attempt to introduce new approaches to improve the capability and flexibility of the industries. In this regard, recently, the concept of the viable supply chain, which tried to incorporate the leagile, resiliency, sustainability, and digitalization aspects into the post-pandemic supply chain, has been introduced by researchers. However, the literature shows that there is lack of study that investigated the viable supplier selection problem, as one of the crucial branches of viable supply chain management. Therefore, to cover this gap, the current work aims to develop a decision-making framework to investigated the viable supplier selection problem. In this regard, owing to the crucial role of the oxygen concentrator device during the COVID-19 outbreak, this research selects the mentioned product as a case study. After determining the indicators and alternatives of the research problem, a novel method named goal programming-based fuzzy best–worst method (GP-FBWM) is proposed to compute the indicators' weights. Then, the potential alternatives are prioritized employing the Fuzzy Vlse Kriterijumsk Optimizacija Kompromisno Resenje method. In general, the main contributions and novelties of the present research are to incorporate the elements of the viability concepts in the supplier selection problem for the medical devices industry and to develop an efficient method GP-FBWM to measure the importance of the criteria. Then, the developed method is implemented and the obtained results are analyzed. Finally, managerial and theoretical implications are provided.

Keywords Viable supplier selection · Fuzzy best–worst method · Goal programming · Oxygen concentrator

1 Introduction

Supply chain (SC) management is one of the most important issues in the business environment, which has a significant effect on society, economics, and nature (Ivanov 2020). Nowadays, due to an increase of the marketplace competition, the SC problem importance has been dramatically bolded (Nayeri et al. 2020). Therefore, setting an efficient plan for improving the productivity of the SCs is one of the main goals of managers. In this regard, the Supplier Selection Problem (SSP) is one of the main branches of the SC problem in which the best suppliers are selected among various suppliers (Fallahpour et al. 2018; Wu et al. 2020; Li et al. 2021). In the traditional perspective, the general indicators such as costs, quality and lead-time were the most important criteria. However, in last decades, due to increasing the environmental and social concerns, enhancing the competition, and increasing market dynamics, other indicators such as sustainability, agility and resiliency have been considered in the SSP problem (interested readers can see Rabbani et al. 2019; Foladi 2020; Li et al. 2020; Rouyendegh et al. 2020; Waleekhajornlert and Sureeyatanapas 2020; Alamroshan et al. 2021; Fallahpour et al. 2021a; Yildizbasi and Arioz 2022)).

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Recently (after the COVID-19 pandemic), the concept of the viable SC (VSC) was introduced by researchers, which simultaneously considers leagile, resiliency, sustainability, and digitalization (Ivanov and Dolgui 2020). In this regard, based on Ivanov (2020) the research stream in the field of the SC is shifting toward the viable supply chain (see Fig. 1). In general, Ivanov (2020) define the VSC as follows. The VSC is an SC that is dynamically adaptable and structurally changeable, which has the following attribute: (i) it can show an agile action to positive changes, (ii) it is resilient to tackle disruptions, (iii) survive at the times of long-term, and (iii) it is in line with sustainable development. On the other side, Fig. 2 depicts the informational, financial, technological, and organizational structure of the VSC based on point of Ivanov and Dolgui (2020) view. Therefore, the concept of the VSC is very crucial for post-pandemic adaptation. In this area, several papers have been conducted in the field of viable SC (Ivanov 2020; Metwally et al. 2020; Lotfi et al. 2021b), viable digital SC (Zekhnini et al. 2021), and viable waste management (Lotfi et al. 2021a). However, despite its high importance, there is no study that investigated the viable SSP problem. In the following, we define each of viability pillars (i.e., leagile, resiliency, sustainability, and digitalization).

In general, sustainability can be incorporated into the supply chain management problem by simultaneous consideration of the social, environmental, and financial pillars (Mamashli et al. 2021). At the first glance, managers may think implementing the sustainability pillars in their companies leads to an extra cost. However, incorporating the sustainability dimensions can provide a green and socially responsible image from the company that enhances the customers' loyalty and increases the profits in the long term (Nayeri et al. 2022). On the other side, one of the crucial concepts that its importance has dramatically highlighted after the COVID-19 pandemic is resilience. In general, resilience includes a set of strategies in order to deal with disruptions (Namdar et al. 2021). Incorporating the resilience concept into the supplier selection process can significantly improve the efficiency and flexibility of this process (Fallahpour et al. 2021a).

A relatively novel approach that enables companies to cope with the fluctuation of the dynamic business environment as well as boost their market share is the leagile strategy (Galankashi and Helmi 2016; Li et al. 2020). To increase the company's competitiveness, the above-mentioned strategy is focused on supplying the customers with the right products, at the right price, and at the right time (Li et al. 2020; Abualigah et al. 2021a). In the leagile view, which integrates the 'lean' and the 'agile' concepts, allows businesses to gain a competitive advantage (Ambe 2017; Li et al. 2020). The following are the most widely accepted descriptions of agile and lean, which are provided by Mason-Jones et al. (2000) and Naylor et al. (1999). The concept of 'agile' can be defined as exploiting

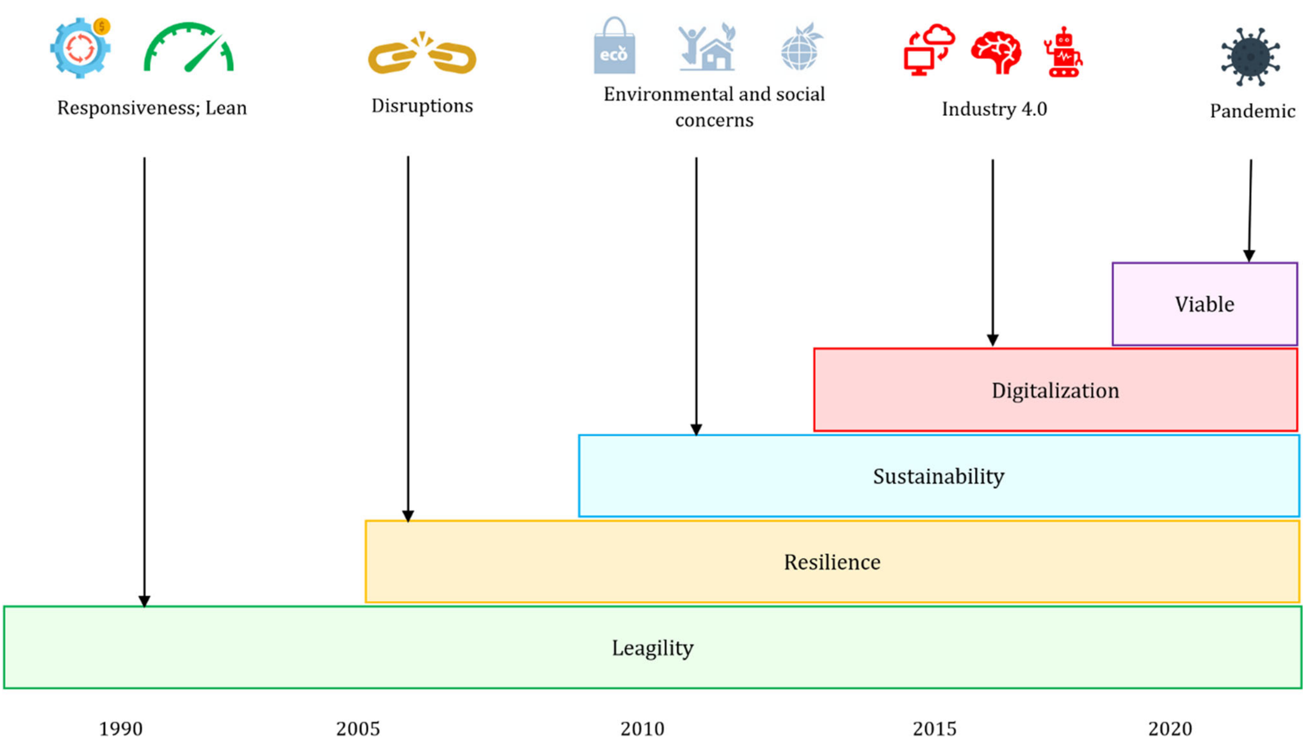


Fig. 1 The research stream over time (Ivanov 2020)

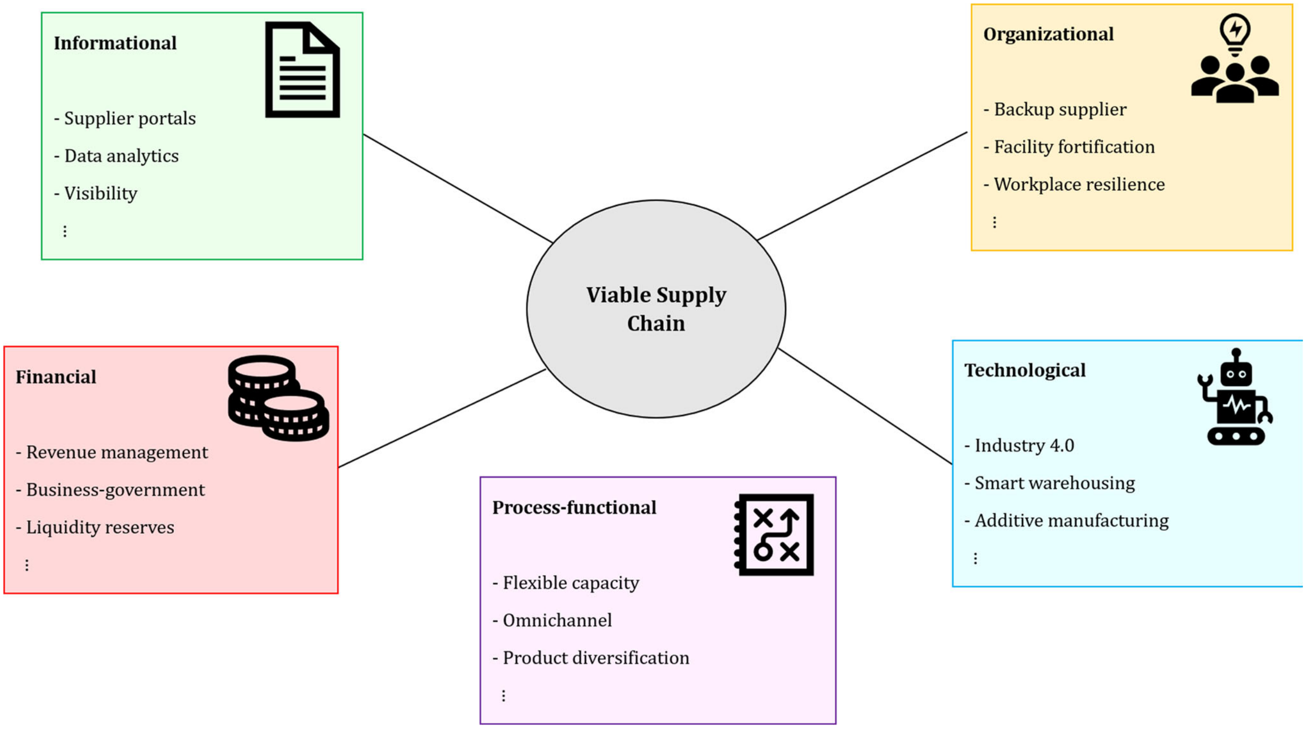


Fig. 2 Multi-structural view of the VSC

profitable opportunities in a competitive market space using a virtual corporation and market knowledge. 'Leanness', on the other hand, is defined as eliminating all unnecessary expenditures such as cost, resources, and time. The leagile approach seeks to achieve flexibility and competitiveness in a cost-effective manner. While these concepts are different, their combination (i.e., the leagile strategy) can be applied effectively to supply chain management, particularly in SSPs (Mason-Jones et al. 2000; Li et al. 2020).

With the fast-paced development of artificial intelligence and digitalization in the last two decades, the business environment has undergone dramatic transformations, which have been referred to as Industry 4.0 (I4.0) (Abualigah 2019; Jamwal et al. 2021). Accordingly, utilizing the latest technologies, such as I4.0 achievements, has profoundly impacted knowledge transfer, information sharing, and communication within SC facilities (Abualigah et al. 2021b; Fallahpour et al. 2021b). Based on Kusi-Sarpong et al. (2019), the SC's performance can be drastically improved by advanced technologies. Generally, I4.0 achievements allow managers to make their SCs more resilient and mitigate disruptions through the application of data analytics. According to Lee and Bagheri (2015), a major benefit of I4.0 in modern businesses is that it significantly increases service levels and optimizes inventory levels. Additionally, Kusi-Sarpong et al. (2019) stated that I4.0 is a critical factor in the SC problems due to its four fundamental principles, namely: (i) decentralization, (ii) real-time information transparency, (iii) technical assistance, and (iv) interconnection. It is therefore essential to take into account the concept of I4.0 in the context of the SSP problem as one of the most critical components of SC management.

Motivated by the above points and the real-world cases, the current research aims to provide a decision-making framework (DMF) to investigate the viable supplier selection problem. In this way, at the outset, the related literature is reviewed to extract the main indicators of the research problem. Then, a new version of the FBWM named the goal programming-based FBWM (GP-FBWM) is provided to compute the indicators weights. Afterward, the potential suppliers are ranked employing the FVIKOR method. It should be noted that the proposed DMF is implemented in a real case study in the medical devices industry to show its efficiency and applicability. The main characteristics of this study are as follows: (i) this is the first paper that studies the viable supplier selection problem, and (ii) this study develops the GP-FBWM that is an efficient method to calculate the criteria weights. In addition, the current work will answer the following questions.

- What are the main indicators of the viable SSP?
- How can a goal programming-based fuzzy BWM be developed?
- Which indicators are more important?
- Which supplier is more appropriate?

Regarding the motivations of this work, it should be noted that during the Coronavirus pandemic, one of the businesses whose importance was dramatically bolded is the medical devices (MDs) industry. During the outbreak, MDs like oxygen concentrators and Ventilator played a crucial role in improving patients' conditions. On the other hand, due to dramatic changes in the business conditions due to the Coronavirus outbreak, researchers have introduced a crucial concept for a post-pandemic business named viability that can improve the efficiency and flexibility of businesses (Ivanov 2020; Lotfi et al. 2021b; Oyelade et al. 2022). So, owing to the importance of the MDs industry, studying SC management problem for this industry is necessary. In this regard, the SSP is one of the significant branches of the SC problem (Fallahpour et al. 2018). Motivated by the mentioned points, the current research attempts to study the viable SSP for the MDs industry.

The rest of the current work is as follows. Section 2 reports the literature. Section 3 presents the research methodology. Section 4 provides the case study and indicators. Section 5 presents the numerical results. Finally, Sect. 6 provides conclusions.

2 Literature review

There are many challenges today that the issue of supplier selection, which is one of the most important decisions for any organization, has serious negative effects. Because the success and performance of organizations depend on their suppliers, organizations must improve their methods in the supplier selection process by considering resilience, sustainability, agility and digitalization capabilities to maintain competition and ensure sustainable performance. Therefore, in this section, we try to review the existing literature and articles in four research streams, including (i) sustainable supplier selection, (ii) resilient supplier selection, (iii) le-agile supplier selection (lean + agile), and (iv) digital supplier selection to be able to justify our existing research gap accordingly.

2.1 Sustainable SSP

Sustainability means focusing on the long-term effects of the company's operations and the durability of resources for future use, while being profitable today. Sustainability in the organization's literature and management has become a vital tool that guarantees competitive advantage and practice social responsibility. Furthermore, the main dimensions in sustainability include economic, social impacts, and environmental impacts. In this research stream, there are many studies focused on sustainable supplier selection. For instance, Yazdani et al. (2021) proposed a neutrosophic-based structure for sustainable supplier selection. They used the interval valued fuzzy neutrosophic (IVFN) model in order to consider several sustainability criteria and score six potential suppliers. The contribution of their study was evaluating the suppliers of a dairy company in Iran as a case study, based on sustainable criteria through different methods. Alavi et al. (2021) proposed a decision support system for evaluating suppliers based on sustainability. They first identified the criteria in three aspects of sustainability (i.e., economic, social, and environment) while the environmental criteria were especially for waste recycle production systems. So that, they weighted the criteria through Fuzzy Best–Worst Method (FBWM) and then prioritized the suppliers of a case study (petrochemical holding company) using Fuzzy Inference System (FIS). One of the main contributions they had expressed is using machine learning for scoring the suppliers in each criterion based on historical data except the expert opinions. Tayyab and Sarkar (2021) also provided a sustainable supplier selection approach with multi-periods and multi-objectives as a robust decision support system. They solved their model using fuzzy interactive goal programming model and could achieve about 90% satisfaction in quality and time in a supply process and about 50% satisfaction for the cost criterion in the textile industry.

However, Wu et al. (2021) also tried to develop an approach for sustainable supplier selection problem, especially for chemical industry. They considered the tree dimensions criteria such as economic, social, and environmental and their relations based on decision-making trial and evaluation laboratory (DEMATEL). The main novelty of their study was that they used specific methods for weighting the criteria related to each dimension. For example, for social-based criteria, failure mode and effects analysis (FMEA) was used. For environmental criteria, the entropy weight method (EWM) is used. Also, the suppliers were ranked through both TOPSOS and Fuzzy Grey Relational Analysis (FGRA). Zhang et al. (2021) used the rough DEMATEL method and the Fuzzy VIKOR (FVIKOR) method for sustainable supplier selection problem. They extracted the criteria relations through DEMATEL and scored all criteria by experts to order the suppliers in a real case study.

Tong et al. (2022) focused on small- and medium-sized enterprises for their sustainable supplier selection decision making. They first defined several criteria (include product and service capability, cooperation degree, and risk factors) and some sub-criteria for each of them and then prioritized the potential suppliers of a sofa production site as a case study using an extended PROMETHEE II method. Xing et al. (2022) focused on sustainable supplier selection in fuzzy environment using Choquet integral-based interval type-2 in BMW automobile company. Coşkun et al. (2022) also proposed a decision support framework for evaluating the suppliers based on sustainability dimension in a chemical manufacturing company. They defined several criteria and then analyzed their relations through analytic network process (ANP). Then, they tried to rank 69 suppliers by preference ranking organization method for enrichment evaluation (PROMETHEE). Finally, they proposed some managerial suggestion for assignment strategies.

2.2 Resilient SSP

Resilience is the ability of the supplier to overcome unpredictable events. Regarding this concept, Cavalcante et al. (2019) focused on resilient supplier selection based on supervised machine learning algorithms. They collected some information about suppliers such as time delivery of suppliers in different risks situation. Their results separate the critical suppliers from others in a digital manufacturing company using K-nearest neighbor algorithm. Davoudabadi et al. (2019) used the data envelopment analysis (DEA) principal component analysis (PCA) methods for resilient supplier selection problems in the fuzzy environment. They used principal component analysis (PCA) to reduce problem variables and correlations between criteria. Data envelopment analysis (DEA) has also been used to weight problem metrics and supplier ratings. Afrasiabi et al. (2022) developed an extended integrated MCDM model in order to solve a sustainable-resilient supplier selection problem. They considered 16 criteria in three dimensions of the sustainability while focused on the COVID-19 pandemic changes in these criteria in resilience dimension. They weighted the criteria in a fuzzy environment using FBWM and ranked the suppliers with integrated GRA-TOPSIS methods. Their results demonstrated that risk awareness was the most important criterion in resilience dimension in their case study.

Besides, Leong et al. (2022) used integrated GRA-BWM-TOPSIS methods for supplier evaluation. They considered seven criteria related to resilience (including quality, lead time, cost, flexibility, visibility, responsiveness and financial stability) and prioritized the suppliers for a food manufacturing company in the fuzzy environment. Shao et al. (2022) focused on sustainable supplier selection while considering disruptions occurred during COVID-19 pandemic. They proposed a multi-objective mathematical model for selecting the suppliers and solved it via a novel nRa-NSGA-II algorithm. They validated their proposed model in a therapy equipment supply chain of a company and suggested some managerial insights for the managers in the recent pandemic. Hoseini et al. (2022) proposed a framework for resilient supplier selection problem while considering uncertainty through interval type-2 fuzzy (IT2F) environment. They also used best–worst method and compared the results with analytical hierarchy process (AHP) and simple additive weighting (SAW) approaches. They finally ranked the suppliers of a case study in construction industry by TOPSIS.

2.3 Leagile SSP

Agile supplier has the ability to respond to changing needs so as to deliver the goods ordered to customers. A supply chain with flexibility and the ability to respond quickly to emergencies can help businesses respond to customer needs. In addition to flexibility, speed and accuracy are also features of the agile supplier. Besides, lean supplier is an approach aimed at producing and delivering products in the fastest possible time with the least production waste. Selecting the suppliers that can offer their products and services with high quality, low prices, and in a timely manner according to the requests and tastes of their customers in different markets, and elimination of waste and optimal use of resources has always been one of the main goals in any organization, which is specifically focused by the researches as leagile (lean + agile) SSP, recently. In this research stream, some researches focused only on the agile supplier selection, some of them considered only lean supplier selection, but some of them mentioned the leagile ones. For example in the agile supplier selection stream, Kumar et al. (2019) tried to select suppliers through agile criteria. They considered 14 criteria had direct impact on agility such as delivery speed, lead-time reduction, uncertainty situation, and etc. They used fuzzy DEMATEL for supplier evaluation. Goker et al. (2020) used fuzzy measure and fuzzy integral for evaluating suppliers based on agility standards for a dye manufacturer. The main criteria were management capability, manufacturing capability, collaboration capability, and agility which had some sub-criteria. The sub-criteria in agility dimension were delivery speed, delivery flexibility, agile customer responsiveness, make flexibility, and source flexibility. Dursun and Ogunclu (2021) used hierarchical fuzzy TOPSIS method in order to evaluate suppliers based on agile dimensions in an airline company for its jet-fuel suppliers. The criteria considered included management capabilities, production capabilities, collaboration capabilities, agility, and cost which had some sub-criteria. In the lean supplier selection stream, Torğul and Paksoy (2019) considered lean and green criteria for supplier selection using fuzzy TOPSIS and a linear mathematical model in an automotive company and tried to evaluate the suppliers. Rezaei et al. (2020) focused on lean criteria for supplier selection using MCDM methods (FAHP) and also bi-objective mathematical modeling. The FAHP was used for criteria weighting and bi-objective model for order allocation in an automotive company. The criteria they used were JIT performance, production management leanness, employee leanness, quality, cost, flexibility, and customer service and evaluated the suppliers.

In the le-agile supplier selection stream, Li et al. (2020) focused on le-agile supplier selection for a company in textile industry. They used DEMATEL and ANP for the criteria relationships related to lean and agility dimensions. Then, using TOPSIS ranked the suppliers of a textile industry company. Galankashi et al. (2021) provided a Lean-Agile approach for supplier selection problem. They first defined the criteria related both dimensions and evaluated the suppliers of an automotive manufacturing company as a case study using fuzzy analytical hierarchical process (FAHP). Alamroshan et al. (2022) focused on green-agile supplier selection problem for a case study related to medical devices industry. For this aim, developed a hybrid DMF by combining different decision-making methods. So, they extracted several criteria, recognized their relationships using FDEMATEL, weighted them through FBWM-FANP, and finally prioritized the potential suppliers using FVIKOR.

2.4 Digital SSP

Digital supply chains (DSCs) are digital systems designed to quickly and efficiently transmit information throughout the supply chain of products and services. In the digital supply chain, the product flow that existed in the traditional supply chain has been replaced by the flow of digital information. Therefore, this factor changes the previous procedures for supplier selection problem. In this research stream, we will investigate the articles focused on digital supplier selection. For instance, Liao et al. (2019) investigated the digital supplier selection in a linguistic environment for supply chain finance. They first identified several digital based criteria (i.e., digital competence, customer centricity, and financing capacity) and sub-criteria and then weighted them through best–worst method (BWM) and then ranked several suppliers related to China's entity manufacturing industry as the case study by additive ratio assessment (ARAS). Sharma and Joshi (2020) focused on digital supplier selection to investigate its impact on supply chain quality management (SCQM). They believed that, today, the geographical dispersion of physical facilities in supply chains is forcing companies to move to digital supply chains (DSCs). They examined the factors influencing the selection of digital suppliers and then evaluated and prioritized alternatives to identify the best supplier. They used the stepwise weight assessment ratio analysis (SWARA) method to identify factor weights and the weighted aggregated sum product assessment (WASPAS) method for alternatives assessment. The results of the study show that the competency criterion is the most important criterion in choosing a digital supplier, which also increases the quality of the product or service. Of course, they point out that similar research should be done in other countries to determine how other organizations and customers respond to the choice of digital supplier. Supply chain quality management, which is in line with the choice of digital supplier selection, also offers quality products that are sustainable and provide social and economic benefits to society. This process will also lead to greater transparency, resilience, and sustainability in the product and service.

Torkayesh et al. (2020) focused on digital supplier selection problem in an online shop. Digital transformation has led to many changes in various industries that affect all parts of the supply chain, including supplier selection, distribution, and other supply chain operations that have had relatively new and complex implications. For this purpose, they use the BWM method and WASPAS model for determining the weight of criteria and they then evaluated the suppliers. Then in order to show the feasibility of their method, they examined a case study involving an online store in Iran. Their results showed that among different criteria (include digital engagement, digital collaboration, information sharing, service quality, flexibility, financing efficiency, security and privacy) information sharing and digital engagement was the most important criteria for supplier selection. Özek and Yildiz (2020) used type-2 fuzzy TOPSIS in order to select the best digital supplier in a case study. They considered five main digital criteria such as digital production systems (DPS), information and communication technologies (ICT), intelligent logistics and inventory systems (ILIS), maintenance and repair systems (MRS), and management systems (MS). They also defined several sub-criteria for each dimension. Finally, they evaluated three suppliers and ranked them. Tavana et al. (2021) also considered 12 digital-based criteria for suppliers. They weighted them using Fuzzy Best–Worst Method (FBWM). Then, they ordered some potential suppliers through integrated the fuzzy multi-objective optimization based on ratio analysis plus full multiplicative form (MULTIMOORA), fuzzy complex proportional assessment of alternatives (COPRAS), and fuzzy technique for order preference by similarity to ideal solution (TOPSIS). Zekhnini et al. (2021) presented a model for the supplier selection process of organizations when different dimensions including resilience, sustainability and digitalization are important to them. After defining the opposite criteria in each of the different dimensions, they used an ontology-based model. Camci et al. (2022) focused on the issue of supplier selection in the fourth industrial revolution and considered digital criteria including computer, communication, and automation technologies in the supplier selection process. In their article, they used the combined method of Analysis Hierarchy Process (AHP) and Fermatean fuzzy set (FFS) to cover the disadvantages of using AHP method alone. Demiralay and Paksoy (2022) also examined the issue of supplier selection by considering the dimensions of sustainability as well as the smart dimension of the supply chain including digitalization components. In the dimension of smart or digital, they considered criteria such as cloud technologies, Internet of Things, big data, and block chain. In this regard, they used multi-criteria decision-making methods including FAHP and FBWM. The papers reviewed in this section are summarized in Table 1.

2.5 Research contributions

As can be seen in the literature section, owing to the importance of the SSP, many articles have been conducted in this field in recent years. These papers considered different features such as sustainability, resiliency, agility, etc. However, there is no study that incorporated the recently introduced concept named viability in the supplier selection problem whereas the mentioned concept is known as one of the most important features of the post-pandemic supply chains (Ivanov 2020). Hence, motivated by the above-mentioned point, the present research aims to develop a hybrid DMF to assess the viable SSP under the fuzzy environment. In this way, first, the main criteria and sub-criteria of the viable SSP are determined based on the experts and literature. Then, a novel method named goal programming-based FBWM is developed to compute the indicators' weights. Afterward, to prioritize the potential suppliers, the FVIKOR method is employed. On the other side, due to the crucial role of the oxygen concentrator during the recent pandemic, the current work selects this product as a case study. Overall, based on the gaps mentioned before, the major contribution of our study could be noted through following points:

- The present research investigates the viable supplier selection problem for the first time. In this regard, the current study considers the viability dimensions (i.e., sustainability, resilience, leagility, and digitalization) in the supplier selection process.
- This study develops a novel extension of the BWM named the GP-FBWM to calculate the indicators' weights.
- This is the first study that investigated the oxygen concentrator device as a case study for the supplier selection problem.

3 Methodology

As mentioned, in this research, a hybrid DMF is carried out based on the FVIKOR and GP-FBWM methods. In the current section, we present the descriptions regarding the proposed hybrid DMF. It should be noted that besides the decision-making field, fuzzy systems can be employed in other problems in the field of data mining, artificial intelligence, etc., that interested readers can see (Al-Qaness et al. 2018, 2021; Al-qaness et al. 2019, 2022a, b; Abd Elaziz et al. 2020; Naji Alwerfali et al. 2020; AlRassas et al. 2021) to more study.

3.1 GP-FBWM

One of the relatively novel methods that attracted researchers' attention is the fuzzy best–worst method (FBWM) (Sofuoğlu 2020). The main advantages of the BWM over similar approaches (e.g., AHP) are as follows (Rezaei et al. 2016; Aria et al. 2020; Abualigah et al. 2022): (i) this method significantly reduced the compute burden, (ii) this approach increases the reliability of the outputs, (iii) this needs less time to pairwise comparison, and (iv) this approach can easily combine with other methods. Before presenting the steps of the FBWM, it should be noted that $\widetilde{a} = (l, m, u)$ is a triangular fuzzy number and the Graded Mean Integration Representation (GMIR), represented by $R(\widetilde{a})$, is calculated by relation (1). The main reason for using this relation is that this approach is a widely-used one in the related literature (for example see Fallahpour et al. 2018, 2021a; Alamroshan et al. 2022)) and showed a good performance in this field.

$$R(\tilde{a}) = \frac{l + 4m + u}{6} \quad (1)$$

Here, we present the steps of FBWM according to Guo and Zhao (2017):

The first step: Determining the worst and the best indicators based on the experts' opinions.
The second step: Forming the Best-to-Other (BO) and Other-to-Worst (OW) vectors base on linguistic variables presented in Table 2. In this way, let B be the best indicator and W shows the worst indicator. Then, the BO and OW, respectively, can be shown by $\tilde{A}_B = (\tilde{a}_{B1}, \tilde{a}_{B2}, \ldots, \tilde{a}_{Bn})$ and $\tilde{A}_W = (\tilde{a}_{1W}, \tilde{a}_{2W}, \ldots, \tilde{a}_{nW})$.
The third step: Solving the mathematical model to achieve optimal weights. In this way, suppose that the OW vector is represented by $\tilde{a}_{jW} = \left(l_{jW}, m_{jW}, u_{jW}\right)$, the BO vector is denoted by $\tilde{a}_{Bj} = \left(l_{Bj}, m_{Bj}, u_{Bj}\right)$, the weights vector is shown by $\tilde{w}_j = \left(l_j^w, m_j^w, u_j^w\right)$, and the objective

Table 1 Reviewed paper summarization

Author	Dimensions					Technique	Application	Advantages and disadvantages
	Sustainability	Resilience	Lean	Agility	Digitalization			
Cavalcante et al. (2019)		*				K-Nearest neighbor algorithm	A digital manufacturing company	Pros: Separate the critical suppliers from others using machine learning models Cons: Do not used any method for criteria defining and weighting
Kumar et al. (2019)				*		DEMATEL		Pros: Focusing on criteria interrelationship Cons: Not considering the other essential dimensions in supplier selection and either fuzzy environment
Torğul and Paksoy (2019)			*			Fuzzy TOPSIS	An automotive company	Pros: Developing a mathematical model for supplier selection Cons: Not considering the other essential dimensions in SSP
Liao et al. (2019)					*	BWM-ARAS	Manufacturing company	Pros: – Cons: Not considering the other essential dimensions in SSP and also fuzzy environment
Rezaei et al. (2020)			*			(FAHP) and also bi-objective mathematical modeling	An automotive company	Pros: Developing a mathematical model for supplier selection Cons: -
Li et al. (2020)			*	*		DEMATEL-ANP-TOPSIS	A textile industry company	Pros: Developing a mathematical model for supplier selection Cons: -
Torkayesh et al. (2020)					*	BWM- WASPAS	An online shop	Pros: – Cons: Not considering the other essential dimensions in supplier selection
Yazdani et al. (2021)	*					MABAC, SAW, ARAS, WASPAS, TOPSIS, CRITIC, and CoCoSo	A dairy company in Iran	Pros: Combining interval valued fuzzy neutrosophic (IVFN) Cons: Not considering the other essential dimensions in supplier selection
Alavi et al. (2021)	*					Fuzzy Best–Worst Method (FBWM) and Fuzzy Inference System (FIS)	Petrochemical holding company	Pros: using machine learning for scoring the suppliers Cons: Not considering the other essential dimensions in supplier selection

Table 1 (continued)

Author	Dimensions					Technique	Application	Advantages and disadvantages
	Sustainability	Resilience	Lean	Agility	Digitalization			
Tayyab and Sarkar (2021)	*					fuzzy interactive goal programming model		Pros: Considering robustness in SSP Cons: Not considering the other essential dimensions in supplier selection
Wu et al. (2021)	*					DEMATEL-FMEA- EWM-FGRA	Chemical industry	Pros: Using different methods for each dimensions criteria of sustainability Cons:
Dursun and Ogunclu (2021)				*		hierarchical fuzzy TOPSIS	An airline company	Pros: - Cons: Considering only criteria related to agility
Galankashi et al. (2021)			*	*		FAHP	Of an automotive manufacturing company	Pros: - Cons: Weighting the criteria using only AHP is not enough for SSP
Xing et al. (2022)	*					Choquet Integral based interval type-2 in BMW	An automobile company	Pros: Type-2 fuzzy environment Cons: Considering only sustainability dimension
Coşkun et al. (2022)	*					ANP-PROMETHEE	A chemical manufacturing company	Pros: Extracting the relations between criteria Cons: Fuzzy environment was not considered
Afrasiabi et al. (2022)	*	*				FBWM- GRA-TOPSIS	A manufacturer of industrial valves, fittings, and pipes	Pros: Focusing on the COVID-19 pandemic changes Cons: Considering only sustainability and resilience
Leong et al. (2022)		*				GRA-BWM-TOPSIS	A food manufacturing company	Pros: Considering appropriate sub-criteria related to resilience Cons: Considering only resilience dimension for SSP
Shao et al. (2022)		*				novel nRa-NSGA-II	A therapy equipment supply chain	Pros: Developing a multi-objective mathematical model for selecting the suppliers Cons: Not using any method for criteria defining and weighting
Hoseini et al. (2022)		*				BWM-AHP-SAW-TOPSIS	Construction industry	Pros: considering uncertainty through Interval Type-2 Fuzzy (IT2F) environment Cons:–

Table 1 (continued)

Author	Dimensions					Technique	Application	Advantages and disadvantages
	Sustainability	Resilience	Lean	Agility	Digitalization			
Alamroshan et al. (2022)			*	*		FDEMATEL-FBWM-FANP-FVIKOR	Medical devices industry	Pros: An integrated MCDM methods for considering criteria relations while prioritizing suppliers Cons:–
Camci et al. (2022)					*	AHP and Fermatean fuzzy set	–	Pros: Using different fuzzy sets for weighting Cons:–

Table 2 The linguistic variables (You et al. 2017)

Linguistic terms	Equally important (EI)	Weakly important (WI)	Fairly important (FI)	Very important (VI)	Absolutely important (AI)
Membership function	(1, 1, 1)	(0.667, 1, 1.5)	(1.5, 2, 2.5)	(2.5, 3, 3.5)	(3.5, 4, 4.5)

function is demonstrated by $\tilde{\xi}^* = (k^*, k^*, k^*)$. Now, the mathematical model of the FBWM is as follows.

$$
\begin{aligned}
&\min\ \tilde{\xi}^* \\
&\text{s.t}: \\
&\frac{l_B^w}{l_j^w} - u_{Bj} \le k^* \quad \forall j \\
&\frac{m_B^w}{m_j^w} - m_{Bj} \le k^* \quad \forall j \\
&\frac{u_B^w}{u_j^w} - l_{Bj} \le k^* \quad \forall j \\
&\frac{l_j^w}{l_W^w} - u_{jW} \le k^* \quad \forall j \\
&\frac{m_j^w}{m_W^w} - m_{jW} \le k^* \quad \forall j \\
&\frac{u_j^w}{u_W^w} - l_{jW} \le k^* \quad \forall j \\
&\sum_{j=1}^{n} R(\tilde{w}_j) = 1 \quad \forall j \\
&l_j^w \le m_j^w \le u_j^w \quad \forall j \\
&l_j^w \ge 0 \quad \forall j
\end{aligned} \tag{2}
$$

The fourth step: Calculating the consistency ratio (CR). In this regard, the consistency index (CI) is determined based on the comparison of the best and worst indicators (see Table 3). Afterward, the CR is computed according to Eq. (3). It should be noted that the smaller value for CR (close to zero) is better.

$$CR = \frac{\xi^*}{\text{CI}} \tag{3}$$

Besides all its merits, in some cases, the BWM may result in multi-optimality solutions (Rezaei et al. 2016; Amiri and Emamat 2020), which may not be desirable for decision-makers. In this regard, Amiri and Emamat (2020) developed a goal programming model for the BWM method that guaranteed a unique optimal solution. Nevertheless, their model is completely a deterministic method that cannot consider the uncertainties. However, since the imprecision is available in business environment, the decision-makers prefer to utilize the approaches that can deal with the uncertainty. In this regard, to fix the mentioned drawbacks, the current work aims to develop the goal programming-based fuzzy BWM (GP-FBWM) to deal with uncertainty/imprecision of the marketplace and guarantee a unique optimal solution, simultaneously. In the

Table 3 The CI according to (You et al. 2017)

$\tilde{a}_{BW}$	CI
(EI)	3.00
(WI)	3.80
(FI)	5.29
(VI)	6.69
(AI)	8.04

following model (GP-FBWM), Y_j^+, Y_j^-, Z_j^+, and Z_j^- are free variables. In this regard, $Y_j^+ + Y_j^-$ shows the preference of the best criterion to other criteria, and $Z_j^+ + Z_j^-$ demonstrates the preference of all criteria to the worst criterion.

$$\begin{aligned} & Min \sum_j \left(Y_j^+ + Y_j^-\right) + \sum_j \left(Z_j^+ + Z_j^-\right) \\ & s.t: \\ & \frac{l_B^w}{l_j^w} - u_{Bj} = Y_j^+ - Y_j^- \quad \forall j \\ & \frac{m_B^w}{m_j^w} - m_{Bj} = Y_j^+ - Y_j^- \quad \forall j \\ & \frac{u_B^w}{u_j^w} - l_{Bj} = Y_j^+ - Y_j^- \quad \forall j \\ & \frac{l_j^w}{l_W^w} - u_{jW} = Z_j^+ - Z_j^- \quad \forall j \\ & \frac{m_j^w}{m_W^w} - m_{jW} = Z_j^+ - Z_j^- \quad (\forall) j \\ & \frac{u_j^w}{u_W^w} - l_{jW} = Z_j^+ - Z_j^- \quad \forall j \\ & \sum_{j=1}^{n} R(\tilde{w}_j) = 1 \quad \forall j \\ & l_j^w \le m_j^w \le u_j^w \quad \forall j \\ & l_j^w \ge 0 \quad \forall j \end{aligned} \tag{4}$$

It should be noted that the CR can be achieved based on the following relations. To better understand how the proposed algorithm works, see Fig. 3.

$$\xi = \max_j \left\{ Y_j^+ - Y_j^-, Z_j^+ - Z_j^- \right\} \tag{5}$$

$$CR = \frac{\xi}{CI} \tag{6}$$

3.2 FVIKOR

VIKOR method is a consensual solution and multi-criteria optimization. VIKOR technique was first introduced by Aprikovich in 1998 to solve multi-criteria decision-making problems and achieve the best possible solution (Kumar and Barman 2021). This method is used to rank and select options according to a set of different indicators. The main purpose of the VIKOR method is to bring most of the options closer to the ideal answer in each index, so that the options are ranked based on this goal. VIKOR method is not able to provide a definite and uncertain amount due to lack of information or sometimes lack of accurate information. On the other hand, fuzzy method as one of the powerful and useful methods in solving complex and ambiguous modeling environments has proven its capabilities in this field (Oyelade et al. 2022). Therefore, the VIKOR method is combined with the fuzzy method and is known as the fuzzy VIKOR method. The steps of the FVIKOR method are as follows:

Step 1: Define alternatives and evaluation criteria based on considered dimensions.
Step 2: Scoring the alternatives based on each criterion using linguistic variables shown in Table 4.
Step 3: Calculate the average of the expert opinion.

$$\tilde{x}_{ij} = \frac{1}{n}\left[\sum_{e=1}^{n} \tilde{x}_{ij}^{e}\right] \tag{7}$$

(i) Inputs:

The first step: Determine the best criterion and the worst criterion according to the expert's opinion

The second step: Form the comparison vectors (BW and OW) based on the expert's opinion

(ii) Implementation:

The third step: Code the developed model and enter the gathered data in the software. To this end, software such as LINGO, GAMS, Cplex, etc. can be applied. It should be noted that we utilized the LINGO software in this study.

The Fourth step: Run the software and check the CR. If $CR \le 0.1$, the obtained results are acceptable, otherwise, check and correct the gathered data.

(iii) Outputs:

The optimal weights of the indicators, and the CR.

Fig. 3 Description of how the developed method works

Table 4 Linguistic variables of FVIKOR

Linguistic terms	Corresponding fuzzy numbers
Very poor (VP)	(0.0, 0.0, 1.0)
Poor (P)	(0.0, 1.0, 3.0)
Medium poor (MP)	(1.0, 3.0, 5.0)
Fair (F)	(3.0, 5.0, 7.0)
Medium good (MG)	(5.0, 7.0, 9.0)
Good (G)	(7.0, 9.0, 10.0)
Very good (VG)	(9.0, 10.0, 10.0)

Step 4: Provide a fuzzy (normal) decision matrix in which $\tilde{x}_{ij}$ is the alternative A_i scores in each criterion of C_j.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & . & . & . & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & . & . & . & \tilde{x}_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ \tilde{x}_{m1} & \tilde{x}_{m2} & . & . & . & \tilde{x}_{mn} \end{bmatrix} \tag{8}$$

Step 5: Defuzzify the $\tilde{x}_{ij}$.

$$x_{ij} = \frac{\left[\left(Ux_{ij} - Lx_{ij}\right) + \left(Mx_{ij} - Lx_{ij}\right)\right]}{3} + Lx_{ij} \tag{9}$$

Step 6: Identify the best value (BV) and the worst value (WV).

$$\text{Worst Value} = f_i^- = \min_i x_{ij} \tag{10}$$

$$\text{Best Value} = f_i^* = \max_i x_{ij} \tag{11}$$

s_i is the profitability index and R_i is the regret index.
Step 7: calculate the value of s_i and R_i.

$$S_i = \sum_{j=1}^{n} w_j \left(f_j^* - x_{ij}\right) / (f_j^* - f_j^-) \tag{12}$$

$$R_i = \max_j \left[w_j \left(f_j^* - x_{ij}\right) / (f_j^* - f_j^-) \right] \tag{13}$$

Step 8: determine s^-, s^*, R^-, R^*, and Q_i.

$$S^* = \min_i S_i, \tag{14}$$

$$S^- = \max_i S_i \tag{15}$$

$$\tilde{R}^- = \max_i \tilde{R}_i \tag{16}$$

$$R^* = \min_i R_i \tag{17}$$

$$Q_j = v(S_i - S^*)/(S^- - S^*) + (1 - v)(R_i - R^*)/(R^- - R^*) \tag{18}$$

In Eq. (16), v is the weight of the group's maximum productivity strategy. When $v > 0.5$, the decision deviate to the majority. While $v = 0.5$, decision will deviate to the opposing person.
Step 9: Ordering the alternatives based on Q_i descending.
Step 10: Determine the agreed solution based on two conditions below:

Condition 1. Acceptable advantage:

$$Q(a'') - Q(a') \geq DQ \tag{19}$$

$$DQ = \frac{1}{m - 1} (DQ = 0.25 \; if \; m \leq 4) \tag{20}$$

Condition 2. a' should be ranked based on S and R.

If one of the conditions above is not satisfied, multiple agreed solutions will be presented.
Step 11: Select the best solution while Q (a') is the best solution that has minimum Q_i.

3.3 Hybrid method

Here, we provide explanations regarding the way of combining the proposed GP-FBWM and the FVIKOR methods. In this way, at the outset, the BO and OW vectors are formed by experts. Then, the indicators' weights are calculated by solving model (4). If the CR is more than 0.1, The gathered data are reviewed and corrected, and the model is again solved. Otherwise, the outputs of the GP-FBWM are considered as the input of the FVIKOR. Also, the decision matrix of the FVIKOR is formed by experts. Eventually, suppliers are ranked using the FVIKOR. Figure 4 illustrates the framework of the current work.

4 Case study

In this section, the case study of this research is presented and the main indicators and alternatives are provided. Medical devices (MDs) are known as one of the most important parts of the healthcare system. In the two last years in which Coronavirus disease has led to significant disruptions and damages across the world, the medical devices industry has played a crucial role. In this regard, one of the most important medical devices, which its demand is dramatically enhanced in the Coronavirus outbreak, is the oxygen concentrator device. Hence, based on the aforementioned points and the necessity of different medical devices during the COVID-19 outbreak, the current work selects one of the most important tools in the recent pandemic namely the oxygen concentrator device. Figure 5 shows the selected product and its components. The case study is a hospital in Tehran, which is one of the main hospitals in Iran during the corona epidemic. The

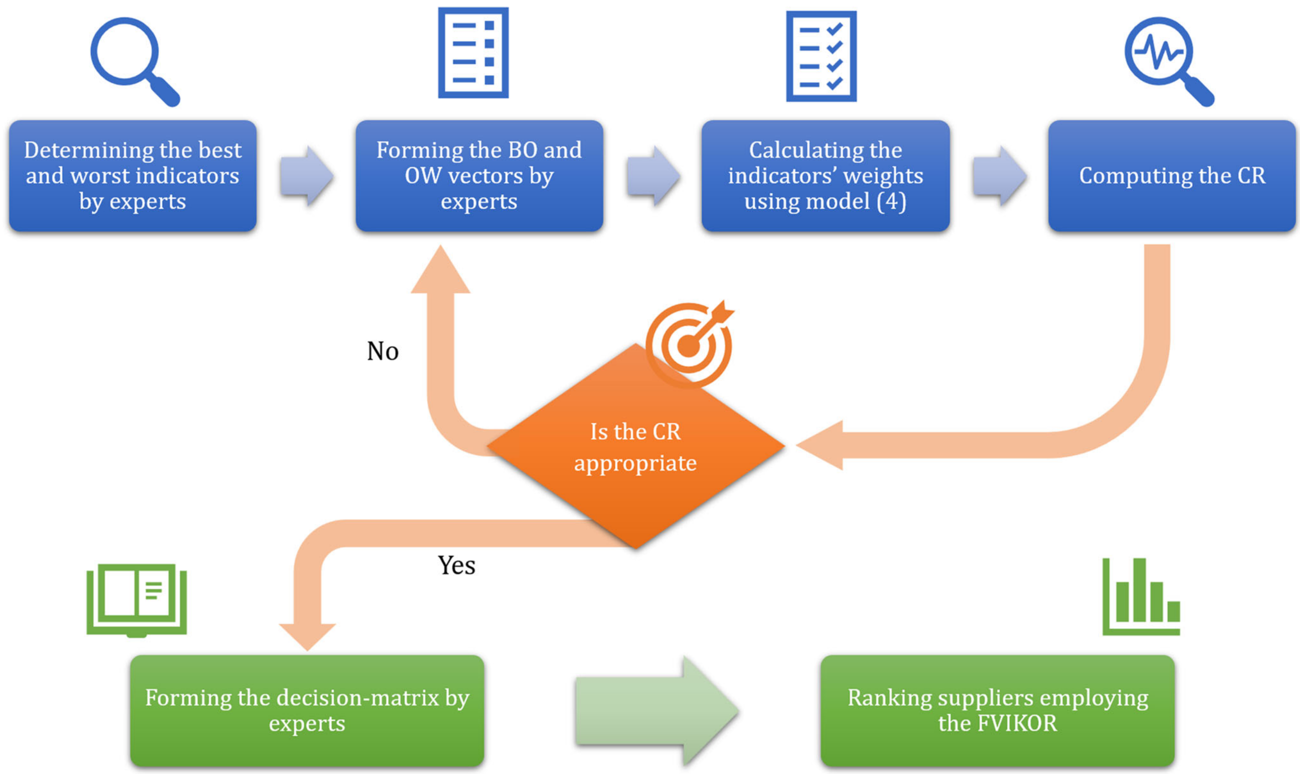


Fig. 4 The research framework

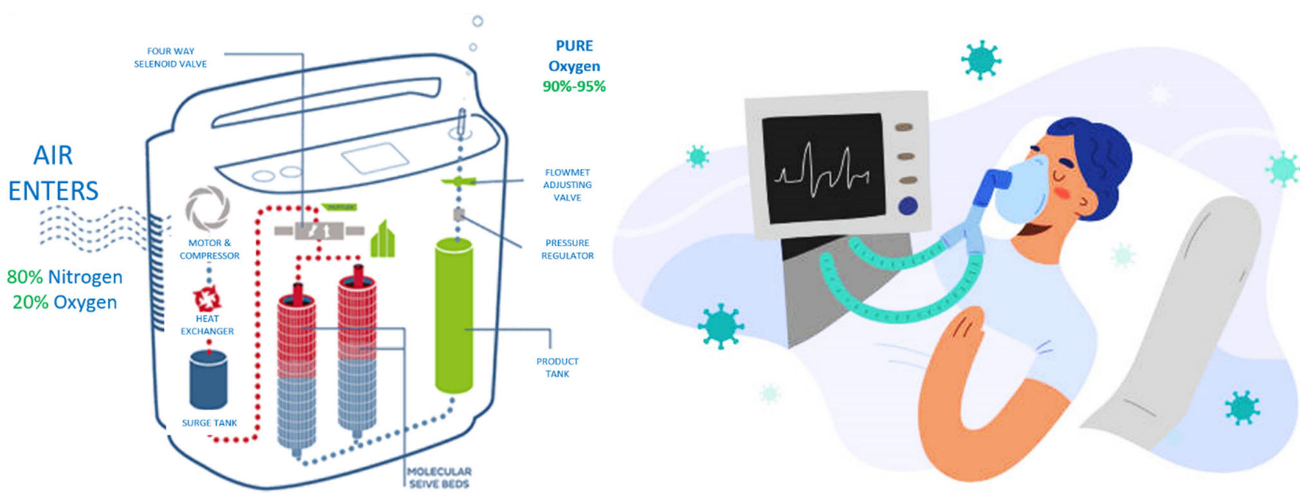


Fig. 5 The selected product (oxygen concentrator)

suppliers of oxygen generators for the studied hospital are from 4 different cities of Mashhad, Karaj, Isfahan and Tehran, which are shown in Fig. 6.

4.1 Aspects and indicators

Since the main elements of the VSC include leagile, sustainability, resiliency, and digitalization, we have divided the indicators into the four mentioned aspects. Here, the main indicators of the research problem are listed. Table 5 shows the main indicators of the leagile aspect and their descriptions. On the other side, Table 6 demonstrates the main indicators of the sustainability aspect. Also, the main indicators of the resilience aspect are given in Table 7. Eventually, the indicators of the digitalization aspect are presented in Table 8. It should be noted that four suppliers called A1–A4 are considered in the current study.

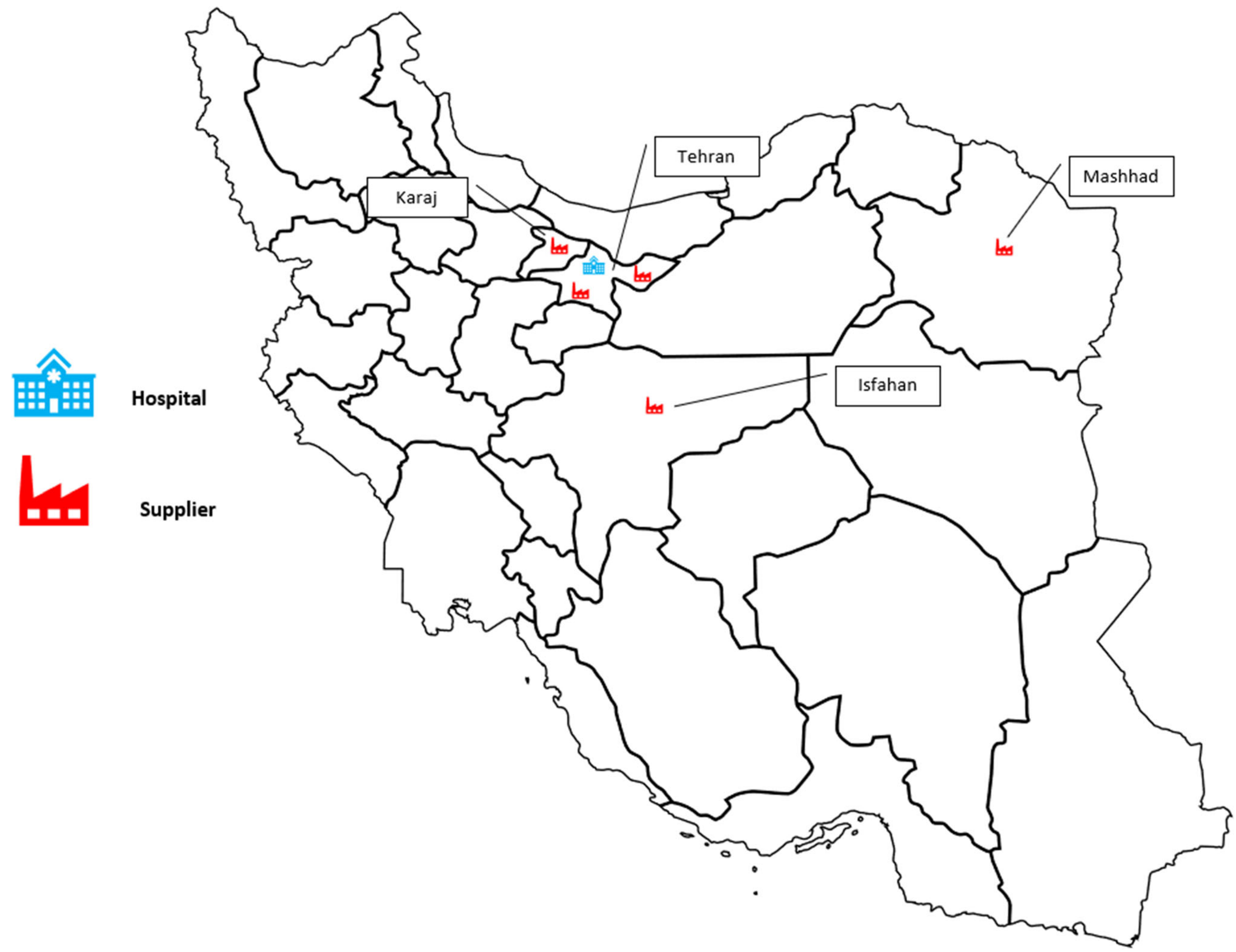


Fig. 6 The case study supplier map

Table 5 The indicators of the leagile aspect

Indicator	Definition
(1) Cost	The effectiveness of the supplier in terms of prices
(2) Quality	The level of the supplier in terms of total quality management
(3) Lead time	The delivery time of the supplier and delivery reliability
(4) Eliminate Muda	The effectiveness of the supplier for eliminating and decreasing waste based on lean principles
(5) Transportation	The flexibility and reliability of the supplier in terms of transportation
(6) Market sensitivity	Reputation, risk degree, diversification

5 Computational results

5.1 Results of the GP-FBWM

In this section, the weights of the indicators are computed using the proposed GP-FBWM. It should be noted that we gather the necessary data from three groups of experts that work in the considered case study. The related data has been provided in the Supplementary Materials-Part A. The outputs of the GP-FBWM are provided in Tables 9, 10, 11, 12, and 13. According to Table 9, among the aspects, leagile, sustainability, resiliency, and digitalization, respectively, are the most important ones. Based on Table 9, among the indicators of the leagile aspect, cost

Table 6 The indicators of the sustainability aspect

Indicator	Definition
(7) Greenhouse gas emission	The supplier's ability to control and reduce the greenhouse gas emission
(8) Waste management	The supplier's capability in managing and reducing wastes
(9) Pollution control	The supplier's ability in monitoring and managing hazardous materials
(10) Energy and resource consumption	The level of the supplier in terms of energy consumption
(11) Job safety and labor health	The supplier's capability in establishing a healthy and safe environment for workers
(12) Job opportunities	Job opportunities created by the supplier
(13) Employment insurance	The responsibility of the supplier regarding the contract of workers

Table 7 The indicators of the resiliency aspect

Indicator	Definition
(14) Extra inventory	The ability of supplier to have extra capacity for the emergency conditions
(15) Restorative capacity	The supplier's capability in restoration, restoration available resource
(16) Rerouting	Adaptive routing capability
(17) Reliability	The availability of the supplier during disruptions
(18) Backup supplier	The supplier's capability to contract with backup suppliers
(19) Cooperation	The ability of the supplier to collaborate with partners

Table 8 The indicators of the digitalization aspect

Indicator	Definition
(20) Information sharing	The ability of the supplier to share information with partners
(21) Security and privacy	The supplier's ability to keep information and data safe
(22) Technical capability	The ability to utilize technologies
(23) Digital engagement	The ability for harmonizing capabilities within and beyond physical boundaries
(24) Digital production system	The level of supplier in terms of establishing the digital production system

Table 9 The weights of the aspects

Aspect	Leagile	Sustainability	Resilience	Digitalization
Weights	0.2839256	0.2797764	0.2782083	0.1580897
$\xi^* = 0.1728419$ CI = 5.29 $\rightarrow$ CR = $\frac{0.1728419}{5.29} = 0.032673$				

Table 10 The weights of the criteria of the leagile aspect

Criteria	Cost	Quality	Lead time	Eliminate Muda	Transportation	Market sensitivity
Weights	0.2506090	0.1725244	0.1720636	0.09394665	0.1254517	0.1854047
$\xi^* = 0.4783141$ CI = 6 .69 $\rightarrow$ CR = $\frac{0.4783141}{6.69} = 0.071496$						

and market sensitivity are the most important ones. In addition, as can be seen in Table 10, GHG emissions and waste management are the most crucial indicators of the sustainability aspect. According to Table 11, among the resiliency indicators, reliability and restorative capacity are the most important ones. Eventually, Table 12 indicates

Table 11 The weights of the criteria of the sustainability aspect

Criteria	Greenhouse gas emission	Waste management	Pollution control	Energy and resource consumption	Job safety and labor health	Job opportunities	Employment insurance
Weights	0.2021518	0.1642566	0.1625709	0.1333924	0.1093320	0.09135578	0.1369406

$\xi^{*} = 0.4809373$ CI = 6 .69 $\rightarrow$ CR = $\frac{0.4809373}{6.69} = 0.071889$

Table 12 The weights of the criteria of the resilience aspect

Criteria	Extra inventory	Restorative capacity	Rerouting	Reliability	Backup supplier	Cooperation
Weights	0.1663749	0.1855037	0.1062489	0.2091226	0.1663749	0.1663749

$\xi^{*} = 0.3139305$ CI = 5 .29 $\rightarrow$ CR = $\frac{0.3139305}{5.29} = 0.059344$

Table 13 The weights of the criteria of the digitalization aspect

Criteria	Information sharing	Security and privacy	Technical Capability	Digital engagement	Digital production system
Weights	0.2510479	0.2085537	0.1989188	0.1136055	0.2278741

$\xi^{*} = 0.4228526$ CI = 5 .29 $\rightarrow$ CR = $\frac{0.4228526}{5.29} = 0.079934$

Table 14 The final weights of the indicators

Aspect	Weight	Sub-criteria	Initial weight	Final weight
Leagile	0.2839256	Cost	0.250609	0.071154311
		Quality	0.1725244	0.048984094
		Lead time	0.1720636	0.048853261
		Eliminate Muda	0.09394665	0.026673859
		Transportation	0.1254517	0.035618949
		Market sensitivity	0.1854047	0.052641141
Sustainability	0.2797764	Greenhouse gas emission	0.2021518	0.056557303
		Waste management	0.1642566	0.04595512
		Pollution control	0.1625709	0.045483501
		Energy and resource consumption	0.1333924	0.037320045
		Job safety and labor health	0.109332	0.030588513
		Job opportunities	0.09135578	0.030588513
		Employment insurance	0.1369406	0.038312748
Resiliency	0.2782083	Extra inventory	0.1663749	0.046286878
		Restorative capacity	0.1855037	0.051608669
		Rerouting	0.1062489	0.029559326
		Reliability	0.2091226	0.058179643
		Backup supplier	0.1663749	0.046286878
		Cooperation	0.1663749	0.046286878
Digitalization	0.1580897	Information sharing	0.2510479	0.039688087
		Security and privacy	0.2085537	0.032970192
		Technical capability	0.1989188	0.031447013
		Digital engagement	0.1136055	0.017959859
		Digital production system	0.2278741	0.036024548

Table 15 The decision matrix of the FVIKOR method

S1	S2	S3	S4	S5
C1				
1	3	3	3	1
3	5	5	5	3
5	7	7	7	5
C2				
1	3	1	3	1
3	5	3	5	3
5	7	5	7	5
C3				
1	6	3	6	1
3	8	5	8	3
5	9	7	9	5
C4				
3	6	3	6	1
5	8	5	8	3
7	9	7	9	5
C5				
6	6	7	6	7
8	8	9	8	9
9	9	10	9	10
C6				
1	6	6	3	3
3	8	8	5	5
5	9	9	7	7
C7				
7	6	3	3	6
9	8	5	5	8
10	9	7	7	9
C8				
0.67	1	1	1	0.67
1	3	3	3	1
1.5	5	5	5	1.5
C9				
3	6	3	6	3
5	8	5	8	5
7	9	7	9	7
C10				
7	7	6	6	7
9	9	8	8	9
10	10	9	9	10
C11				
6	6	3	3	7
8	8	5	5	9
9	9	7	7	10
C12				
7	6	3	3	6
9	8	5	5	8
10	9	7	7	9
C13				
7	6	3	6	7

Table 15 (continued)

S1	S2	S3	S4	S5
9	8	5	8	9
10	9	7	9	10
C14				
7	6	3	3	6
9	8	5	5	8
10	9	7	7	9
C15				
7	3	3	3	6
9	5	5	5	8
10	7	7	7	9
C16				
6	6	1	3	7
8	8	3	5	9
9	9	5	7	10
C17				
7	7	3	6	6
9	9	5	8	8
10	10	7	9	9
C18				
7	6	3	3	7
9	8	5	5	9
10	9	7	7	10
C19				
1	3	3	3	1
3	5	5	5	3
5	7	7	7	5
C20				
7	6	6	5	7
9	8	8	7	9
10	9	9	9	10
7	6	3	6	7
C21				
9	8	5	8	9
10	9	7	9	10
C22				
6	3	3	6	7
8	5	5	8	9
9	7	7	9	10
C23				
7	6	6	3	7
9	8	8	5	9
10	9	9	7	10
C24				
6	6	3	3	7
8	8	5	5	9
9	9	7	7	10

that information sharing and digital production system are the most important indicators of the digitalization aspect. Also, the final weights of the indicators are given in Table 13. Based on the outputs, cost, reliability, greenhouse gas emission, market sensitivity, restorative capacity, and quality are the most important indicators, respectively (Table 14).

5.2 Results of the FVIKOR method

In this section, we will present the outputs of the FVIKOR approach. In this way, at the outset, the decision matrix is formed by data gathered from experts (see Table 15). On the other side, Fig. 7 illustrates the values of *Qj* and the ranking of the alternatives. Based on Fig. 7, the ranking of the alternative is as follows: (1) S5, (2) S1, (3) S2, (4) S4, (5) S3. It should be noted that the detailed results of the steps of the FVIKOR method are provided in Supplementary Materials-Part B.

5.3 Validation and robustness of the proposed method

5.3.1 Comparing the obtained results with other methods

In this section, to show the validity of the employed approach, we compare the achieved outputs with the results of the traditional methods. In this way, at the outset, the results of the GP-BWM are compared with the results of the traditional FBWM (TFBMW) and the fuzzy analytic hierarchy process (FAHP) approaches. The results of the mentioned comparison are given in Table 16. As depicted in Table 16, the obtained results of the proposed GP-FBWM are very close to the TFBWM and FAHP that show the validity and applicability of the developed method.

In the next step, we compare the results of the FVIKOR method with a traditional approach, namely the Fuzzy TOPSIS (FTOPSIS) method. Table 17 shows the outputs of the mentioned comparison. Based on Table 17, the first, second, and third suppliers in both methods are the same that shows the validity of the results of the FVIKOR method.

5.3.2 The efficiency of the proposed GP-BWM

To show the efficiency of the proposed GP-FBWM, we compare its results with two traditional methods namely the TFBMW and the FAHP approaches. To do this, the following metrics are employed.

- The consistency ratio (CR): The CR is a smaller-is-better measure, which shows the reliability of the outputs.
- The total deviation (TD): The TD, which calculated according to Eq. (6), computes the Euclidean Distance (ED) between the ratios of weights and their related pairwise comparison. It should be noted that the TD is a smaller-is-better metric. On the other hand, for making a fair comparison between the FAHP, TBWM, and GP-FBWM the TD is divided by the total number of pairwise comparisons of each method.

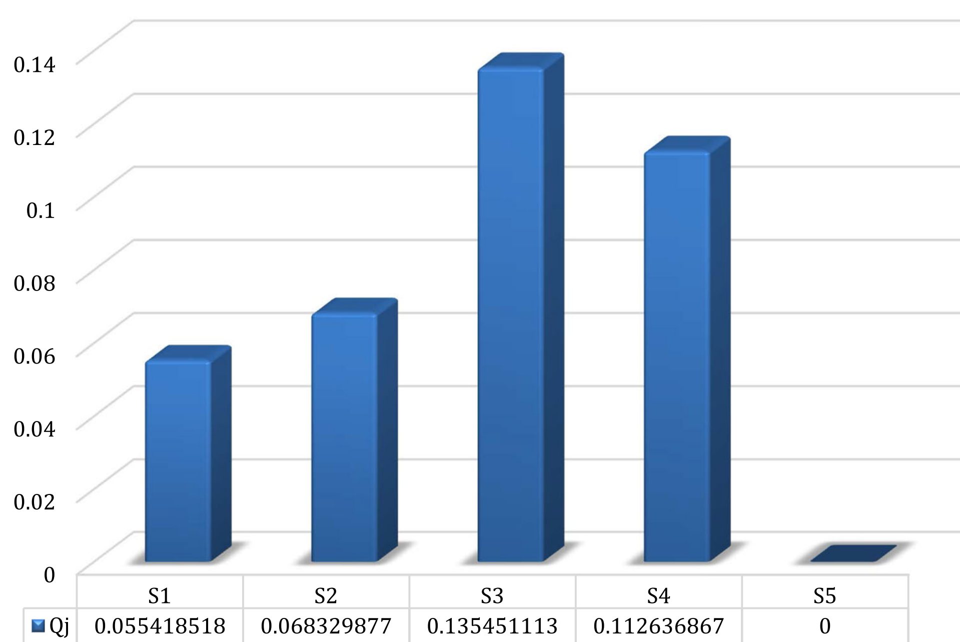


Fig. 7 The ranking of the suppliers

Table 16 Comparing the results of the GP-BWM with the other methods

Indicator	GP-FBWM	TFBWM	FAHP
1	0.071154311	0.070784309	0.070968348
2	0.048984094	0.049129377	0.048257113
3	0.048853261	0.049499224	0.048627922
4	0.026673859	0.025535155	0.025601546
5	0.035618949	0.03603373	0.036127418
6	0.052641141	0.050667407	0.051799142
7	0.056557303	0.057063205	0.057211569
8	0.04595512	0.044116153	0.044230855
9	0.045483501	0.046146987	0.046266969
10	0.037320045	0.036425981	0.037520688
11	0.030588513	0.031229453	0.030310649
12	0.030588513	0.030229453	0.031308049
13	0.038312748	0.039113522	0.039215217
14	0.046286878	0.045946186	0.045865646
15	0.051608669	0.052040304	0.052175609
16	0.029559326	0.028705618	0.027780252
17	0.058179643	0.058077109	0.059228109
18	0.046286878	0.045346186	0.045464086
19	0.046286878	0.047046186	0.047168506
20	0.039688087	0.038881709	0.038982801
21	0.032970192	0.033298747	0.034385324
22	0.031447013	0.031283489	0.030364826
23	0.017959859	0.017866468	0.017212921
24	0.036024548	0.03683722	0.037935597

Table 17 The comparison between the outputs of FVIKOR and FTOPSIS

Alternative	Rank	
	FVIKOR	FTOPSIS
S1	2	2
S2	3	3
S3	5	4
S4	4	5
S5	1	1

$$TD = \sum_i \sum_j \left(a_{ij} - \frac{w_i}{w_j} \right)^2 \quad (21)$$

- Conformity (CY): The CY indicates the conformity of an approach with the intuitive rankings of managers (decision-makers), which is one of the typical ways for assessing the efficiency of a method (Bolloju 2001). Inspired by Rezaei (2015), the ED among weights and the intuitive weights are considered as the conformity metric in the current work. So, the CY is computed based on relation (7). In this relation, Con_{km} denotes the ED between the weight achieved by mth method and the weigh allocated by manager k. $FWI_{\text{intuitive},r}$ shows the importance of rth indicator obtained by intuitive evaluation, and $FWM_{m,r}$ denotes the importance of rth indicator obtained by mth method.

$$Con_{km} = \sum_r FWM_{m,r} - FWI_{intuitive,r} \quad (22)$$

Table 18 shows the results of comparing the GP-BWM, FAHP, and TFBWM. In Table 18, the mean demonstrates the average of each metric. For instance, for the GP-BWM, the mean of CR has been computed by

$$\frac{CR_A + CR_L + CR_S + CR_R + CR_D}{5} = \frac{0.032673 + 0.071496 + 0.071889 + 0.059344 + 0.079934}{5} = 0.06307$$

where CR_A, CR_L, CR_S, CR_R, and CR_D are the CR of aspects, leagile indicators, sustainability indicators, resilience indicators, and digitalization indicators, respectively. Also, S.D demonstrates standard deviation. According to Table 18, the developed GP-FBWM has better performance among all methods in all metrics, which indicates the efficiency of this method. To better understand, Fig. 8 illustrates the achieved results.

Also, to support the obtained results in a statistical, we design several decision-making examples in different sizes (e.g., 10 indicators, 15 indicators, 20 indicators to 55 indicators) and calculate the values of CR, TD, and conformity for each algorithm in each problem. Afterward, we define a metric named the relative percentage deviation (RPD) that calculated based on Eq. (23) where MD_m shows the value of the metric (i.e., CR, TD, and Conformity) obtained by each method (i.e., $GP - FBWM$, $TFBWM$, and $FAHP$), and $Best_m$ demonstrates the best value obtained among all methods.

$$RPD = \frac{MD_m - Best_m}{Best_m} \times 100 \quad (23)$$

Then, we conduct an analysis of variance (ANOVA) is applied to evaluate the statistical validity of the obtained results based on the RPD metric. Figure 9 depicts the Least Significant Deviation (LSD) diagram for the methods at the confidence level of 95%. As shown in Fig. 9, the developed method (GP-FBWM) outperforms the traditional ones in all metrics.

Table 18 Comparing the results of the stochastic BWM, TBW, and AHP methods

	GP-FBWM		TFBWM		FAHP	
	Mean	S.D	Mean	S.D	Mean	S.D
CR	0.06307	0.0165	0.07237	0.0194	0.08106	0.0256
TD	1.5403	0.3948	1.6672	0.5361	2.1486	0.8306
Conformity	0.0162	0.0120	0.0202	0.0147	0.0290	0.0178

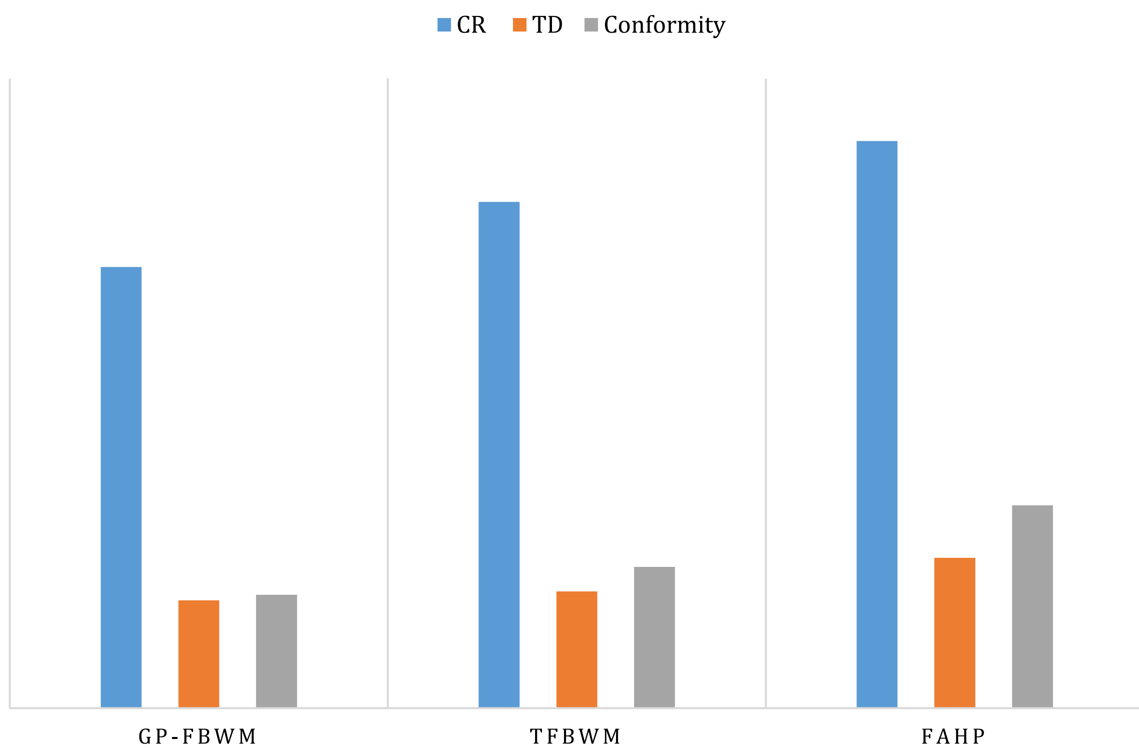


Fig. 8 The comparison of the different methods based on the considered metrics

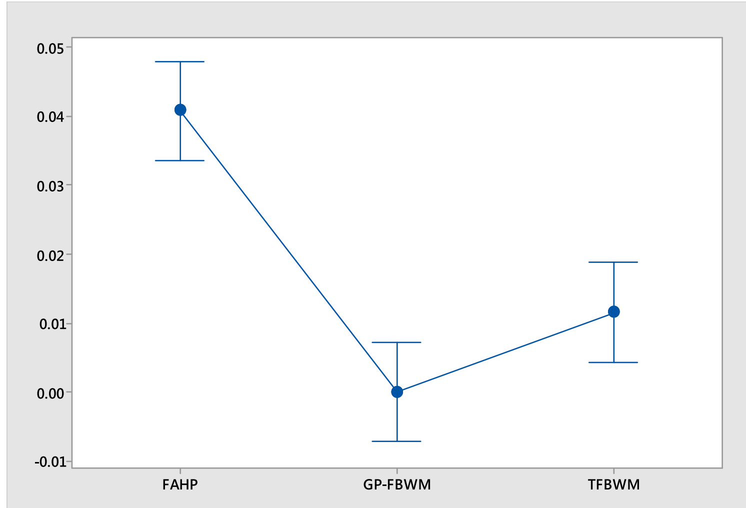
5.3.3 Sensitivity analysis of the FVIKOR method

Sensitivity analysis by altering the defuzzification method is one of the common approaches to assess the robustness of fuzzy decision-making methods (Fallahpour et al. 2021a). Therefore, here, we apply five different defuzzification methods, namely the center of sums method (COS), centroid of area (COA), bisector of area method (BOA), mean of maxima method (MOM), and last of maxima method (LOM) to investigate the robustness of the FVIKOR method. See (Saade and Diab 2004; Mogharreban and Dilalla 2006) for more study about the different defuzzification methods. The outputs of sensitivity analysis are presented in Table 19. Based on Table 19, when the defuzzification method has changed, no significant change occurs in the rank of the suppliers, and in all modes, S5 and S1 are the best alternatives. The mentioned point demonstrates the validation and robustness of the employed approach.

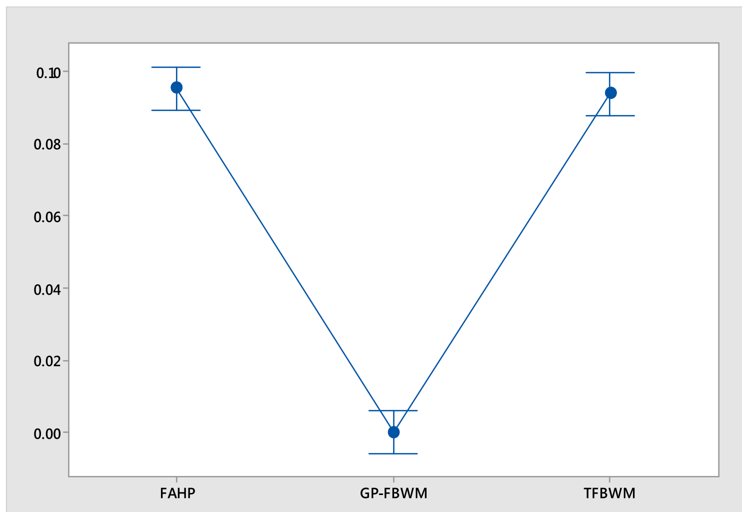
5.3.4 Discussion regarding the complexity of the proposed method.

In this section, we have compared the proposed method (GP-FBWM) with the traditional ones (FBWM and BWM) in the terms of complexity. To this end, we solve several decision-making problems under different sizes and report the required CPU time for each method (Abualigah et al. 2022). Table 20 shows the obtained results. According to this table, the BWM has the minimum complexity among all methods. Nevertheless, although the developed GP-FBWM has more complexity in comparison with other methods, it has a major advantage over those methods. In this regard, the developed method guarantees obtaining a unique optimal solution and dealing with uncertainty/imprecision of the marketplace, simultaneously.

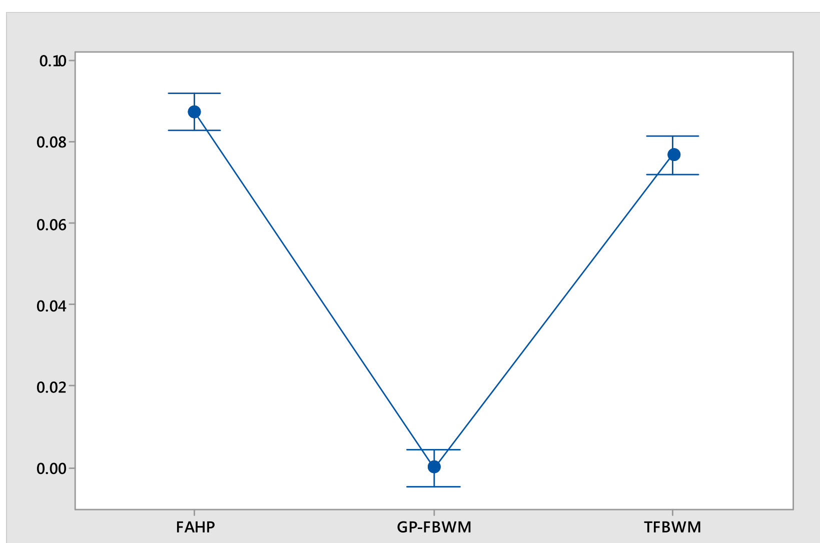
Fig. 9 LSD intervals (at the 95% confidence level) for the methods



(a) CR metric



(b) TD metric



(c) Conformity metric

Table 19 The values of Q_j in the different defuzzification methods

	COS	COA	BOA	MOM	LOM
S1	0.05542	0.054589	0.056861	0.058339	0.059189
S2	0.06833	0.067305	0.070107	0.07193	0.072976
S3	0.13545	0.133418	0.115569	0.118574	0.144661
S4	0.11264	0.11095	0.138972	0.142585	0.1203
S5	0	0	0	0	0

Table 20 Investigating the complexity of the proposed method

Problem	Size	CPU time (s)		
		BWM	FBWM	GP-FBWM
1	25 indicators	1.5	1.9	2.3
2	35 indicators	1.8	2.4	2.8
3	45 indicators	2.5	3.3	3.7
4	55 indicators	3.6	4.2	4.8
5	65 indicators	5.1	6.3	7.2

5.4 Findings and discussions

The current work aimed to study the viable SSP in which the leagile, sustainability, resiliency, and digitalization aspects have been simultaneously considered. In this way, the main indicators of the research problem have been identified and then the potential alternatives have been determined. Afterward, a new version of the BWM method named GP-FBWM has been developed to calculate the indicators' weights (Lin and Ho 2007; Abualigah et al. 2021c; Agushaka et al. 2022; Al-qaness et al. 2022a; Hashim and Hussien 2022). Eventually, the FVIKOR method has been employed to rank the suppliers. This study has selected the oxygen concentrator device, as one of the most crucial products during the COVID-19 outbreak, as the case study. The outputs showed that the leagile, sustainability, resiliency, and digitalization, respectively, are the most important aspects. Also, according to the achieved results, cost, reliability, greenhouse gas emission, market sensitivity, restorative capacity, and quality are the most important indicators. On the other side, the results of the FVIKOR method demonstrated that supplier #5 and supplier #1 are the best alternatives. Based on the outputs of the GP-FBWM method, all of the CRs were less than 0.1 and close to zero, which showed the results reliability. Also, a comparison has been made between the proposed GP-FBWM, the traditional FBWM, and the FAHP to demonstrate the performance of the applied model, which the outputs confirmed the validity and robustness of the proposed GP-FBWM. In this regard, the achieve results showed that the proposed GP-FBWM has outperformed the traditional FBWM and the FAHP methods based on the CR, total deviation, and conformity metrics. On the other side, sensitivity analysis of the FVKIOR method demonstrated that defuzzification method change has not a significant effect on the outputs, which showed the robustness of the employed approach. Also, comparing the results of the employed FVIKOR with the FTOPSIS showed the validity of the applied method.

5.5 Theoretical implications

In this section, we provide the main theoretical implications of the current study. As aforementioned, the present work has proposed a DMF to study the viable SSP. The theoretical implications of the current work can be divided into two parts. The first part relates to studying the viable SSP that has been never conducted in the literature. In this regard, this study has attempted to incorporate the main aspects of the viable SC (i.e., leagile, sustainability, resiliency, and digitalization) in the supplier selection problem. In this way, a list of indicators consisting of four criteria and 24 sub-criteria have been provided that can help the related researchers to understand the concept of viable SSP, especially for the case study of medical devices. Indeed, the current work can effectively help supply chain researchers to better understand the concept of the viable SSP, get acquainted with the relevant indicators, and also the most important ones. On the other side, another theoretical contribution of this paper is developing the GP-FBWM. In this regard, since the BWM may result in multi-optimality solutions, which may not be desirable for decision-makers, the current study has proposed the GP-FBWM to get rid of the mentioned drawback. It should be noted that the results of the comparison of the proposed GP-FBWM with the other traditional methods (i.e., FBWM and FAHP) showed that the developed approach has better performance, which demonstrated its efficiency.

5.6 Managerial implications

Over the years, the issue of supplier selection has always been increasingly considered by researchers and experts for supply chain optimization. The COVID-19 epidemic has affected millions of people worldwide and led to unprecedented disruptions in various supply chains, especially hospital supply chains. Disorders that COVID-19 has placed on the supply chain of hospitals include vulnerabilities in delivery times, order quantities, high demand fluctuations, and financial problems of organizations. Following the COVID-19 epidemic, the demand for medical devices, especially oxygen generators, has increased. In the case study hospital, the need for oxygen generators at different times increased due to the peak of the disease and more requests for hospitalization without prior planning. For this reason, in this period, the most important criteria for evaluating hospital suppliers are the criteria of agility and reliability of suppliers. To meet this need, suppliers must always have complementary capacities to meet the immediate needs of hospitals. In addition, due to economic problems, cost is other important criteria in evaluating suppliers. Besides, one of the criteria that is always considered in the evaluation of suppliers is the quality criterion. Since in the present study, the device under study is an oxygenator, which is an important device in maintaining the health of patients, so it is very important to evaluate the supply of suppliers in accordance with the quality criteria. In addition to the above materials, it is very important to pay attention to environmental criteria and greenhouse gas emissions of oxygen generators in the hospital environment, which should always be considered in the evaluation of hospital suppliers.

In the current study, all the identified criteria are the most important criteria in evaluating suppliers. For example, supplier 5, which has been selected as the top supplier, performs well in terms of cost due to its high flexibility in payments by hospitals. It also has the complementary capacity to respond quickly to the urgent needs of hospitals, which is why it is so important during an epidemic. The reliability of supplier 5 is also good, and the quality of the devices is very good in terms of greenhouse gas emissions, but in terms of efficiency it is lower quality than some suppliers. Supplier 5 delay time is very short in response to the needs of hospitals and is therefore very convenient and also has good coordination with other parts of the supply chain. The reason for this ability is high capacity and production completion, but the supplier does not have support, which is why it is weaker than some suppliers such as Supplier 1. However, supplier 1 acts as a supplier of financial flexibility as well as Supplier 5, as well as complementary and supporting suppliers and has the better quality in terms of greenhouse gas emissions. But the important point is that the speed of operation, low delivery time of products, and coordination with the supply chain are of great importance, which supplier 5 has a higher weight than other suppliers.

The summary of this section concludes that there is financial flexibility in payment by hospitals as well as reasonable price, flexibility, speed of operation, and high agility of suppliers in responding quickly to the needs of the hospital affected by the existence of complementary production capacities and the existence of supporting suppliers. The proper quality of the devices is very important for the hospitals in terms of efficiency and environment and the stability of the suppliers in the corona epidemic and the digitization criteria are less important and applicable at this time.

5.7 Limitations

Similar to every academic article, the present work has some limitations. For example, the method developed in this paper only can deal with fuzzy uncertainty and cannot tackle other types of uncertainty, such as randomness. In this way, developing other versions of BWM such as scenario-based BWM or robust BWM can be useful. On the other side, when the number of criteria is limited (for example, 3 criteria), the developed method is not very effective in comparison the similar methods such as AHP. Also, another limitation of the current study is the number of indicators. In this work, due to the scope of this work, we have considered 24 indicators for the research problem. Future studies can consider more indicators for expanding the present work.

6 Conclusion

This research addressed the medical devices viable SSP. In this regard, a list of related indicators was provided according to the literature. Afterward, a hybrid DMF was proposed based on the goal programming-based FBWM and the FVIKOR approach to compute the indicators' weights and rank the alternatives. Given the high importance of the oxygen concentrator device, as one of the most consumed products during the recent pandemic, the current work studies the SSP for the mentioned product. Based on the achieved results, among the aspects, the leagile, sustainability, resiliency, and digitalization, respectively, were the most important ones. Also, among the criteria, cost, reliability, greenhouse gas emission, market sensitivity, restorative capacity, and quality were the most important ones. On the other side, the outputs demonstrated that supplier #5 and supplier #1 were the best suppliers. Eventually, to show the robustness and efficiency of the developed approach, the outputs were compared with the other methods (i.e., traditional FBWM, FAHP, and FTOPSIS), and the results confirmed the validation and robustness of the utilized method. Future studies can combine the artificial intelligence methods with the GP-FBWM to investigate the viable SSP and compare their results with the current research. Also, another direction for future studies is considering other features such as developing goal programming-based interval type-2 fuzzy BWM method to calculate the indicators' weights.

Authors' contributions Omid Rostami was involved in the conceptualization, methodology, and original draft preparation. Mahdieh Tavakoli contributed to the supervision, investigation, and validation. AmirReza Tajally contributed to the software, methodology, writing—reviewing and editing. Mohssen GhanavatiNejad was involved in the methodology, writing—original draft preparation, and visualization.

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Declarations

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

Ethical approval and informed consent The authors certify that this paper does not contain any studies or involvement with human participants or animals performed by any authors in any organization or entity with any financial or nonfinancial interest in the subject matter or materials discussed in this paper.

Supplementary Information

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