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ORIGINAL PAPER

Designing an Anti-fragile Supply Chain in the Textile Industry under Conditions of Uncertainty Using the Fuzzy BWM and TOPSIS

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Abstract- **The rapid changes and transformations of the markets and the complexity and disorder of the market environment and the conditions of the economic situation in the country due to the sanctions have made it necessary to pay attention to anti-fragility approach in the industries. The textile industry is one of the strategic industries that should be considered and rewarded due to the large domestic consumption market. Various textile industries can quickly adapt to new conditions and maintain and even improve their competitive value in a safe and stable condition. The current research was conducted with a review of the literature in order to achieve anti-fragility of textile industries throughout the supply chain. In this way, the anti-fragility components were first identified and weighed using the updated best-worst model technique under conditions of uncertainty. Then, by reviewing the literature of the textile industry and interviewing the experts of this industry, stressful factors were identified and evaluated using the TOPSIS method in order to identify and rank the most important factors that disrupt anti-fragility. Finally, the results of the research showed that the components: unexpectedness, sufficient supervisors and redundancy are the most important components. Also, the results obtained from the TOPSIS method showed that the lack of access to foreign capital and the main export markets, the wear and tear of the machinery of the spinning chain industry, and the import of clothing from low-cost producing countries are the most important in the supply chain of the textile industry.**

***Keywords*: supply chain anti-fragility, textile industry, anti-fragility theory, fuzzy BWM, TOPSIS**

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I. INTRODUCTION

The textile industry is one of the oldest industries, which reached its peak during the industrial revolution. This industry is considered as one of the largest active industries in the country after the oil industry [1]. The textile industry was initially limited to the production of yarn, but over time it has expanded and created a variety of products and due to the completion of its value chain, it has included a wide range of industrial activities in the field of spinning, weaving, dyeing, printing and finishing. Textile industry is one of the important economic fields, which by creating stable employment, causes the growth of the economic process and provides the practical necessities of human life [2]. The rapid growth of the population and economy has resulted in a significant increase in the production and consumption of textiles. After the industrialization of the country and establishment of manufacturing factories, the clothing industry has a long historical background, but its achievements are with a very small average share of 0.26% of the industrial added value and 0.14% of the industrial output value during the years 2004 to 2019, which is not proportionate with its history.

The supply chain is one of the basic elements in manufacturing industries, and if this chain fails, the entire industry may be destroyed; therefore, to maintain the sustainability of the textile industry, its supply chain must be made anti-fragile. Today, due to its strategic business advantages, sustainability has gained significant importance in supply chain management; therefore, industries face the risks of supply chain instability caused by various sources [1]. Anti-fragility is one of the concepts that is closely related to supply chain sustainability. Supply chain is not static and evolves and improves in case of unnecessary events and unpredictable irregularities that are among the inherent features of today's business world. Anti-fragility in the supply chain gives the opportunity to turn challenges into opportunities and progress in a random world [4].

Knowing about the fragile factors of an industry and the importance of each of these factors help a lot with improving and fixing them in order to plan more efficiently. The rapid changes and transformations of the markets and the complexity and disorder of its environment and the conditions of the country's economy have made it necessary to pay attention to the anti-fragility approach in industries. In this way, organizations can quickly adapt to new conditions and maintain and even improve their competitive value in a safe and stable condition. Considering the strategic importance of textile industries, it is necessary to apply the theory of anti-fragility in the supply chain of this industry. For this purpose, the present research aims to identify the fragility components and fragile factors of the textile industry by reviewing the relevant literature and interviewing the experts of the mentioned industry and using the best-worst and TOPSIS methods to rank these factors in order to find solutions to achieve a sustainable excellence for this industry.

II. EXPERIMENTAL

A. Theoretical Foundations

The textile industry is one of the oldest industries that, with the progress and development of science and technology, has been able to create an economic advantage for countries along with other emerging industries. The development of the textile industry has been affected by changes in the turbulent environment, and it is necessary for the decision-makers at the macro-level to design the connection between the various parts of the supply chain of this industry. In addition, micro-level decision-makers (artisans) guide their business with macro-orientations and are trying to gain a certain share of the market of textile products and other artifacts.

Ebadi *et al.* [1], introduced strategies for the development of Iran's advanced textile industry in a study. The use of worn out and old machines and devices in the production of fibers and textiles, the problems of providing the necessary raw materials and the absence of foreign investors in the country were among the factors that can be solved by measures towards the development of the textile industry.

Shafiei *et al.* [5], identified and ranked the challenges of production development, policies and strategies to improve the situation in the textile industry as a case study for black veil (Chador) production. The lack of raw materials with the right price and quality in Iran, the lack of skilled and specialized manpower in the field of production and operations, as well as the import of fake and cheap foreign black veil fabric (smuggled) were among the important challenges they identified. In addition, to improve these issues, they proposed solutions such as amending laws and regulations in importing high-quality raw materials, strengthening and developing companies supplying textile raw materials, and creating specialized textile technology and training centers in the country.

The term anti-fragility was first introduced by Nasim Nicholas Taleb in 2012 [6] and he defined it as gaining strength in the face of pressure factors. A fragile system is interested in absorbing pressure factors, and each factor, if it does not lead to the destruction of the system, increases its stability and durability. In fact, anti-fragility allows organizations to take advantage of unknown events to put themselves in a better position than before [7].

Khosh Sepehr *et al.* [8], investigated the effect of applying the theory of anti-fragility in the supply chain in order to improve the productivity of organizations. In their research, the anti-fragility criteria of organizations were identified and the importance of each of them was determined using the ANP method. Finally, risk acceptance and learning criteria were the most important. Johnson and George [9], introduced learning from stressful factors as one of the most important components of anti-fragility. Using the anti-fragility theory, Fakhrpour *et al.* [10] presented a model to realize the resistance economy in organizations and evaluated the criteria for making organizations anti-fragile by using DEMATEL Gray method, and the most important sub-criteria in their research was learning through controlled risk.

In previous studies, many decision-making methods have been used for the issue of sustainability in the supply chain. Vishwakarma *et al.* [11], analyzed the barriers of sustainable supply chain in apparel and textile sector using multi criteria decision making (MCDM) approach. This paper shows that implementation of sustainable supply chain is extremely important for better operational excellence. Base their results, communication gap among stakeholders, barriers that affect performance of this sector and lack of training and education about sustainability, are the critical barriers.

Rahman *et al.* [12], studied on sustainable supplier selection in the textile dyeing industry using MCDM approach. They identified 15 critical economic, environmental, and social evaluation criteria for sustainable supplier selection.

Majumdar *et al.* [13], with the purpose of identifying the barriers of circularity in the textile and clothing supply chain, developed strategies to overcome them. In those paper, 18 barriers were identified from the literature and through a questionnaire survey among textile and clothing domain experts. They used MCDM methods to analyze these barriers. According their results, lack of supply chain collaboration, lack of effective planning for circular supply chain, lack of incentives for circularity in supply chain, and lack of technical know-how for recycling emerged as the crucial causal barriers.

Lahri *et al.* [14], used BWM and TOPSIS methods to design a sustainable supply chain network design model, with purpose of minimizing the economic, environmental goals and maximizing the social sustainability goals. Amiri *et al.* [15], presented a new model with a triangular fuzzy approach based on BWM method for sustainable supplier selection in the supply chain.

Anti-fragile systems are identified with special characteristics, and in this research, the components considered in Momeni *et al.*'s research [16] have been used. These characteristics are as follows:

Unexpectedness (Q1): Unexpected results occur when the output of a system does not fit with its input. If mechanisms are embedded in the system that prevent the influence of external factors on it, the outputs of the system will become more predictable and the system's anti-fragility will be higher [9].

Proportion of productivity and risk (Q2): In order to lower the risk, additional components may be used, however, this may reduce the efficiency of the system. Devices with fewer components are more efficient but more fragile. Therefore, it may increase the proportion between the productivity and the anti-fragility risk of the system [9,17].

Balancing Constraints vs. Freedom (Q3): A system that is too open is exposed to unknown events. Therefore, anti-fragility in the system can be increased by creating a degree of restriction (to a reasonable extent) [9].

Reducing system connections (Q4): Systems are more susceptible to failure due to the dependence between their components, because a change in one part can have many effects on other parts. In the reward system, the components act independently of each other and there are few connections between them [9,17-19].

Sufficient supervisors (Q5): In order to control the behavior of system agents, there is a need for a sufficient number of supervisors. If the number of observers in the system is not enough, the behavior of the system becomes unpredictable and unknown events increase and cause system failure [9,17,18].

Regular and controlled stress (Q6): The complete removal of stress from the system may lead to the weakness and fragility of the system. By applying tension in a regular and controlled manner, the system becomes stronger and eventually leads to anti-fragility [9].

Redundancy (Q7): The capacity of a system to face unknown events increases by creating different ways to reach the goal and multiple methods to obtain the required information [9,17].

Learning from mistakes (Q8): Learning from mistakes and negative consequences in a system leads to the production of new information and acts as a layer of defense against stresses and increases the anti-fragility of the system [9].

Absorption (Q9): It is the system's ability to withstand a potential stress (of a given intensity and duration) to remain in a predetermined state. This ability of the system is called absorption power. The higher the absorption power, the lower the fragility of the system [9,17].

B. Methods

B.1. Measurement

The present research is descriptive-survey in terms of practical purpose and method. It is non-experimental in terms of how to obtain the required data. Also, since this research examines data related to a period of time, it is considered a cross-sectional type of research. In order to collect the theoretical foundations of the subject, the library method has been used. By using library method, the literature and the background of the research were studied and analyzed, and by using the opinions of academic experts, a suitable framework was chosen for the study of the subject.

Based on the review of previous studies, 9 components of anti-fragility of industries were identified. Then, with the formal approval of academic experts, questionnaires were presented to collect information from informants and experts, and data analysis was performed using the fuzzy best-worst model method. Further, in order to design a sustainable supply chain for the textile industry, after reviewing the literature and surveying experts, 21 important factors of fragility of the textile industry were identified and classified into three different categories. Then, these factors were ranked by considering the fragility indices in the previous step, using the TOPSIS method. TOPSIS is one of the MCDM method base on criteria and alternative. Anti-fragility components are considered as criteria and factors of fragility of the textile industry considered as alternative in TOPSIS method. The flowchart of the current research is according to Fig. 1.

Considering that the research problem in question is an expert-oriented problem, therefore, the expert index was used to select the experts. The selection criteria of the experts were to have an academic education in the field of textile engineering with a PhD or master's degree with at least 10 years of managerial experience in industry. According to the opinion of "Al-Thomas Saati" in the sample size in expert-oriented methods, a questionnaire

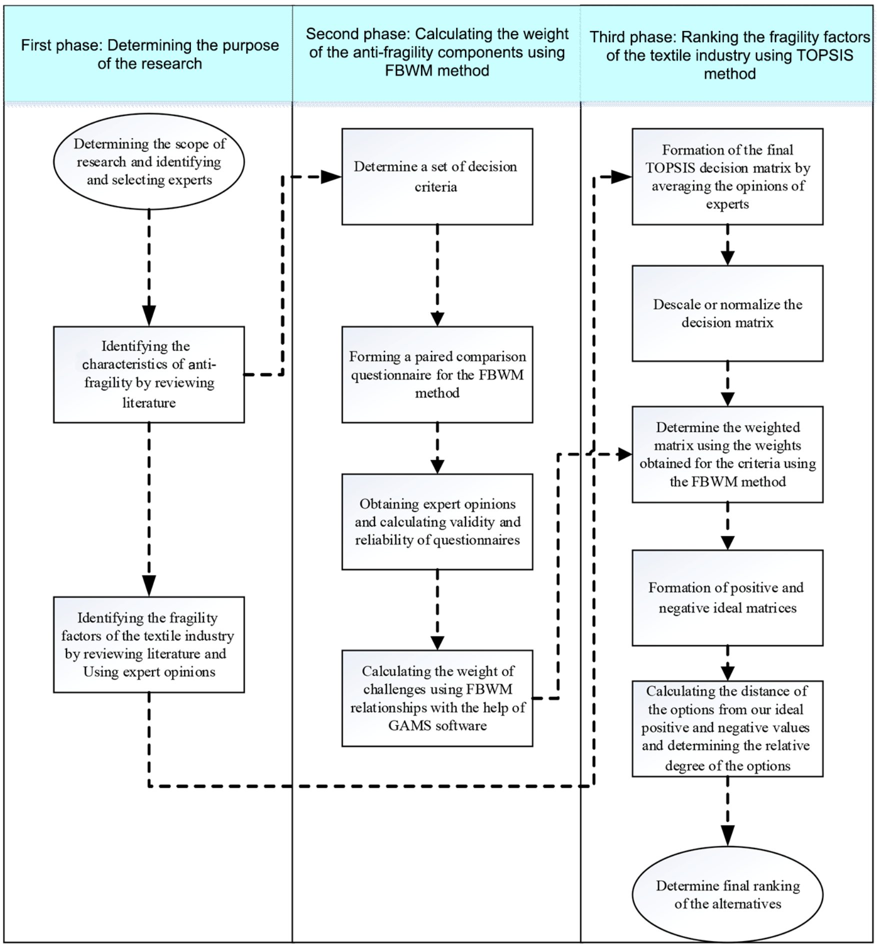

Fig. 1. Flowchart of the current research.

was designed and sent to 11 experts who were available and they were analyzed.

B.2. Best-Worst Method

The best-worst method (BWM) was invented by Rezaei [20] in 2015. This method is one of the newest and most efficient multi-criteria decision-making methods, which is used to weigh decision-making factors and criteria. In this method, the best and worst decision-making indicators and criteria and sub-criteria can be ranked by pairwise comparisons and analysis of experts' opinions, and they are ordered from the most preferred and the most important to the least important. Among the prominent features of the best-worst method model compared to other existing multi-criteria decision-making techniques, we can mention the fewer number of pairwise comparisons and the achievement of more consistent pairwise comparisons. Also, the use of this method leads to more reliable results.

These comparisons can be done in a fuzzy manner when the experts' opinion is uncertain. Experts complete the questionnaires with linguistic variables, and then the fuzzy numbers corresponding to each linguistic variable are considered as input to the model. There are four common types of fuzzy, which are: triangular fuzzy, trapezoidal fuzzy, single fuzzy, and Gaussian fuzzy [21] and in this research, triangular fuzzy method is used. The application of triangular fuzzy number is more tangible to achieve greater flexibility and accuracy in expert judgments, especially in options that have more complex qualitative criteria. Each of these fuzzy numbers written as a triangular fuzzy number represents a linguistic variable (similar to Table I).

In the first step of the FBWM method, the most important

TABLE I
TRIANGULAR FUZZY QUANTITES

Fuzzy quantity	Linguistic variable
(1, 1, 1)	Equal preference
(0.667, 1, 1.5)	Very little advantage
(1.5, 2, 2.5)	Relative superiority
(2.5, 3, 3.5)	Great superiority
(3.5, 4, 4.5)	Absolutely superior

and least important indicators are determined. At this stage, experts determine the most important and least important components according to their opinion by examining the identified components.

In the third step, the degree of superiority of the components compared to the worst component is determined. At this stage, according to the worst specified component, the degree of preference of other indicators compared to this component is determined by using the existing verbal variables similar to Table I, and the matrix (Aw) is formed as Aw= (a_{1w},...,a_{nw}). The values of a_{jw} show the preference ratio of other indicators compared to the least important indicator, which is selected as a linguistic variable by the expert, and at the end, the corresponding fuzzy number is considered and displayed in the model. In the last step, the weight of the components is calculated using the relationship model (1) [22]:

$$\begin{aligned}
&\text{Min } \zeta^* \\
&\text{s.t.} \\
&\left|\frac{(l_B^w, m_B^w, u_B^w)}{(l_j^w, m_j^w, u_j^w)} - (l_{Bj}, m_{Bj}, u_{Bj})\right| \le (k^*, k^*, k^*) \\
&\left|\frac{(l_j^w, m_j^w, u_j^w)}{(l_W^w, m_W^w, u_W^w)} - (l_{jw}, m_{jw}, u_{jw})\right| \le (k^*, k^*, k^*) \\
&\sum_{j=1}^{n} R(\tilde{W}_j) = 1 \\
&l_j^w \le m_j^w \le u_j^w \\
&l_j^w \ge 0\ ,\ j = 1, 2, ..., n.
\end{aligned} \tag{1}$$

Method inconsistency rate (CR) is obtained using Eq. (2). In this regard, CI is the consistency index, which is extracted from Table II according to aBW, which indicates the superiority of the best selected index over the worst:

$$CR = \frac{\zeta^*}{CI} \tag{2}$$

B.3. TOPSIS

In order to rank the fragile factors of the textile industry, the TOPSIS multi-criteria decision-making technique has been used. The basic principle of TOPSIS is that the chosen strategy should have the "shortest distance" from the positive ideal solution and the "farthest distance" from the negative ideal solution [23]. In this method, first, the decision matrix is formed using the opinions of experts, and by taking the average of these matrices, the final decision matrix is obtained. In this research, the decision matrix includes anti-fragility components (columns) and fragile factors of the textile industry (rows). Next, using Eq. (3), the decision matrix is made dimensionless, and then it is weighted by multiplying this matrix by the weights obtained from the basic criterion method:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{3}$$

In the next step, after forming positive and negative ideal matrices, the distance of each strategy from them is calculated using Eqs. (4) and (5). In these relationships, the weights of the weighed matrix are the largest and smallest values of the strategies for each index:

$$\begin{aligned}
d_i^+ &= \sqrt{\sum_{j=1}^{n} (\upsilon_{ij} - \upsilon_j^+)^2} \\
d_i^- &= \sqrt{\sum_{j=1}^{n} (\upsilon_{ij} - \upsilon_j^-)^2}
\end{aligned} \tag{4}$$

Finally, the relative value of each option is calculated using Eq. (6) and the strategies are ranked from the highest to the lowest value of their relative degree:

$$cl_i^+ = \frac{d_i^-}{d_i^- + d_i^+} \tag{5}$$

III. RESULTS AND DISCUSSION

First, the identified anti-fragility components were weighed using the FBWM method. In order to carry out this method, questionnaires were provided for the experts who first identified the most important and least important component in their opinion and then made pairwise comparisons between the most important and the least important selected component compared to other components. After that, the questionnaires were approved by academic experts. Using GAMS software (GAMS 24.1), the desired method was performed based on the opinion of

TABLE II
COMPATIBILITY INDEX

a_{BW}	Absolutely superior	Great superiority	Relative superiority	Very little advantage	Equal preference
CI	8.04	6.69	5.29	3.8	3

TABLE III
THE IMPORTANCE OF ANTI-REFRACTORY COMPONENTS

ID code	Anti-refractory components	Weight	Rank
Q1	Being unexpected	0.1828	1
Q2	Proportion of productivity and risk	0.0873	7
Q3	Balancing constraint versus freedom	0.0479	9
Q4	Reduce system connections	0.0965	6
Q5	Adequate supervisors	0.1771	2
Q6	Regular and controlled stress	0.1113	4
Q7	Redundancy	0.1172	3
Q8	Learning from mistakes	0.0761	8
Q9	Attraction	0.1039	5

each expert, and at the end, by taking the average of the obtained weights based on the opinion of each expert, the final weight of each index was calculated, and the results obtained can be seen in Table III. In the third column of this table, the final weight obtained from the FBWM method is given, and in the fourth column, the ranking based on the obtained weights is given.

The results obtained by FBWM method show that unexpectedness, sufficient observers, and redundancy are the most important components of fragility. The inconsistency rate was calculated using Eq. (2), which was equal to 0.0026, and since it is less than 0.02 [20], it indicates the consistency of the method. The weights obtained in this step will be used in the next step to rank the fragile factors of the textile industry.

In the next step, the fragile factors of the textile industry have been identified by reviewing the literature and surveying experts, and these factors are shown in the third column of Table IV. These factors were ranked using Eqs. (3) to (6) after forming the TOPSIS questionnaire and polling experts.

Positive and negative ideal vectors were calculated using Eqs. (4) and (5), respectively, which are shown in the fourth and fifth columns of Table IV. Next, using Eq. (6), the relative value of each option was calculated, which is given in the sixth column of Table IV. Finally, the fragile factors of the textile industry were ranked according to the relative values obtained for each of them. The results of the TOPSIS method show that the factors are the of lack of access to foreign capital and the main export markets. Depreciation of machinery in the spinning chain industry machinery and the import of clothing from low-cost producing countries are the most important factors in the supply chain of the textile industry, which are ranked first to third, respectively. Fig. 2 shows the average scores given by experts to 6 important factors of fragility of the textile industry according to the anti-fragility components. As it is clear in the figure, the dispersion of scores for the factor of lack of access to foreign capital and main export markets and depreciation of machinery in the spinning chain industry is more than other factors, and for this reason, they were ranked first and second.

IV. MANAGERIAL INSIGHTS

Anti-fragility is the ability of a system or organization to thrive and improve in the face of adversity or unexpected events. The textile industry faces several challenges that could be transformed into opportunities if managed properly. Here are some managerial insights on how the textile industry can become anti-fragile:

• One way to overcome lack of access to foreign capital and main export markets is to focus on the domestic market and look for ways to innovate and improve products for local customers. This could involve investing in R&D, leveraging local sourcing and production, and building strong brand reputation through marketing and customer engagement. Another approach could be to form partnerships and alliances with other businesses in the industry to share resources and expertise.

• Businesses should adopt a proactive approach to maintenance and repair of machinery. They should also invest in modern machinery and technology that are more efficient and durable. Additionally, they can consider diversifying into related product lines or other industries where their existing machinery can be repurposed.

• Textile businesses should seek to differentiate themselves by focusing on unique designs, high-quality materials, and sustainable and ethical manufacturing practices. This could involve developing stronger relationships with suppliers, investing in training and development of employees, and improving transparency and accountability throughout the supply chain. In addition, businesses should also explore

TABLE IV
RANKING OF FRAGILE FACTORS OF TEXTILE INDUSTRY USING TOPSIS METHOD

	ID code	Fragil factors of the textile industry	cl^+_i	d^-_i	d^+_i	Rank	References
Spinning chain	R1	The supply of raw materials in the stock market by major fiber producers in the country	0.0547	0.0468	0.4613	12	expert
	R2	Lack of supply of raw materials in the country	0.0660	0.0421	0.3895	19	[1,5,24-26]
	R3	Lack of specialized and experienced manpower in the spinning chain	0.0574	0.0520	0.4754	11	expert
	R4	Depreciation of machinery in the spinning chain industry	0.0359	0.0586	0.6199	2	[1,8,22,25,26]
Weaving and sewing chain	B1	Lack of competitive industrial infrastructure	0.0685	0.0395	0.3657	20	[4,5,24-26,28]
	B2	Lack of investment in the (clothing) industry	0.4090	0.0460	0.0664	16	[5,18,24-27]
	B3	Importing clothes from cheap producing countries	0.6097	0.0587	0.0376	3	[5,24,25,27]
	B4	Saturation of the market with counterfeit brands due to the structural weakness of the distribution and smuggling network	0.3994	0.0393	0.0590	18	[2,4,5,24,25,27]
	B5	Facilitating imports and receiving low taxes and duties from clothing importers	0.3357	0.0329	0.0651	21	[25]
	B6	The heterogeneous growth of clothing design and fashion	0.5151	0.0548	0.0516	9	[24,25]
	B7	Informal clothing production	0.5303	0.0529	0.0469	8	[25]
	B8	Undeveloped distribution network	0.4000	0.0407	0.0610	17	[25]
	B9	Lack of access to foreign capital and main export markets	0.6424	0.0651	0.0362	1	[5,25]
	B10	Lack of specialized and experienced manpower in the knitting and clothing chain	0.5346	0.0593	0.0516	6	[5]
	B11	Depreciation of weaving and clothing chain machinery	0.5325	0.0560	0.0492	7	[1,5,25,27,28]
Dyeing, printing, and finishing chain	C1	Restrictions on building factories with emissions higher than level 2	0.4105	0.0447	0.0642	15	expert
	C2	Importing raw materials of dyes and specialized textile chemicals	0.4592	0.0448	0.0527	13	[24,25]
	C3	Lack of trust in the cooperation of production circles (spinning, weaving, dyeing, and clothing)	0.5631	0.0631	0.0489	5	expert
	C4	Lack of development due to the technical knowledge and capital-intensive nature of this chain	0.5991	0.0611	0.0409	4	[4]
	C5	Lack of specialized and experienced manpower in the dyeing, printing and finishing, chain	0.4456	0.4456	0.0600	14	expert
	C6	Depreciation of the machinery of the dyeing, printing, and finishing chain	0.4975	0.4975	0.0498	10	[1,9,25,28]

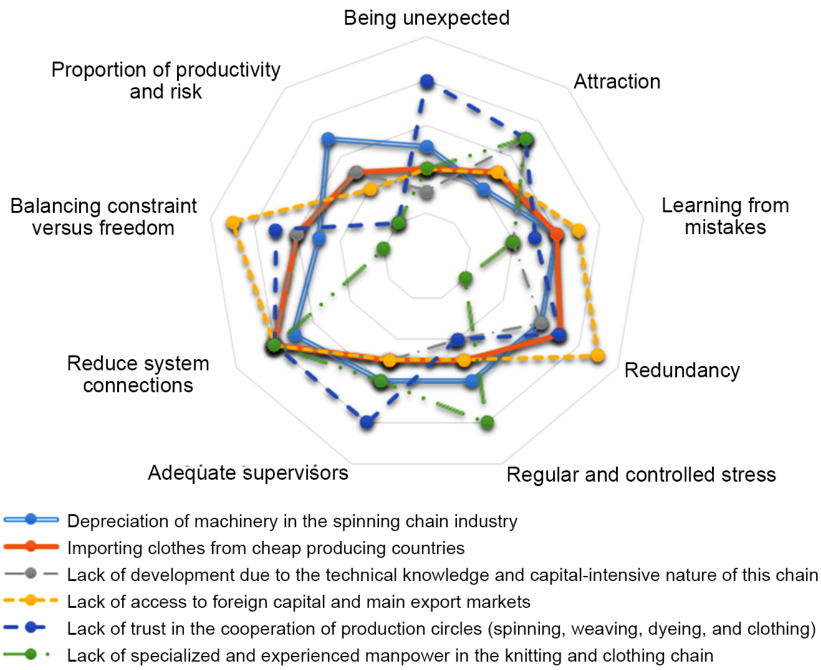

Fig. 2. Scattering of the obtained scores of the first 6 brittle factors of the textile industry according to the anti-brittleness components.

new export markets and build relationships with customers who value quality and sustainability over price.

• Overall, it's important for textile businesses to be proactive and adaptable in the face of challenges. By embracing anti-fragility and taking steps to leverage adversity into opportunities for growth and innovation, the textile industry can thrive in an ever-changing global market.

V. CONCLUSION

Anti-fragility is an emerging concept which proposes that certain systems, when built to withstand and even benefit from shocks and disruptions, can actually become stronger over time. This philosophy can be applied in the textile supply chain to help companies create resilient and adaptable systems that can cope with the ever-changing demands of the industry. By building anti-fragile structures, companies can better mitigate risks and capitalize on opportunities when they arise. This approach can promote more sustainable and efficient practices within the textile supply chain.

In this research, in order to design a sustainable supply chain, the factors of fragility have been identified and then its importance has been determined. The clothing industry, due to its direct connection with daily life and the basic needs of the household, is the third in terms of importance after food and housing. Therefore, it is necessary to design a compensatory supply chain for the textile industry so that the influence of exogenous and endogenous factors does not reduce the efficiency of its supply chain.

In the statistics related to the added value and the output value, there are problems and challenges that the textile industry in the supply chain is faced with, which make its productivity questionable, and it is necessary to identify and investigate these disruptive factors in the current dynamic conditions. By reviewing the conducted studies, anti-fragility components were identified and weighed using the fuzzy best-worst method. The most important components obtained were unexpectedness, sufficient observers and redundancy. According to the weight of the obtained components, the fragile factors identified in the supply chain of the textile industry were ranked in the TOPSIS method. The results indicate that the factors of lack of access to foreign capital and main export markets, depreciation of machinery in the spinning chain industry, and the import of clothing from low-cost producing countries are respectively in the first to third place of the greatest importance in the supply chain of the textile industry.

Also, the weaving and sewing chain is the most important area of the supply chain of this industry due to the number of fragile factors and the amount of weight obtained.

In order to expand this research, the authors intend to analyze scenarios for effective management in the textile industry to control the risks caused by sanctions and lack of resources and facilities so that ultimately sustainable employment in the textile industry can come true.

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